United States
Department of
Agriculture

Soil
Conