United States
Department of
Agriculture

**Soil
Conservation
Service**

Soil Mechanics Training Series

Basic Soil Properties

Module 5 - Compaction

Part A - Introduction, Definitions, and Concepts

Study Guide

ENG-SOIL MECHANICS TRAINING SERIES--

BASIC SOIL PROPERTIES

MODULE 5 - COMPACTION

PART A

INTRODUCTION, DEFINITIONS, AND CONCEPTS

STUDY GUIDE

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

PREFACE

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

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

Completion of Module 4, Volume-Weight Relations, is a prerequisite for this Module. If you have not completed Module 4, you should do so before attempting completion of this module.

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

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INTRODUCTION

This is Part A of Module 5 - Compaction - of the ENG-Soil Mechanics Training Series-Basic Soil Properties. The module 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 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.

In the Study Guide, instructions are given at the bottom of each page to assist you in each Activity. Carefully note and follow the instructions.

Part A has four 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 A 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.

You will need a pocket-type calculator for calculations in several parts of this module.

CONTENTS OF PACKAGE

2 slide trays
1 audio cassette
1 Study Guide

ACTIVITY 1 - OBJECTIVES

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

1. Define the terms, symbols, and equations used with compaction of soil.

2. State from memory how the engineering properties of the major Unified Soil Classification System groups are affected by compaction. State generally whether each effect is beneficial or harmful.

3. List the three primary factors that affect the compaction characteristics of a soil.

4. Describe the general compaction characteristics and most appropriate construction equipment for each major Unified Soil Classification System group.

START THE TAPE WHEN YOU HAVE FINISHED

ACTIVITY 2 - DEFINITIONS AND TERMINOLOGY

Important terms and their definitions that apply to the subject of compaction are listed below. Additional terminology and definitions that you will need are in Soil Mechanics Module 1 - Unified Soil Classification System, and Soil Mechanics Module 4 - Volume-Weight Relationships.

Compaction - The densification of a soil by means of mechanical manipulation.

Consolidation - The gradual reduction in void space of a soil mass resulting from an increase in compressive stress. The volume change results from air and/or water being expelled from the soil voids due to the stress increase.

Compaction is a dynamic process, whereas consolidation is a static process. Compaction usually results in substantial rearrangement of soil particles, which does not occur to any great degree in the application of a static load. In consolidation, the expulsion of air and water from the soil pore spaces is the primary action; minimal particle rearrangement takes place. Consolidation will be covered in more detail in other Modules.

A few other terms are used in this module with which you should be familiar:

Compactive effort - An expression of the amount of energy expended to compact a soil mass. It is usually expressed as foot-pounds per cubic foot or meter-kilograms per cubic meter.

Density - The mass per unit volume of a substance. Because weight is equal to mass times the gravity constant, weight may vary with gravity over the earth's surface. Strictly speaking, the terms weight and mass are not interchangeable, but for practical purposes, the two are about the same. Consequently, you may see both dry unit weight and dry density used to express the amount of dry soil solids per unit volume.

CONTINUE TO THE NEXT PAGE

ACTIVITY 2 - QUESTIONS

In each of the following situations, state whether the phenomenon occurring is one of compaction or consolidation, and why you think so.

1. A building is constructed on a thick deposit of clay soil. Subsequently, the groundwater table is lowered by excessive groundwater withdrawal. As a result, the building settles and cracks.

2. Soil is transported to a site in dump trucks and spread in a rectangular strip to a thickness of about 4 feet. Bulldozers are used to spread the soil, but no other equipment is used. A building is constructed on the pad, and several years later, the building is observed to have cracks in one corner.

3. A farm pond would not hold water after construction. The pond was drained and a small flock of sheep was penned in the bottom of the pond area for several weeks. The sheep were then removed and the pond allowed to refill with water. It subsequently held water satisfactorily.

4. A house was constructed on a loose sand deposit. Subsequently, a major highway was constructed close to the house. The house was observed to settle excessively and suffer considerable structural distress. The vibrations of the traffic were considerable because of the high incidence of heavy truck traffic on the road.

WRITE YOUR ANSWERS ON THE WORKSHEET ON THE FOLLOWING PAGE

ACTIVITY 2 - ANSWER SHEET

1.

2.

3.

4.

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

ACTIVITY 2 - ANSWERS

1. The phenomenon occurring is consolidation. The settlement occurred as a result of an external load application and an increase in intergranular stress, as the groundwater table was lowered. The settlement was not due to the mechanical manipulation of the soil mass.

2. Consolidation of the loosely dumped fill was the cause of the distress to the building. The static weight of the building was the primary force, and not any mechanical manipulation of the soil.

3. The penned animals effectively compacted the soil in the bottom of the pond by the mechanical manipulation of the soil by their hooves. The soil in the bottom of the pond was compacted and the permeability was reduced.

4. The loose sand under the house was densified by the vibration of the sand caused by the adjacent traffic. This mechanical application of energy to the soil induced excessive settlement of the foundation and subsequent damage to the structure.

START THE TAPE WHEN YOU HAVE FINISHED

ACTIVITY 3 - TYPES OF LOAD APPLICATION IN COMPACTION

Compaction is the application of mechanical forces to a soil mass. The ways in which these forces may be applied are grouped as follows:

1. Static load application, live weight.
2. Kneading action.
3. Vibratory action.
4. Impact load application.
5. Combinations of two or more of the above.

Examples of static load live weight application are heavily loaded trucks or scrapers moving slowly over a fill, smooth wheeled steel drum rollers, heavily loaded pneumatic (rubber-tired) rollers that have closely spaced rollers, and heavy crawler tractors.

Examples of kneading action compactors are tamping rollers, hand tamping, motorized, hand-held compactors, wobbly-wheeled rollers, and pneumatic-tired equipment that has widely spaced rollers.

Vibratory compaction equipment types include steel-wheeled rollers that have a vibrating mechanism, small vibratory plate compactors, and the vibratory action of crawler tractors (bulldozers) treads. Other types of equipment use vibratory rods inserted into a soil deposit.

Impact loads may be applied with motorized, hand-held compactors (pogo-stick type action), with hand tampers, and by dropping heavy weights from a considerable height onto a soil deposit.

Most machines employ a combination of these actions to compact soil. A crawler tractor imparts static live load and at the same time vibrates the underlying soil considerably. A tamping roller uses static live load application and kneading action to compact soil.

CONTINUE TO PAGE 9

ACTIVITY 3 - PROBLEMS

Describe the action(s) of each of the following equipment or procedures in compacting a soil. Describe as one, or a combination of, the four types of force applications discussed.

1. The effect of the foot traffic of animals on a deposit of a soil.

   ____

2. A set of explosive charges placed around the perimeter of a soil deposit and simultaneously exploded.

   ____

3. The traffic of a farm tractor over a fill. ______________________

   ____.

4. The action of a fence post tamper. ______________________

   ____.

SEE THE FOLLOWING PAGE FOR DISCUSSION OF THE PROBLEMS

ACTIVITY 3 - ANSWERS

1. The foot traffic of animals is primarily a kneading type of compaction. Some static compaction also results.

2. The explosions create a vibratory action that would be effective in compacting coarse-grained soil.

3. The farm tractor's tires would compact by static load primarily, but some kneading action would also take place.

4. A fence post tamper would compact primarily by impact, but some kneading action would also occur.

Remember that nearly any mechanical device uses one or more of the types of compactive effort to compact soil. Few devices apply only one type of compactive effort.

START THE TAPE WHEN YOU HAVE FINISHED

ACTIVITY 4 - VOLUME-WEIGHT RELATIONS REVIEW

This Activity reviews the concepts of Module 4, Volume-Weight Relations, that are essential to the completion of this Module.

The important definitions and terms needed in this module include:

Moist Unit Weight - The weight of moist soil per unit volume. Calculated from the equation:

$$\text{Moist unit weight} = \frac{\text{total weight}}{\text{total volume}}$$

It may be expressed in pounds per cubic feet, pcf, or as kilograms per cubic meter, kg/m^3.

Dry Unit Weight - The weight of soil solids per unit of total volume of a soil mass. It is usually obtained by weighing the soil mass after drying in an oven set to 110 degrees Centigrade for 12 hours or until a constant weight is obtained. Calculated from the equation:

$$\text{Dry unit weight} = \frac{\text{weight of solids}}{\text{total volume}}$$

Note: The weight of solids may also be calculated knowing the total moist weight and the water content.

$$W_S = \frac{W}{1+\frac{w\%}{100}}$$

Dry unit weight may be expressed in pounds per cubic feet, pcf, or in kilograms per cubic meter, kg/m3.

Remember that density is often used interchangeably with the term unit weight, and that the differences are minor, changing only with the effect of gravity over the surface of the earth. Where gravity is substantially different, as on the surface of the moon, the difference is substantial and cannot be ignored.

Water Content - The ratio of the weight of water in a soil sample to the weight of soil solids in the sample is expressed as a percentage. It is usually obtained by weighing a moist sample, then drying in an oven, then weighing the dry sample and calculating the water content by the equation:

$$\text{Water content (\%)} = \frac{\text{(wet weight - dry weight)}}{\text{dry weight}} * 100$$

Specific Gravity of Soil Solids, abbreviated Gs - The ratio of the weight in air of a given volume of soil solids at a stated temperature to the weight in air of an equal volume of distilled water at a stated temperature. It is

CONTINUE TO NEXT PAGE

obtained from a laboratory test, or may be estimated on the basis of soil classification as follows:

sands/gravels - 2.65 to 2.67
silts - 2.66 to 2.69
clays - 2.66 to 2.80

More detailed information on specific gravity is given in another activity in Part E of this module.

Percent Saturation - The ratio of the water content of a sample to the theoretical saturated water content of the sample is expressed as a percentage. Calculated from the equation:

$$\%S = \frac{\text{water content (\%)}}{\text{saturated water content(\%)}} * 100$$

Saturated Water Content - The water content is measured when a soil sample's voids are completely filled with water. No air is in the sample.

In English units, it is calculated from the equation below:

$$W_{sat}(\%) = \left[\frac{62.4}{\text{Dry Unit Weight(pcf)}} - \frac{1}{G_s}\right] \times 100$$

In metric units, the equation is as shown:

$$W_{sat}(\%) = \left[\frac{1.0}{\text{Dry Unit Weight(g/cm}^3\text{)}} - \frac{1}{G_s}\right] \times 100$$

CONTINUE TO THE NEXT PAGE

ACTIVITY 4 - PROBLEMS

To test your understanding of these definitions from Module 4, work the following problems.

1. A sample container is measured and its volume is .01768 cubic feet. The sample in the container is weighed in a moist state and weighs 2.12 pounds. After drying, the sample weighs 1.69 pounds. The soil solids' specific gravity is 2.69.

   Determine the moist unit weight, water content, dry unit weight, and percent saturation of the sample.

WRITE YOUR ANSWERS ON THE WORKSHEET ON PAGE 15

ACTIVITY 4 - ANSWER SHEET

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

ACTIVITY 4 - PROBLEM SOLUTIONS

$$\text{Moist unit weight} = \frac{\text{total weight}}{\text{total volume}}$$

$$= \frac{2.12 \text{ pounds}}{0.01768 \text{ cubic feet}}$$

$$= 119.9 \text{ pounds per cubic foot}$$

$$\text{Water content} = \frac{(\text{wet weight-dry weight})}{\text{dry weight}} \times 100$$

$$= \frac{(2.12-1.69)}{1.69} \times 100$$

$$= 25.4\%$$

$$\text{Dry unit weight} = \frac{\text{wet unit weight}}{1 + \frac{w\%}{100}}$$

$$= \frac{119.9 \text{ pcf}}{1 + \frac{25.44}{100}}$$

$$= \frac{119.9 \text{ pcf}}{1.2544}$$

$$= 95.6 \text{ pounds per cubic foot}$$

$$\text{Saturated water content} = \frac{62.4}{\text{Dry Unit Weight/pcf}} - \frac{1}{G_s} \times 100$$

$$= \frac{62.4}{95.6} - \frac{1}{2.69} \times 100$$

$$= 28.13\%$$

$$\text{Percent saturation} = \frac{w_n (\%)}{w_{sat}(\%)} \times 100$$

$$= \frac{25.44}{28.13\%} \times 100$$

$$= 90.4\%$$

START THE TAPE WHEN YOU HAVE FINISHED

ACTIVITY 5 - EFFECT OF COMPACTION AND COMPACTION WATER CONTENT ON ENGINEERING PROPERTIES OF SOILS

The increase in the density of a soil mass resulting from compaction causes significant changes in the engineering properties of the soil mass. Properties such as shear strength, consolidation, and permeability are affected. Other properties that are affected include flexibility and shrink-swell potential.

The water content at which a soil is compacted is also important in determining the engineering properties of the compacted soil.

Table 1 summarizes the important properties of soils that are affected by compaction, how compaction affects those properties, and what the influence of compaction water content is on the properties. The table also notes whether this effect is in general beneficial or detrimental for most uses.

This table assumes no particular kind of soil. Remember that in general the effects of densification and the importance of water content at compaction are most significant for fine-grained soil and coarse-grained soil with significant fines content.

You should understand that other factors also strongly affect the resultant engineering properties of a compacted soil mass. In other words, density alone does not determine many of these properties. For instance, the shear strength of a clean angular sand will be higher than that of a clean sand that has round particles, even though both are compacted to the same density. The way in which a soil is compacted may also influence its engineering properties. A clay soil which is compacted with kneading type compaction may have different shear strength behavior than one which is compacted to the same density using static load application. These factors may also affect the other properties discussed such as permeability and consolidation potential.

A designer must consider all of the probable effects of degree of compaction and water content at compaction on a soil. If a soil is compacted to a high degree at a low water content, the soil will have high shear strength and low compressibility. But, the soil will have reduced flexibility and increased swell pressure potential. Likewise, if the soil is compacted to a low degree of compactness at a high water content, it will have lower shear strength and higher compressibility, but it will be more flexible and less prone to have swell problems.

The balancing of adverse and favorable properties resulting from compaction and water content at compaction is often referred to as "trade-offs" in the design of the earth fill. Generally, the designer must decide which engineering property is most important for that earth fill and select the compaction and water content which will produce the greatest reward in that property. The adverse results of that decision will have to be handled by other design features.

START THE TAPE AFTER YOU HAVE STUDIED THE TABLE AND FIGURES ON PAGES 18-26

ACTIVITY 5

Table 1. Effect of densification and water content on engineering properties of soil

Engineering Property	Effect of Compaction	Beneficial/ Harmful	Effect of Higher Water Content	Beneficial/ Harmful
Shear Strength	Increases	Beneficial	Reduces	Harmful
Consolidation Potential	Reduces	Beneficial	Increases	Harmful
Permeability	Reduces	Beneficial	Reduces	Beneficial
Flexibility	Reduces	Harmful	Increases	Beneficial
Shrinkage Potential	Reduces	Beneficial	Increases	Harmful
Swell Potential	Increases	Harmful	Reduces	Beneficial

Figure 5.1

EFFECT OF COMPACTION ON ENGINEERING PROPERTIES

SHEAR STRENGTH

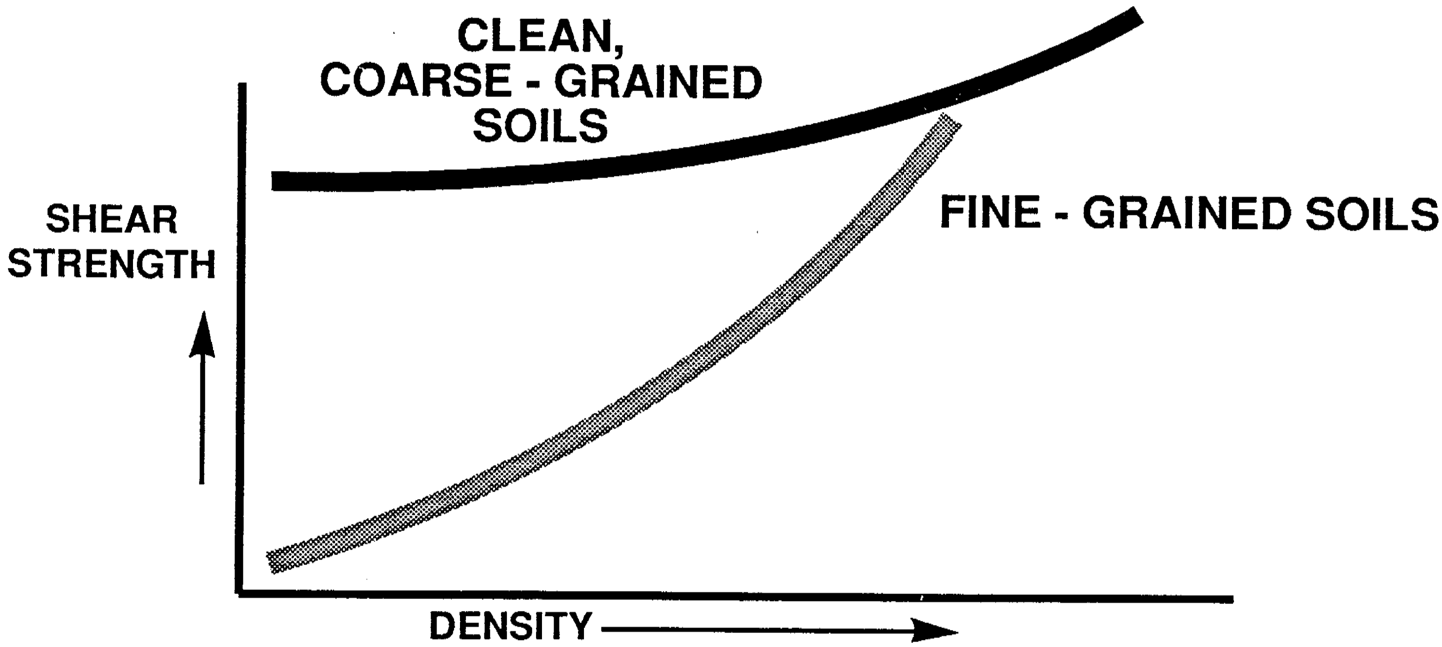


Figure 5.2

FACTORS OTHER THAN DENSITY AND WATER CONTENT AFFECT STRENGTH

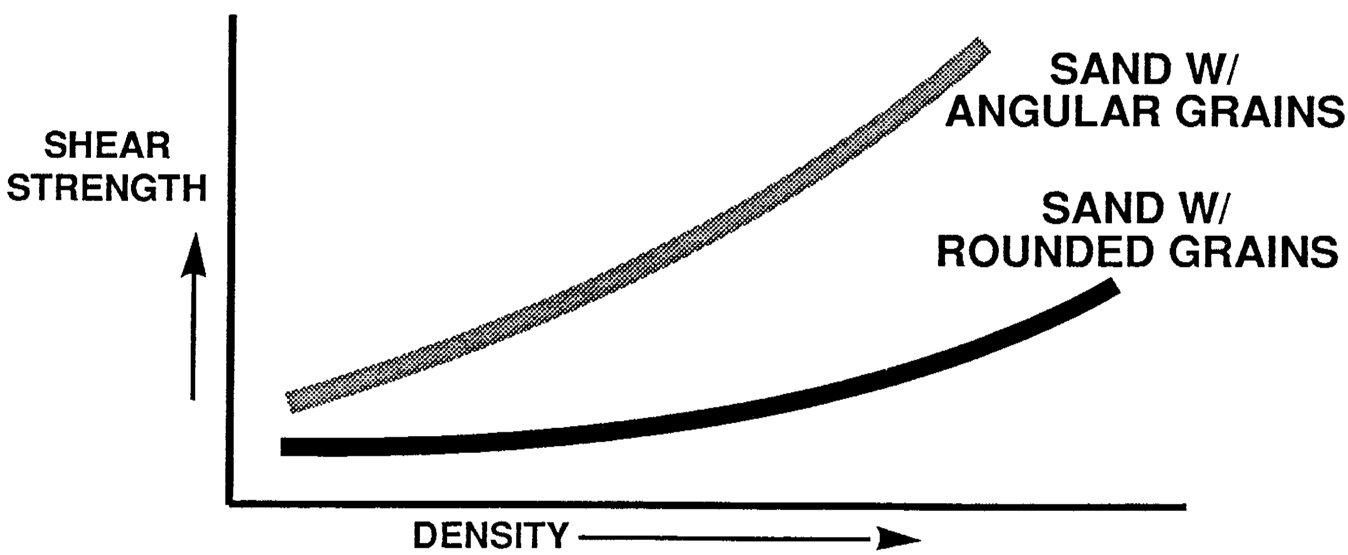


Figure 5.3

EFFECT OF COMPACTION ON ENGINEERING PROPERTIES
SHEAR STRENGTH

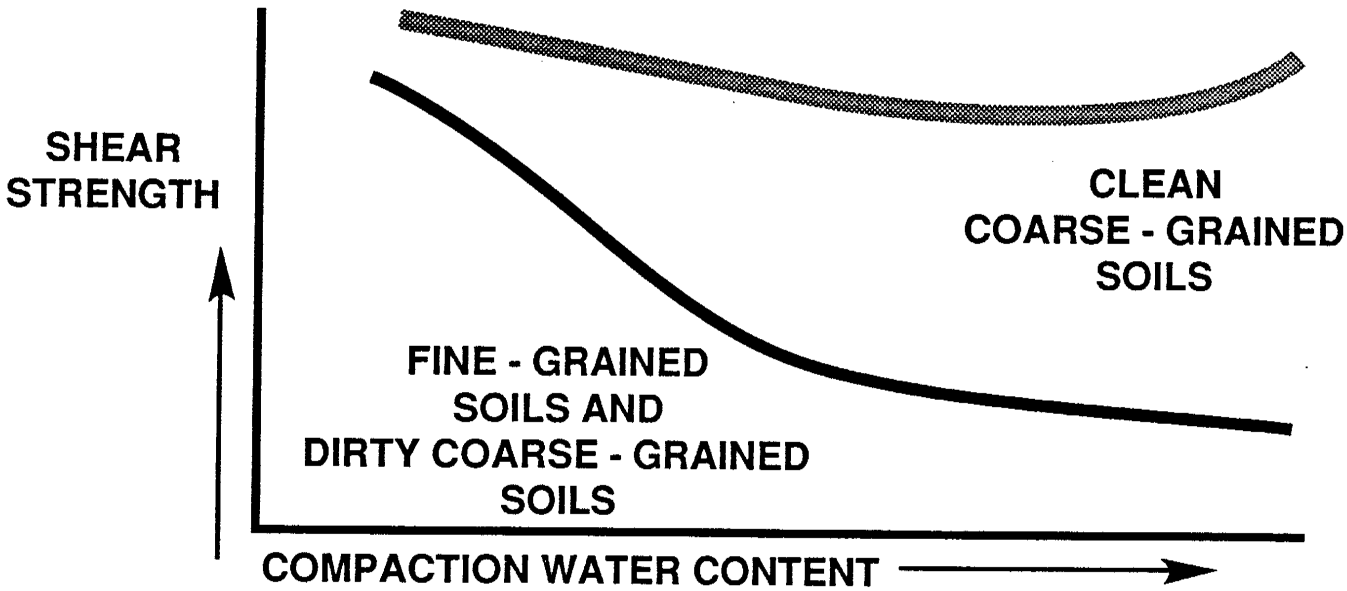


Figure 5.4

EFFECT OF COMPACTION ON ENGINEERING PROPERTIES

CONSOLIDATION POTENTIAL

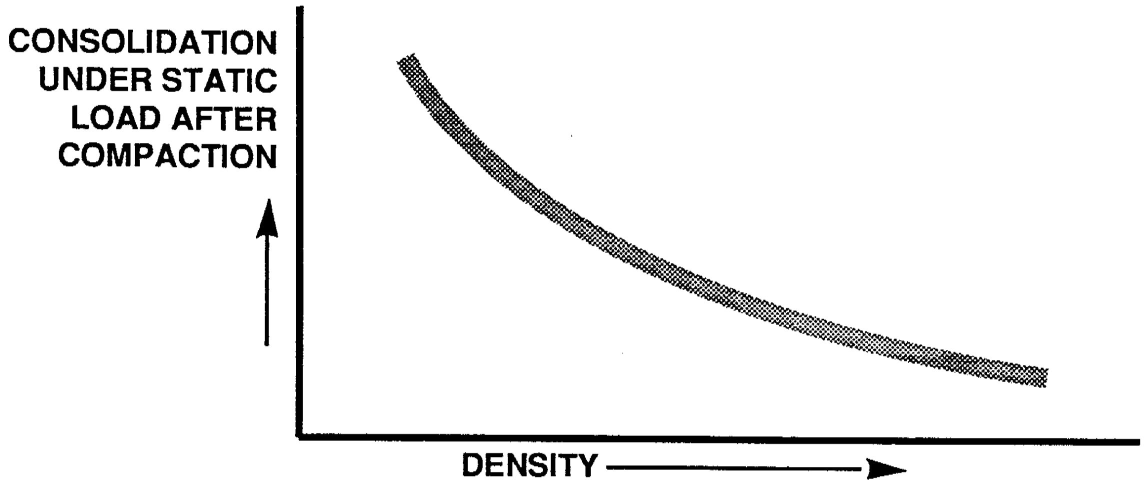


Figure 5.5

EFFECT OF COMPACTION WATER CONTENT ON ENGINEERING PROPERTIES

CONSOLIDATION POTENTIAL

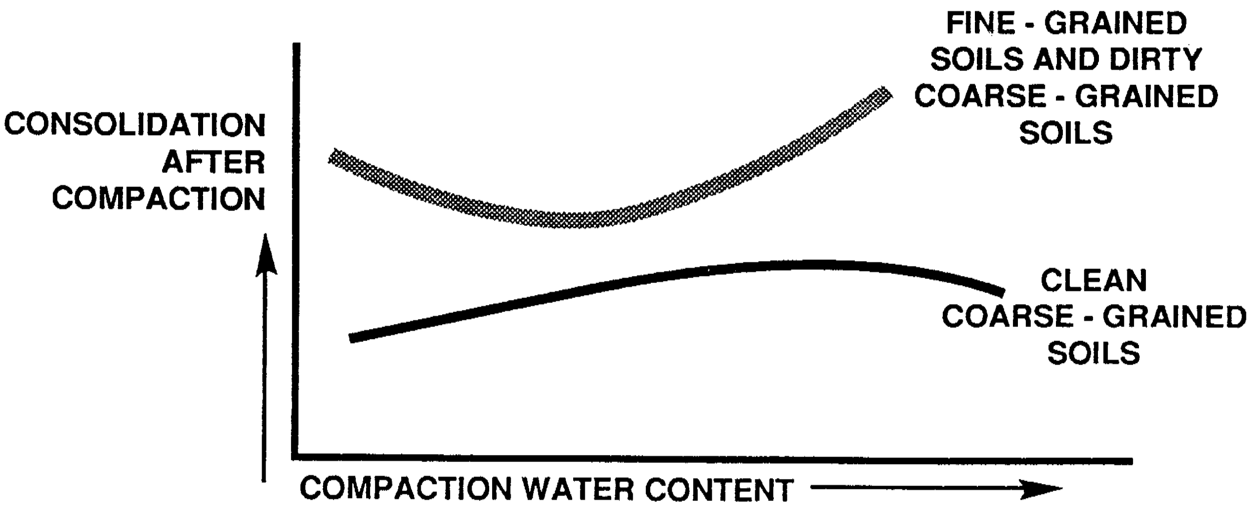


Figure 5.6

EFFECT OF COMPACTION ON ENGINEERING PROPERTIES
PERMEABILITY

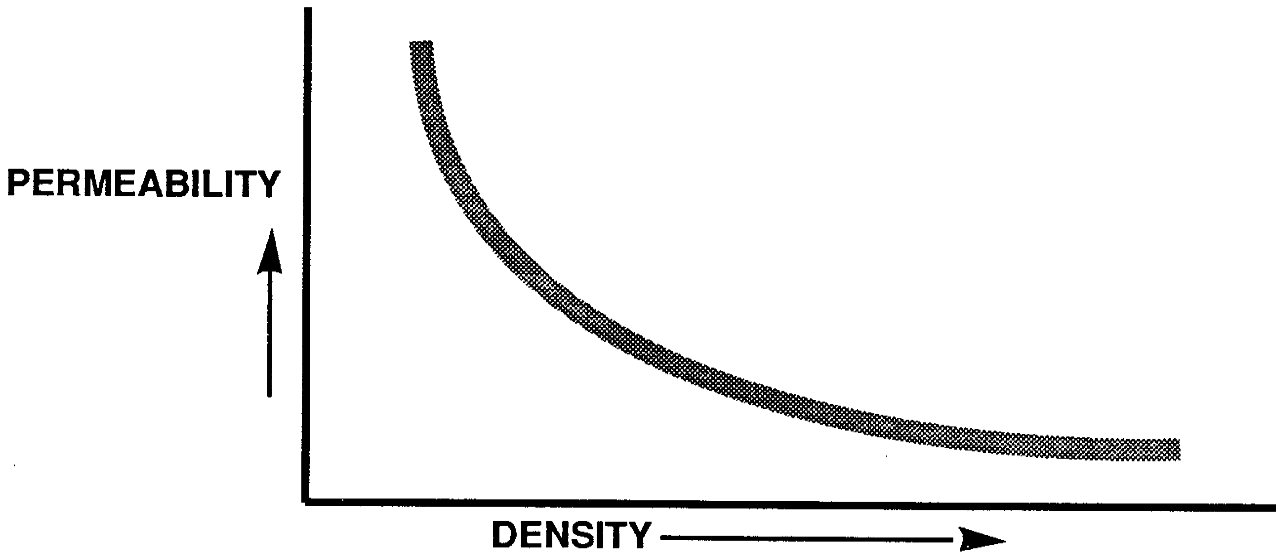


Figure 5.7

EFFECT OF COMPACTION WATER CONTENT ON ENGINEERING PROPERTIES
PERMEABILITY

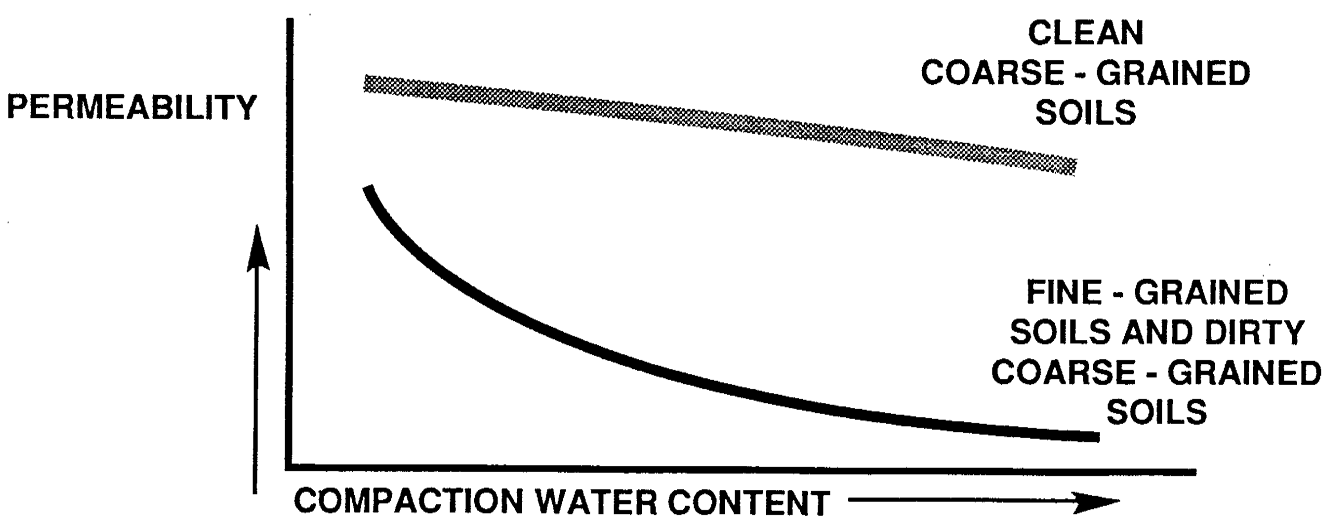


Figure 5.8

EFFECT OF COMPACTION WATER CONTENT ON ENGINEERING PROPERTIES

SHRINK - SWELL

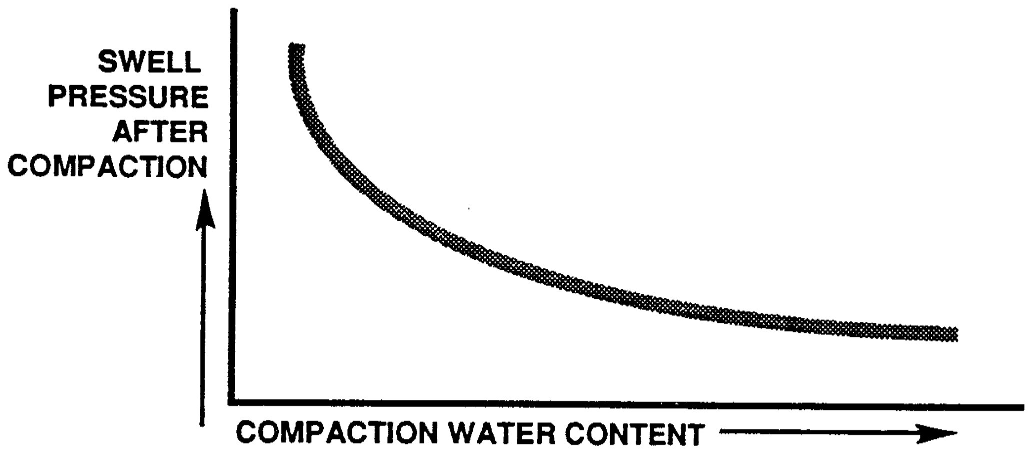


Figure 5.9

EFFECT OF COMPACTION WATER CONTENT ON ENGINEERING PROPERTIES

SHRINK - SWELL (CONT.)

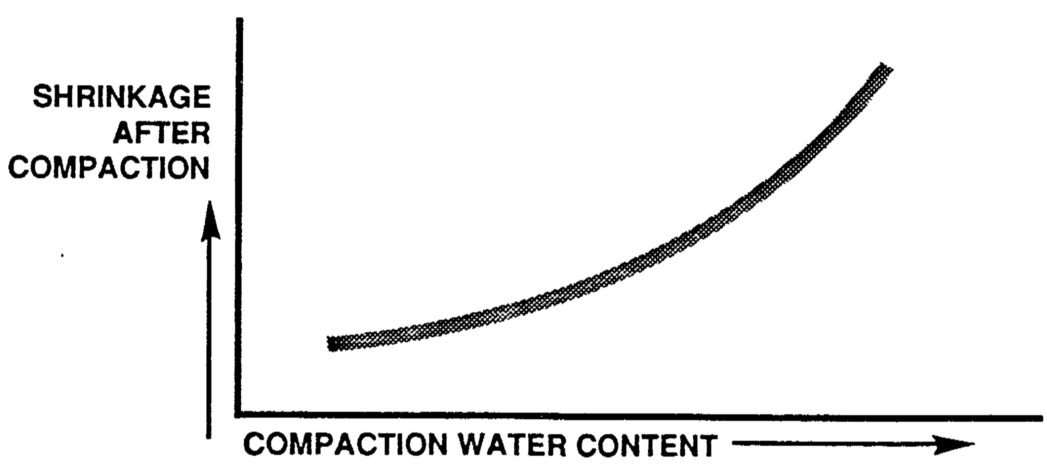


Figure 5.10

EFFECT OF COMPACTION ON ENGINEERING PROPERTIES
FLEXIBILITY

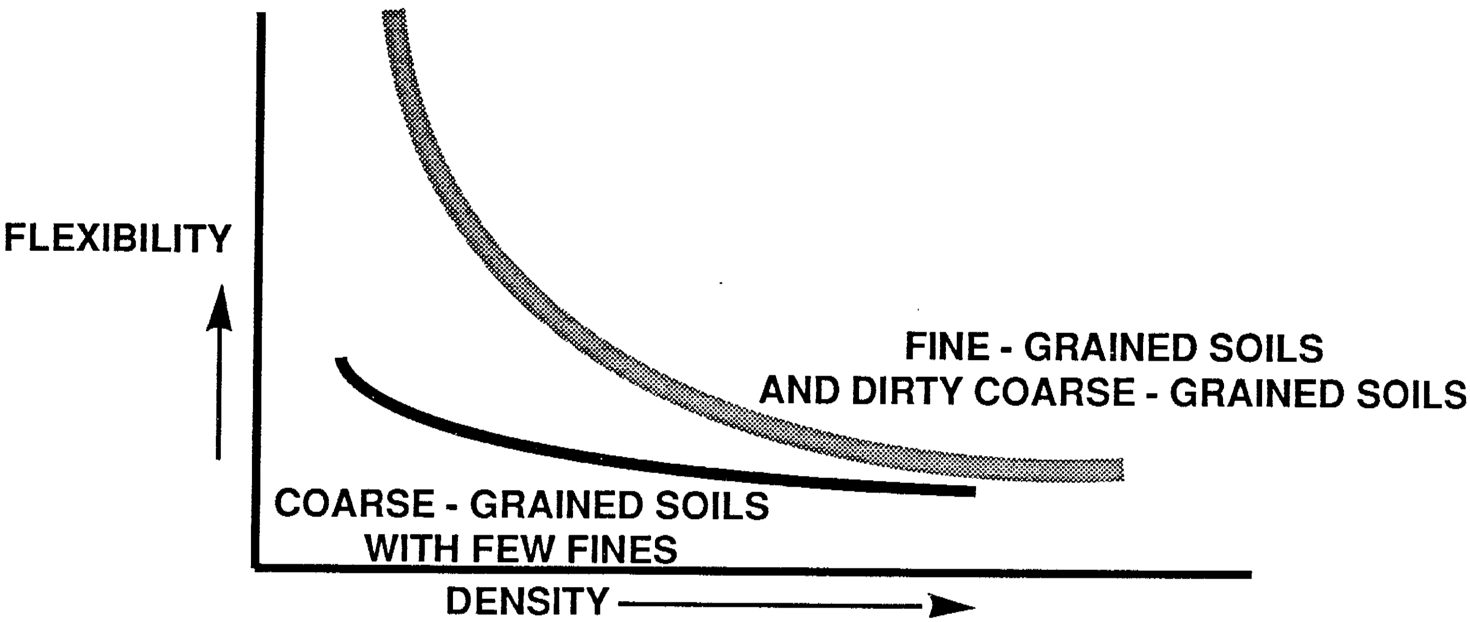
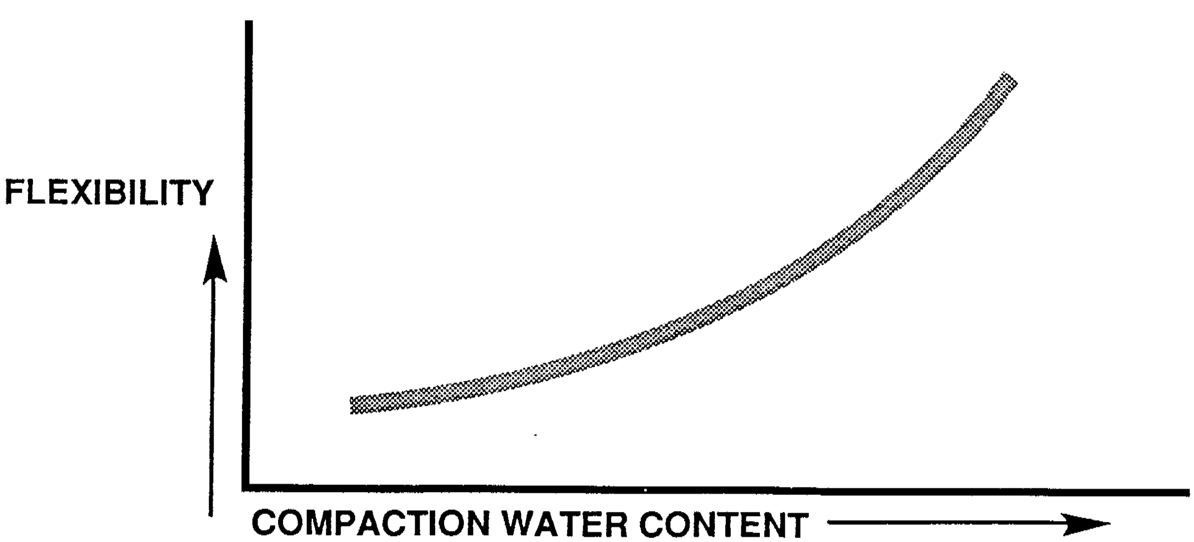


Figure 5.11

EFFECT OF COMPACTION WATER CONTENT ON ENGINEERING PROPERTIES
FLEXIBILITY



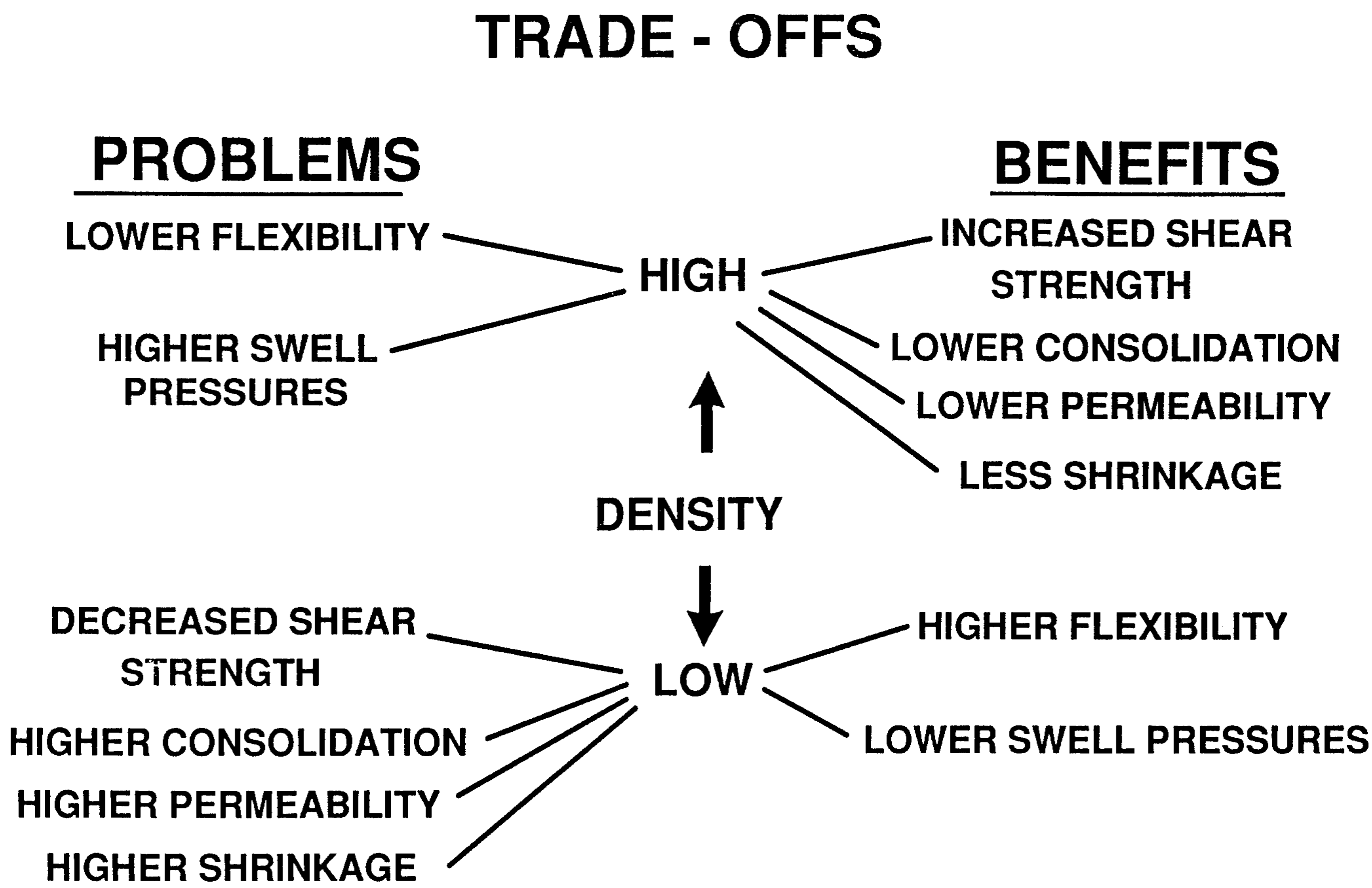

TRADE - OFFS
PROBLEMS
BENEFITS
LOWER FLEXIBILITY
HIGH
INCREASED SHEAR STRENGTH
HIGHER SWELL PRESSURES
LOWER CONSOLIDATION
LOWER PERMEABILITY
LESS SHRINKAGE
DENSITY
DECREASED SHEAR STRENGTH
LOW
HIGHER FLEXIBILITY
HIGHER CONSOLIDATION
LOWER SWELL PRESSURES
HIGHER PERMEABILITY
HIGHER SHRINKAGE

Figure 5.12

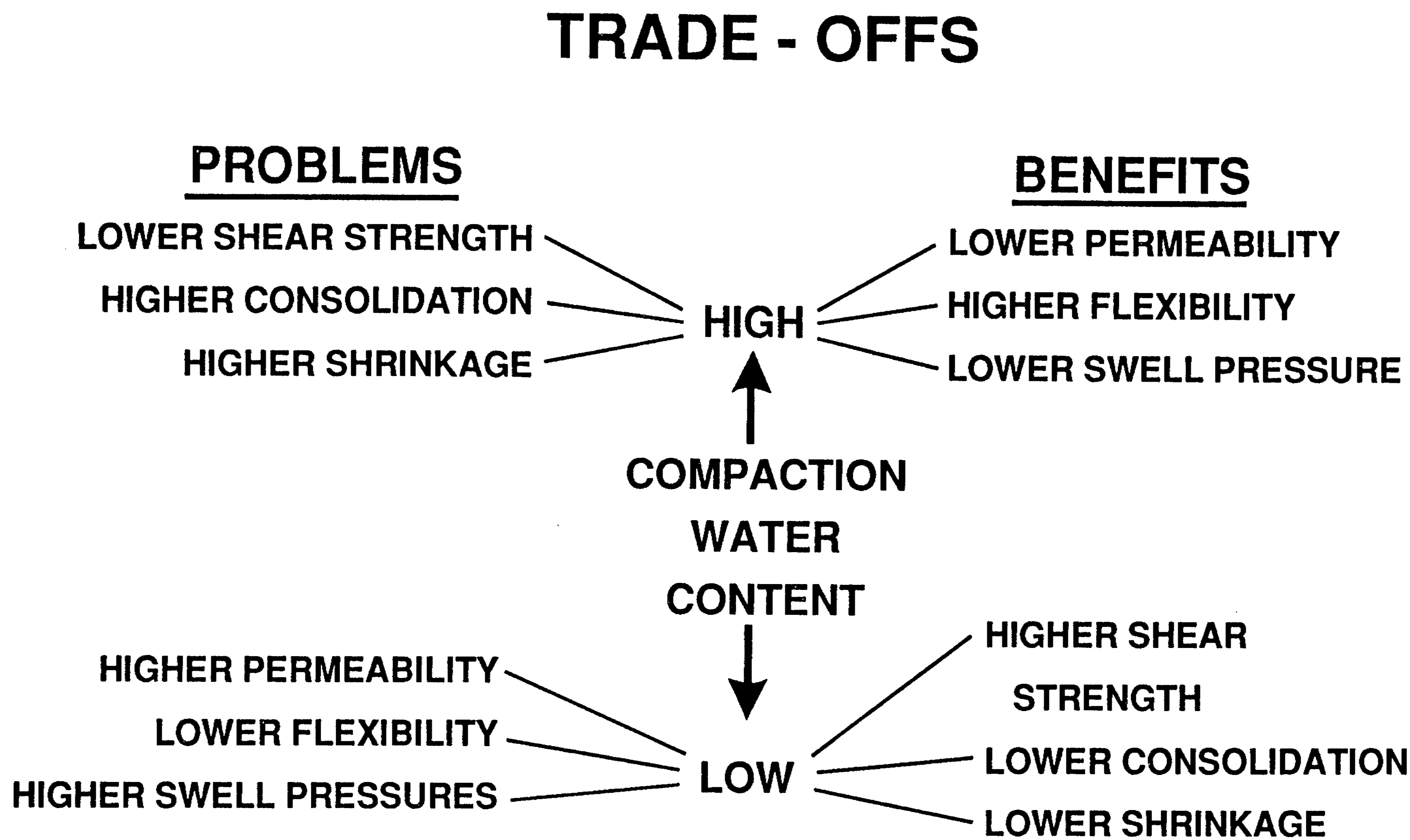

TRADE - OFFS
PROBLEMS
LOWER SHEAR STRENGTH
HIGHER CONSOLIDATION
HIGHER SHRINKAGE
BENEFITS
LOWER PERMEABILITY
HIGHER FLEXIBILITY
LOWER SWELL PRESSURE
HIGH
COMPACTION
WATER
CONTENT
LOW
HIGHER PERMEABILITY
LOWER FLEXIBILITY
HIGHER SWELL PRESSURES
HIGHER SHEAR
STRENGTH
LOWER CONSOLIDATION
LOWER SHRINKAGE

Figure 5.13

ACTIVITY 6 - FACTORS AFFECTING THE COMPACTION CHARACTERISTICS OF SOILS

Three factors determine the compaction characteristics of a soil. They are:

I. The soil characteristics.
II. The water content at which the soil is compacted.
III. The type and amount of energy applied in compaction.

In discussing each of the factors affecting compaction characteristic, it is convenient to group soils according to their Unified Soil Classification System groupings. In following discussions for each group of soils, the importance of soil characteristics and water content on compaction characteristics are covered in detail. More detail is given on the effect of energy in the next Activity.

Three soil characteristics may be listed which affect a soil's compaction. They are:

A. Grain-size.
B. Size and distribution of void spaces.
C. Electro-chemical properties.

In the following discussions of soil groups, the importance of these factors is covered in detail.

The first group of soils to be discussed are the relatively clean sands and gravels. Recal that these soils have 12 percent or fewer fines. The following classifications are included:

GP, GW, SP, SW, GP-GM, SP-SM, GP-GC, SP-SC, GW-GM, SW-SM, GW-GC, and SW-SC

For this group of soils, the electro-chemical properties are relatively unimportant. Electro-chemical properties apply primarily to silt and clay fines, and are discussed later. These soil classifications have so few fines that this soil property is of little importance. The main soil characteristics affecting compaction of these soil types are the grain-size and the size and distribution of the voids in the samples.

The grain-size of the soil and the size and distribution of the voids in these soils is important because of the presence of surface tension forces. These forces exist in moist coarse-grained soils due to the water films between the particles. These forces permit a sand castle to be constructed of clean sands with no cohesion between its particles. These forces are most powerful for finer sands which are poorly graded. They are almost non-existent in coarse gravels.

One way to overcome these forces which tend to resist compaction is to flood the soil being compacted. Commonly, when compacting fine, clean sands, the Soil Conservation Service requires thorough wetting of the soils during compaction to destroy the surface tension forces and reduce the tendency of the sands to bulk or increase in volume when placed. Flooding destroys the surface tension forces, just as a tide melts away a sand castle.

CONTINUE TO THE NEXT PAGE

The most effective type of energy application for these soil types is vibratory. Vibration also is helpful in destroying surface tension forces, thus permitting compaction. Vibratory energy is much more effective for these soil types than static load application or kneading compaction. Types of equipment that apply vibratory energy are smooth-wheeled vibratory rollers and crawler tractor treads.

Generally, the smaller the void space in the soil, the more powerful are the surface tension forces. Therefore, the more difficult soils to compact are the fine, poorly graded sands, classifying as SP. In well-graded sands, the wide distribution of particle sizes results in much fewer voids, and the sand is inherently more dense than a poorly graded sand. Gravels have much larger voids generally than sands, and therefore the surface tension forces are much less. This is summarized in Figure 6.1, p. 30.

The next soil group to be discussed are the fine-grained soils. The following Unified Classifications are included:

CL, ML, CL-ML, CH, MH, OL, and OH

These soils consist of various percentages of silt and clay fines, together with lesser amounts of sands and gravels. The most important factor affecting compaction of these soils is the electro-chemical properties of the fine particles. Silt size particles are relatively inert, and the soil classifications which are predominated by silt are less affected, such as the ML and CL-ML classifications.

Soils with a high percentage of clay, where the clay particles have a high electrical charge are strongly affected by these electrically charged particles. Clays with a finer structure and higher electrical charge, such as montmorillonite, are the most affected. Clays with a more coarse lattice structure and less electrical charge, such as kaolinite, are less affected.

Clay particles have a high attraction to water, and to each other. They can only be compacted over a narrow range of water contents effectively. At very low water contents there is insufficient water for lubrication and to generate the attraction of the particles for one another. At very high water contents, the soils are difficult to compact, because expelling water from the voids is difficult. Due to the small size of the voids in clays, permeability is low, and expelling water is very slow.

Generally speaking, the higher the liquid limit, and the higher the plasticity index, the more difficult a fine-grained soil is to compact, and the more important water content is to effective compaction.

The most effective type of energy application for these soils is kneading action. Kneading is necessary to destroy the bonds of the particles and permit rearrangement necessary for densification. A tamping roller is the only type of equipment that effectively applies this type of energy. Some fine-grained soils with very low plasticity fines, such as the ML classification, may be effectively compacted with pnuematic rollers, but most fine-grained soils require tamping rollers.

CONTINUE TO THE NEXT PAGE

ACTIVITY 6 - Continued

The final soil group to be discussed are the dirty, coarse-grained soils. The following Unified Soil Classification System Groups are included:

GC, SC, GM, SM, GC-GM, SC-SM

Recall that these soil groups may contain anywhere from 13 to 49 percent fines. The amount of fines and the type of fines are probably the most important influence on the compaction of these soils. Although the size of the soil grains and the size and distribution of voids in the soil are important, the presence of the fines in the voids is a more important factor. Depending on whether the fines are non-plastic or plastic, water content may be very important in the ease of compaction. For low fines content with silty fines, however, suface tension forces may be highly significant, and flooding to permit compaction may be advisable.

START THE TAPE WHEN YOU HAVE FINISHED

SURFACE TENSION FORCES AND EASE OF COMPACTION

Surface Tension	Soil		Ease of Compaction
HIGH	Fine Poorly Graded Sands	- SP	DIFFICULT
	Fine Well Graded Sands	- SW	
	Fine Poorly Graded Gravels	- GP	
	Coarse Poorly Graded Sands	- SP	
	Fine Well Graded Gravels	- GW	
	Coarse Well Graded Sands	- SW	
LOW	Coarse Well Graded Gravels	- GW	EASY

ACTIVITY 7 - FACTORS AFFECTING COMPACTION - III ENERGY

One of the three factors affecting compaction of soil is the amount and type of energy applied to the soil mass. This energy is also called compactive effort. Factors that affect the amount of energy delivered to a soil mass in compaction are:

A. Thickness of soil layer being compacted, often referred to as lift thickness.

B. Size and type of equipment. Size may be expressed in total weight of the equipment or in terms of contact pressure of the equipment tires, feet, or treads on the fill surface.

C. Speed of operation of the equipment over the surface, and in the case of vibratory equipment, the frequency of vibration of the exciting mechanism on the equipment.

Slower speed of operation of equipment is beneficial on fine-grained, plastic soil. Faster speeds are acceptable on sands in thin lifts and other coarse-grained soil placed in thicker lifts.

D. Number of passes of equipment over the fill surface. Equipment with narrow contact surfaces such as bulldozers may have to traverse a fill several times just to get one coverage of the treads over the fill surface; other equipment such as smooth wheeled steel rollers exert uniform pressure over the entire machine area. Normally, each pass of equipment over a fill will produce additional compaction, but a point of diminishing returns is reached for most equipment after four to six passes.

Specifications should also contain provisions for scarifying between lifts. The aim of this is to obtain better bonding of the successive lifts in a fill.

Typical specifications for equipment control of compaction are:

Tamping roller - 4 passes with contact pressure of 450 psi, towed at a minimum speed of 4 mph with a maximum 6-inch loose lift thickness.

Pneumatic roller - 4 passes with a wheel load of at least 22,000 pounds and a tire pressure of 100 psi, towed at a speed of at least 4 mph with loose lift thickness of 12 inches.

Crawler tractor weighing at least 50 tons - 6 passes with a minimum tread contact pressure of 10 psi. Maximum loose lift thickness of 12 inches.

Smooth wheeled vibratory roller - 4 passes with a minimum weight of 50 tons and a vibration frequency of at least 2,000 cycles per second. The contact pressure shall be at least 10 pounds per square inch.

Soils may be compacted with a variety of types of equipment. If compaction is to be efficient, the appropriate equipment must be selected. The most important factor in determining the suitable type of equipment is the kind of

CONTINUE TO THE NEXT PAGE

soil to be compacted. Using machinery and operation techniques not appropriate for the soil to be compacted is inefficient and will also probably not result in a desirable fill product.

Similar soils are grouped below with a discussion of the most effective means of compacting each group, and the importance of water content upon compaction.

Relatively Clean Sands and Gravels (less than 15% fines)

The Unified Soil Classifications included in this group:
GP GW SP SW GP-GM SP-SM GW-GM SW-SM GP-GC SP-SC GW-GC SW-SC

These soils are compacted best with equipment that has vibratory action. Significant static load is also effective. Compaction is most efficiently accomplished at either low or high water content. Usually, two to three passes of equipment coverage is sufficient to produce a desirable product for SCS structures.

Poorly graded, finer sands are difficult to compact at intermediate water contents and should be compacted either dry or thoroughly wet. Water content is less critical for well-graded soils because their density is inherently higher. Use of high water content is inadvisable for soils that have higher fines contents.

Loose lift thickness of 12 to 15 inches can usually be compacted with good results.

These soils can also be compacted in-place, as well as after transporting to a fill area. In-place compaction is usually done for foundations of structures when excavating and re-compacting the deposit is less economical than treating the soil in place. Special equipment has been developed for this purpose. One type of equipment consists of rods that can be inserted into the deposit and then vibrated. Another method of treating these soils in place is the use of large weights that are dropped onto the surface of the deposit from a great height. The impact of the weight produces vibration and densification of the deposit. Blasting has also been used successfully for densifying these soils in the field.

CONTINUE TO THE NEXT PAGE

ACTIVITY 7 - Continued

Fine-grained, plastic soils and dirty coarse-grained soils that have plastic fines

The Unified Soil Classifications included in this group:

CH CL MH SC GC

These soils are best compacted with kneading type compactors, specifically tamping rollers. No other type of equipment will efficiently compact these soils. These soils must be spread in relatively thin layers, usually 9 to 12 inches in depth. Water content of the soils when compacted is critical in how efficiently compaction is accomplished. Usually, four to eight passes of the proper size roller will produce an acceptable fill for most SCS structures.

Fine-grained, low plasticity soils and fine sands and gravels that have low plasticity fines.

The Unified Soil Classification included in this group:

ML GM SM CL-ML GC-SM SC-SM

The best type of equipment for compaction of these soils may be a heavy, rubber-tired roller or a heavy wobbly-wheeled roller. A tamping roller may be the best suited equipment for soils of this group with a high percentage of fines, especially the ML and CL-ML groups. Water content must be ideal for most efficient compaction. Compaction is most effective when layer thicknesses are 6 to 9 inches. Usually four to eight passes of equipment is sufficient to produce an acceptable fill for SCS structures.

The tables on the following pages contain generalized information on the compaction characteristics of various soil groups. Some of the tables use the Unified System for grouping, and some tables use a more generalized grouping of soils. You should carefully study these tables before continuing with this Module.

START THE TAPE AFTER YOU HAVE STUDIED THE TABLES AND FIGURES ON PAGES 34-39

ACTIVITY 7
Summary of Compaction Characteristics of Unified Soil Classes

USCS CLASS	RELATIVE EASE OF COMPACTION	BEST SUITED EQUIPMENT	COMPACTED LIFT THICKNESS	IMPORTANCE OF WATER CONTENT CONTROL
GW	Very Easy	Vibratory Roller Crawler Tractor	10 -12 Inches	Either Dry Or Saturated
GP	Good To Excellent	Vibratory Roller Crawler Tractor	10 - 12 Inches	Either Dry Or Saturated
GM	Good With Close Control	Rubber-Tired Or Tamping Roller	6 - 8 Inches	Fairly Important
GC	Good	Tamping Or Rubber-Tired Roller	6 Inches	Very Important
SW	Excellent	Crawler Tractor Vibratory Roller	10 - 12 Inches	Either Dry Or Saturated
SP	Fair	Crawler Tractor Vibratory Roller	10 - 12 Inches	Either Dry Or Saturated
SM	Fair	Rubber-Tired Or Tamping Roller	6 - 8 Inches	Important
SC	Good	Tamping Or Rubber-Tired Roller	6 Inches	Very Important

Continued to next page

ACTIVITY 7 (continued)
Summary of Compaction Characteristics of Unified Soil Classes

USCS CLASS	RELATIVE EASE OF COMPACTION	BEST SUITED EQUIPMENT	COMPACTED LIFT THICKNESS	IMPORTANCE OF WATER CONTENT CONTROL
ML	Fair	Tamping Roller	6 Inches	Important
CL	Good To Fair	Tamping Roller	6 Inches	Very Important
OL	Fair	Tamping Roller	6 Inches	Important
MH	Poor	Tamping Roller	6 Inches	Very Important
CH	Very Poor	Tamping Roller	6 Inches	Critical
OH	Very Poor	Tamping Roller	6 Inches	Important
Pt	Not Suitable			

ACTIVITY 7
Summary of Compaction Characteristics of Unified Soil Classes

UNIFIED CLASS	PREFERRED TYPE OF EQUIPMENT	NUMBER OF PASSES	TYPICAL DRY UNIT WEIGHTS (PFC)	TYPICAL WATER CONTENTS (%)
GW	Crawler Tractor Vibratory Roller	3-4	125-135	9-12
GP	Crawler Tractor Vibratory Roller	3-4	115-125	12-16
GM	Rubber-Tired Tamping Roller	3-5	120-135	8-13
GC	Tamping Roller Rubber-Tired	6-8	115-130	9-14
SW	Crawler Tractor Vibratory Roller	3-4	110-130	10-18
SP	Crawler Tractor Vibratory Roller	3-4	100-120	13-22
SM	Rubber-Tired Tamping Roller	6-8	110-125	10-16
SC	Tamping Roller Rubber-Tired	4-6	105-125	10-18
ML	Tamping Roller	4-6	95-120	12-22
CL	Tamping Roller	4-6	95-120	12-22
MH	Tamping Roller	4-6	70-95	22-40

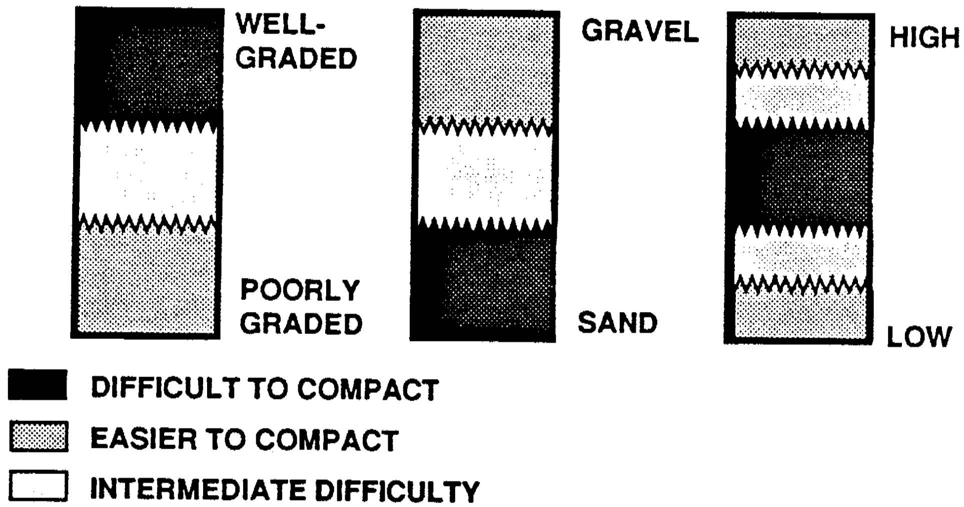
Continue to next page

ACTIVITY 7 (continued) Summary of Compaction Characteristics of Unified Soil Classes				
UNIFIED CLASS	PREFERRED TYPE OF EQUIPMENT	NUMBER OF PASSES	TYPICAL DRY UNIT WEIGHTS (PFC)	TYPICAL WATER CONTENTS (%)
CH	Tamping Roller	4-6	75-105	20-40
OL	Tamping Roller	4-6	80-100	20-32
OH	Tamping Roller	4-6	65-100	20-45
Pt	Not suitable for most fills - usually placed with draglines and little compaction			

COMPACTION OF CLEAN COARSE - GRAINED SOILS SUMMARY

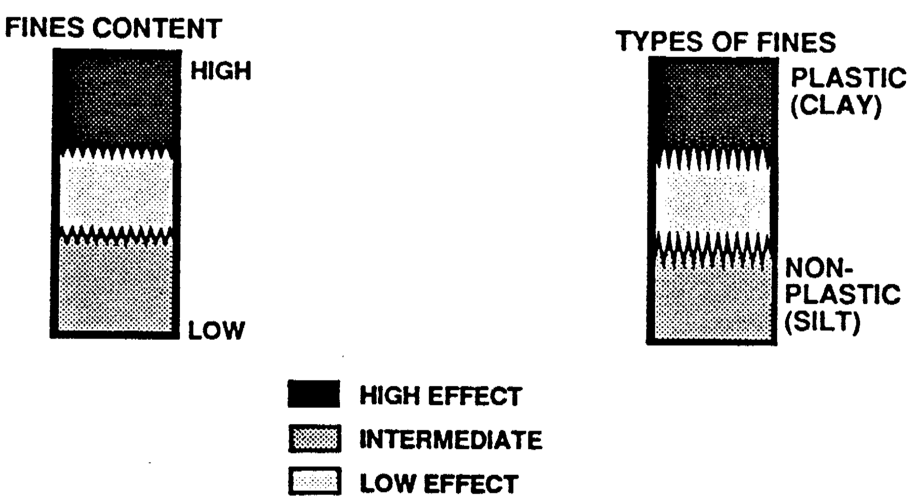
FACTOR I. SOIL TYPE

I.A. GRADATION   I.B. GRAIN - SIZE   WATER CONTENT



COMPACTION OF COARSE - GRAINED SOILS WITH FINES

FACTOR I.C. SOIL TYPE & ELECTRO - CHEMICAL FORCES

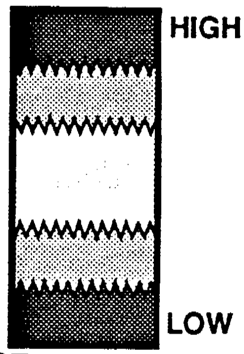


FACTORS AFFECTING COMPACTION OF SOILS WITH FINES

FACTOR II.

WATER CONTENT AT COMPACTION

WATER CONTENT



DIFFICULT TO COMPACT

EASIER TO COMPACT

INTERMEDIATE DIFFICULTY

ACTIVITY 8 - REVIEW PROBLEMS

To test your understanding of the objectives in Part A, complete the following questions. If you have difficulty completing any questions, you should review the material involved before proceeding to the next part of the Module.

Match the definitions on the right with the terms on the left.

1.	Compactive effort	A.	The weight of soil solids per unit of volume.
2.	Compacted lift thickness	B.	The ability of a soil to deform without cracking.
3.	Consolidation	C.	The amount of energy applied to a soil mass.
4.	Kneading compaction	D.	The depth of soil after spreading and compaction.
5.	Dry unit weight	E.	The application of mechanical forces to a soil mass which results in densification of the soil mass.
6.	Compaction	F.	The primary action imparted by a tamping roller.
7.	Flexibility	G.	The gradual reduction in void space of a soil mass resulting from an increase in compressive stress.

Fill in the blanks for the following sentences:

1. The shear strength increase that usually results from the compaction of soil is a ______________________________ effect of compaction. (beneficial/detrimental/supplemental)

2. Shear strengths of most fine-grained soils will be higher if the soils are compacted at ____________________ water contents. (low/high/intermediate)

3. Relatively clean sands and gravels are compacted best with ____________ rollers or ________________ tractors. (pneumatic/vibratory/tamping) ** (crawler/farm)

4. A ______________________________ roller is one that has many tires and a ballast for load. (tamping/vibratory/pneumatic)

CONTINUE TO THE NEXT PAGE

ACTIVITY 8 - Continued

5. The flexibility of most soils is ____________________ by compacting at higher water contents. (unaffected/increased/decreased)

6. To reduce the swell potential of most soils you should compact them at ________________ water content. (low/high/intermediate)

7. The three major factors affecting compaction are ______________________ ______________________, and ______________________________________.

8. The most efficient type of equipment for compacting fine-grained, plastic soils is a __________________. (tamping roller/pneumatic roller/scraper)

9. Compacted soil is usually less permeable because the __________________ is reduced. (void space/density/shear strength)

10. (Well-graded/Poorly graded) ___________________________ soil has higher tension forces, given a comparable water content for both.

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

1. Decreased consolidation potential is a desirable effect of the compaction of the fill for a foundation for a concrete structure. _____

2. Clean, coarse-grained soils are difficult to compact. _____

3. Density and dry unit weight are equivalent for practical purposes. _____

4. Compaction of plastic clays at low water contents at a given density substantially reduces their swell potential. _____

5. The dry unit weight of a soil mass is calculated from known values of its specific gravity and water content. _____

6. Thicker lifts are permissible for fine-grained, plastic soils than for clean, coarse-grained soils. _____

7. Well-graded coarse-grained soils cannot be compacted to as high dry unit weights as can poorly graded coarse-grained soils. _____

CONTINUE TO THE NEXT PAGE

ACTIVITY 8 - Continued

8. Four to six passes of a tamping roller per lift of soil are usually adequate to compact soil for most fills. _____

9. Vibratory rollers compact soil primarily by a kneading action. _____

10. The water content at which a GP soil is compacted is critical. _____

11. Surface tension forces are minor in a clean, fine, poorly graded sand at an intermediate water content. _____

12. Highly plastic clays are difficult to compact because of the high attraction of the clay minerals to water and because of the small void sizes. _____

13. Surface tension forces are low at both low and high water contents in clean, coarse-grained soils. _____

If you have difficulty in completing the Activity, or wish to check your answers to the problems, the answers are shown on the following page.

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

ACTIVITY 8 - Solution

Matching questions:

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

Fill in blank question:

1. beneficial
2. lower
3. vibratory/crawler
4. pneumatic
5. increased
6. high
7. kind of soil, water content, energy applied
8. tamping roller
9. void space
10. Well-graded

True/false questions:

1. T	6. F	11. F
2. F	7. F	12. T
3. T	8. T	13. T
4. F	9. F	
5. F	IO. F	

START THE TAPE WHEN YOU HAVE FINISHED

APPENDIX

SCS Logo

ENG-SOIL MECHANICS TRAINING SERIES--
BASIC SOIL PROPERTIES
MODULE 5 - COMPACTION
PART A
INTRODUCTION, DEFINITIONS, AND CONCEPTS

1

-

Soil Mechanics
Level II
Module 5

Soil Mechanics Module 5 covers compaction of soils for engineering uses. The standard compaction tests and applications of the test results are covered. Soil compaction is important in many Soil Conservation Service structures.

2

-

This module consists of five parts:

Module 5

Part A reviews terms and definitions, factors affecting compaction of soils, and the purposes of compacting soils.

Part B explains compaction test procedures used for soils that have a low gravel content and significant fines content.

Part C explains compaction test procedures used for soils that have a high gravel content and significant fines content.

3

Part D explains the tests for determining compaction characteristics of coarse-grained soils that have less than 12 percent fines.

Part E discusses the evaluation of compaction test data and methods of estimating compaction test data for fine-grained soils.

-

Objective 1

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

Objective 1:

4

Define the terms, symbols, and equations used with the compaction of soils.

-

Objective 2 5	Objective 2: State from memory how the engineering properties of the major Unified Soil Classification System groups are affected by compaction. State generally whether each effect is beneficial or harmful.
Objective 3 6	Objective 3: List the three primary factors that affect the compaction characteristics of a soil.
Objective 4 7	Objective 4: Describe the general compaction characteristics and most appropriate construction equipment for each major Unified Soil Classification System group.
Activity 1 8	These objectives are listed in your Study Guide, Part A, Activity 1. Stop the tape player and carefully study the Activity before continuing.
Terms/Definitions 9	First, the terms, symbols, and definitions needed to explain compaction will be discussed.
Definition and Compaction 10	Compaction is the densification of a soil by mechanical means.

Expulsion of Air

11

This densification results primarily from the expulsion of air from the soil mass. However, in relatively clean sands and gravels, and some non-plastic silts, water may also be expelled from the soil pores. In either case, the soil solids are more closely packed, and the density of the mass increases, since soil solids are much heavier than air or water.

Compaction = Consolidation

12

The terms compaction and consolidation should not be confused.

Contrast Compaction and Consolidation

13

Consolidation occurs when a static load is placed upon a soil mass and air or water, or both, are expelled from the voids of the soil mass caused by the load application. Compaction occurs when a dynamic load is applied to a soil mass. In compaction, substantial re-arrangement of the soil particles occurs, but in consolidation, particle re-arrangement is minimal. Consolidation is time-dependent, whereas compaction occurs rather instanteously.

Activity 2

14

Activity 2, Part A, covers the definitions of compaction and consolidation in more detail. Examples and problems are given. Stop the tape player and complete the Activity.

Definitions
Borrow Area
Fill

15

In construction of a compacted fill, soils are usually excavated at one location, transported to another location, spread in thin layers, and then compacted. The site where the soils are obtained is the borrow area. The compacted soils are called the fill.

Slide of Earth Dam

16

Examples of structures constructed with compacted soil are earthen embankments for flood prevention and water storage, highway fills, and levees for containing stream flows.

Slide of Highway Subgrade

17

Examples of compacted fills used as foundations for other structures are a compacted soil pad under a building, or a compacted soil base for a concrete or asphalt highway.

Purpose of Compaction

18

Soil that is not compacted usually has poor engineering properties. The purpose of compaction is to improve the soil and produce a product that has known engineering properties. Details on the effects of compaction on engineering properties are given later in the Module.

Types of Mechanical Forces

19

The application of mechanical forces to compact soil may be grouped into several categories as follows:

1. Static load.
2. Kneading action.
3. Vibratory action.
4. Impact loading.
5. Combinations of one or more of the above methods.

(4 slides)

20 21 22 23

Types of equipment that impart static loads for compaction include:
1. loaded scrapers,
2. smooth wheeled steel drum rollers,
3. heavily loaded rubber tired rollers (pneumatic rollers) that have closely spaced rollers.
4. Crawler tractors.

(1 slide)
24

Kneading compaction is usually accomplished with a tamping roller.

Examples of vibratory compaction equipment are:

(3 slides) 25 26 27

1. Vibratory rollers with a smooth steel drum,
2. A crawler tractor,
3. A vibrating rod - used to compact soil in place.

-

Impact compaction may be accomplished by:

(3 slides) 28 29 30

1. Dropping heavy weights from great heights onto a soil surface.
2. Hand-held, motorized compactors,
3. Hand tamping.

-

Combination of Forces

31

Most equipment used for compacting soil actually apply a combination of these methods of load application. For example, a crawler tractor or bulldozer applies static loading as well as vibratory load application to a soil. Tamping uses impact and kneading in combination.

-

Picture of Harvard Miniature Compaction Device

32

Laboratory equipment is often designed to simulate field load applications. This is a Harvard miniature compactor that simulates kneading compaction of soil specimens for laboratory tests.

-

ACTIVITY 3

33

Activity 3 summarizes the concepts just reviewed. It contains examples and discussion problems to test your understanding of these concepts. Stop the tape player and complete Activity 3 before continuing.

-

Volume-Weight Terms

34

Many of the terms and equations you learned in Module 4 - Volume-Weight Relations are used extensively in this Module. Some of the important terms you should know include:

Dry Unit Weight
Wet Unit Weight
Water Content
Saturated Water Content
Specific Gravity

-

ACTIVITY 4

35

To review your knowledge of these definitions and to review important equations that are used in this Module from the Volume-Weight Module, complete Activity 4 at this time. If you have trouble with this Activity, you should review Module 4 before continuing.

-

Engineering Properties Affected by Compaction

36

Compaction densifies a soil mass. Most of the important properties of a soil are changed by this densification. The primary engineering properties affected are shear strength, consolidation, and permeability. Other important properties that are affected include flexibility and shrink swell.

-

Effect of Compaction Water Content on Engineering Properties

37

The water content at which soils are compacted may also strongly affect the resulting engineering properties of the compacted soil. The effects of densification on soil properties will be discussed first, and then the effects of compaction water content are discussed last.

-

Effect of Compaction on Shear Strength

38

The shear strength of soils is increased by compaction or densification. The effect of densification on shear strength is usually more pronounced in fine-grained soils than in cleaner, coarse-grained soils.

-

Other Factors Affect Shear Strength

39

You should understand that other factors also affect the strength of soils in addition to unit weight. For example, clean angular sand usually has a higher shear strength than sand that has rounded particles even though both are compacted to the same unit weight. For a given soil, however, the shear strength will be increased as the soil is compacted to a higher unit weight at the same water content.

-

Effect of Compaction on Consolidation Potential

40

The consolidation or settlement potential of a soil is decreased by compaction. The primary reason many fills are compacted is to create a more suitable foundation for structures that cannot tolerate much settlement, such as buildings or rigid concrete structures. Excessive settlement could cause cracking or other distress in the structures.

-

Effect of Compaction on Permeability

41

Soils are also compacted to reduce permeability. Permeability is a measure of the soil's capacity to convey water through the pores of the soil mass. Compaction reduces the void space, making the pores smaller, so that less water can pass through the mass. For this reason, compacted fills are often used as dams and dikes to impound and retain water.

-

Definition of Flexibility

42

Flexibility is another property of soils that may be strongly affected by compaction. Flexibility is the ability of a soil to deform without cracking. Flexibility is important for fills constructed on yielding foundations. This fill has cracked due to foundation settlement.

-

Effect of Compaction on Flexibility

43

Compaction usually reduces flexibility. Fine-grained soils and sands and gravel that have significant amounts of fines are most strongly affected. Flexibility of compacted fills constructed of these soils is decreased by compaction.

-

Definition of Shrink-swell

Shrink-swell is another soil property that may be strongly affected by compaction. Soils that have plastic fines are most affected. Shrink-swell is the decrease and increase in volume of a soil caused by alternately drying and wetting the soil. Shrinkage cracks and large pressures exerted in swelling soil can be serious engineering problems. Compaction generally increases swell pressures and decreases
44 the shrinkage potential.

Effect of Compaction Water Content

Shrink-swell behavior of plastic fine-grained soils is strongly affected by the water content at which the soils are compacted. Other engineering properties are also affected by compaction water content. These properties are discussed
45 next.

Effect of Water Content on Shear Strength

Usually, a soil compacted at a higher water content is weaker in shear strength than the same soil compacted to the same unit weight at a lower water content. This effect is more pronounced for silts and clays and sands and gravel that have significant fines content. The shear strength of clean sands and gravel is not drastically affected by the water
46 content at which the soils are compacted.

Effect of Water Content on Consolidation

Most soils will consolidate more if they are compacted to a higher water content. The effect of water content on consolidation potential is more pronounced in fine-grained soils and dirty sands and gravel and less pronounced in clean,
47 coarse-grained soils.

Effect of Water Content on Permeability

A soil compacted at a higher water content is usually less permeable than the same soil compacted at a lower water content. Again, this effect is more pronounced for fine-grained soils and less important for clean, coarse-grained
48 soils.

Effect of Water Content on Swell 49	The shrink-swell behavior of susceptible soils is strongly affected by compaction water content. Susceptible soils may develop high swell pressures when subsequently saturated if compacted at a low water content. -
Effect of Water Content on Shrinkage 50	These soils are also susceptible to shrinkage cracking if compacted at a high water content and then subsequently dried. -
Effect of Water Content on Flexibility 51	Flexibility of fine-grained soils and dirty sands and gravel is increased by compaction at a higher water content. This may be an important consideration for fills constructed on yielding foundations. Clean, coarse-grained soils have little flexibility. -
TRADEOFFS 52	A designer must consider all of the effects of compaction and compaction water content on the resulting properties of soils used in a fill. Although a high degree of compaction may produce increased shear strengths and lower consolidation potential, flexibility and swell behavior of the fill may be adversely affected. These considerations are often referred to as trade-offs in the design of a compacted fill. -
OTHER TRADEOFFS 53	Other trade-offs are involved in selection of compaction water content. Higher compaction water content will create more flexible soils, but the fill will have lower shear strength and higher consolidation potential. -
ACTIVITY 5 54	Activity 5 of your Study Guide covers the effects of densification and compaction water content on the engineering properties of several basic groups. Stop the player and study Activity 5 before continuing. -

Factors Affecting Compaction of Soils

The three factors that determine the compaction properties of soils are as follows:

I. The kind of soil being compacted.
II. The water content at which the soil is being compacted.
55 III. The type and amount of energy applied to the soil.

Soil Properties Affecting Compaction

The kind of soil compacted strongly affects its compaction characteristics. The soil's properties that are most important include:

A. The grain-size of the soil.
B. The size and distribution of voids in the soil.
56 C. The electro-chemical properties of the soil.

Clean Coarse-Grained Soil Groups

In discussing these factors, soils are grouped according to their Unified Soil Classification groupings. First, the relatively clean, coarse-grained soil groups, those that have twelve percent or less fines, are discussed.

57 This group includes the classes shown.

The two soil properties which are most important for clean, coarse-grained soils are the grain-size and size and distribution of the voids in the soils. The electro-chemical properties are not important, as these soils are largely inert. Electro-chemical properties will be covered later in discussion of fine-grained soils and dirty, coarse-grained
58 soils.

Some clean, coarse-grained soils, particularly fine, poorly graded sands, classifying as SP in the Unified System, are highly affected by a phenomenon known as surface tension. This picture shows a pyramid built of moist, clean, fine sands as you would find on a beach. The forces holding the sand together, permitting the structure to stand unsupported,
59 are called surface tension forces.

Surface tension forces are present where films of water exist
between soil particles. In clean, moist, fine-grained sands,
these films are so numerous that the total force created by
them is considerable, and difficult to overcome in compacting
60 the soils.

When the moist sand is flooded, all of the voids in the sand
become full of water, and no films between particles which
create surface tension are left. As a result, the sand
structure collapses. This principal is important in
61 compacting fine sands.

Flooding of clean sands prior to compaction is helpful in
achieving the greatest compaction with a given amount of
62 energy.

Bulking is the tendency of moist fine sands to maintain a
loose structure when placed. Bulking refers to the
increasing of the volume, or decreasing of the density.
Bulking is caused by surface tension forces which support a
loose structure in the loosely dumped sands. This photo
shows a calibrated cylinder into which loose, moist clean
sand has been dumped. As you can see, the sand occupies a
63 volume of about 500 cubic centimeters.

When this loose sand is flooded, the surface tension forces
are destroyed, and densification, or compaction, is easily
accomplished. Most of the densification that is attainable
occurs at the time the sand is flooded, although additional
vibration will cause additional densification. Note that
after flooding, the volume of the sand is now 330 cubic
64 centimeters.

This illustration summarizes the factors affecting compaction
of clean, coarse-grained soils. The more difficult soils of
this group to compact are fine, poorly graded sands. These
sands can only be effectively compacted at either very low or
nearly flooded water content conditions. Bulking at moist
conditions makes compaction much more difficult. Coarser
soils such as well graded gravels are relatively dense even
when loosely dumped, and vibration alone is usually effective
65 in densifying satisfactorily.

-

Compacting clean, coarse-grained soils is most effectively
done with vibratory rollers. The vibratory action helps to
break down the surface tension forces in the water films
between the particles, just as vibration of a bubble breaks
the bubble. Some coarse-grained soils can be effectively
66 compacted with crawler tractors which are heavy enough.

-

The next group of soils discussed are the dirty sands and
gravels, of the Unified Soil Classification System groups
67 shown.

-

In this group of soils, two types of forces may be present
which have to be considered in compaction. Dirty sands and
gravels may have both surface tension forces, and the
presence of clay fines may also contribute to forces between
the particles, referred to as electo-chemical forces. Water
68 content at compaction relates to both of these forces.

-

Clay fines in dirty sands and gravels may have powerful
internal forces. These forces are caused by the fact that
most clays are negatively charged, and they are attracted
69 strongly to water molecules.

-

Silt-size particles are not as electrically active as clay-size particles, but their small size, compared to sands,
70 results in high surface tension forces.

-

Soils with significant amounts of clay and silt fines are effectively compacted only within a narrow range of water contents. At very low water contents, there is insufficient water to lubricate the particles and permit rearrangement. At very high water contents, the soils can be compacted only
71 by expulsion of the water from the soil mass.

-

Expelling water from a very wet clay or silt is difficult due to the low permeability of the soil. The trapped water in the pores of the soil resists compaction, since water itself
72 is incompressible.

-

Soils with active clay minerals such as montmorillonite are the most difficult to compact, since these minerals have such a high electrical charge. Soils with less active minerals such as kaolinite, are easier to compact. Also, silts are generally less difficult to compact due to their lack of
73 electrically charged particles.

-

Soils with higher liquid limits and higher plasticity index values usually have more active clay minerals. Generally speaking, the higher these values are, the more difficult it
74 is to compact the soils.

-

This chart shows the preferred type of compaction equipment for this group of soils. Tamping rollers are required for sands and gravels with clay fines, because the tamping action is necessary to destroy bonding of the clay particles.
75 Vibration or static load alone will not do the job.

-

The third group of the soil types to be discussed are the fine-grained soil classifications. The Unified
76 Classification groups shown are included.

-

The primary factor affecting the compaction characteristics of these soils is the electro-chemical properties. Although the presence of sands and or gravels in the samples may have some effect, the primary factor is that of the type and
77 amount of clay in the sample.

-

This chart summarizes the relative difficulty of compaction of this group of soils. As you see, those soils with silty, or non-plastic type of fines are easier to compact, and compaction difficulty increases with increasing liquid limits
78 and plasticity.

-

This chart summarizes the types of construction equipment suited to compaction of these soils. As you can see, a tamping roller is essential to good compaction of most of these soils. Pneumatic rollers are acceptable for some silts
79 with very low plasticity fines.

-

80 STOP THE TAPE AND CHANGE THE CAROUSEL TRAY

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Activity 6

81

Activity 6 in your Study Guide summarizes compaction characteristics. Stop the tape and carefully study this Activity before continuing.

-

Factors Affecting Compaction ENERGY

82

The third major factor affecting the compaction of soil is the amount and type of energy applied to the soil. The following items are involved in the amount of energy applied to a compacted fill:

A. Lift thickness.
B. Type, size, and weight of equipment.
C. Number of passes and speed of travel of equipment.

-

Loose Lift Thickness

83

Loose lift thickness is the thickness of the soil after it is transported and spread on a surface prior to compaction. It is important to spread the soil uniformly so that when compacted, an equal effort is applied to all of the soil.

-

Loose Lift Thicknesses For Various Soil Groups

84

A loose lift thickness of about nine inches is often specified for fine-grained soils. A larger loose lift thickness may be acceptable for relatively clean sands and gravels. Loose lift thicknesses of as much as two feet may be used for these soils. Clean rockfill may be placed in loose lifts as thick as four feet.

-

Compacted Lift Thickness

85

Compacted lift thickness refers to the thickness of the layer after it is compacted. The compacted lift may be from three-fourths to one-half the loose lift thickness, depending on the soil, the amount of energy applied, and the water content.

-

Type of Equipment

86

The type of equipment and its weight also affect the amount of energy applied to a compacted soil. Usually, heavier equipment will produce more densification than light equipment. In some soil, equipment may be so heavy that soil shearing occurs with operation of the equipment, which is undesirable.

-

Contact Pressure

87

In addition to the total weight of the compaction equipment, the contact pressure of the equipment is important. Contact pressure of equipment is usually expressed in pounds per square inch. Equipment may be specified in terms of contact pressure rather than total weight, when this type of compaction specification is used. Tamping rollers may have contact pressures of as high as 500 psi.

-

Contact Pressure

88

When using pneumatic rollers the tire size, inflation pressure, and ballast load are usually specified.

-

Other Equipment Factors

89

The speed at which equipment traverses a fill and the number of passes of the equipment over each layer of the fill also affect the amount of energy applied to a compacted fill. The frequency of vibrations in vibratory rollers is also important.

-

Equipment Specifications

90

One method of specifying earth fill compaction is to specify the permissible loose lift thickness and the type of equipment, including its size. The number of passes of the equipment over each lift and the speed of travel of the equipment are also specified. These specifications are usually based on previous favorable experience with the soil being compacted.

-

ACTIVITY 7

91

Activity 7 of your Study Guide summarizes the factors involved in the energy application to soil in the compaction process. Stop the tape and carefully study the Activity before continuing.

-

REVIEW OBJECTIVES

92

Let's review the objectives of Part A to ensure that you have accomplished all of them. You should be able to define conceptually from memory the important terms, symbols, and equations associated with compaction of soil.

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93

Objective 2 was to state conceptually from memory the effect of compaction and compaction water content on the engineering properties of the major USCS soil groups, and to state generally whether the effects are beneficial or harmful.

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94

Objective 3 was to list the three primary factors affecting the compaction characteristics of soils.

-

95

Objective 4 was to describe the general compaction characteristics and the best suited compaction equipment for each major USCS soil group.

-

ACTIVITY 8

96

To test your completion of these objectives, stop the tape player and complete Activity 8.

-

THE END

97

You should now proceed to Part B of Module 5 on compaction.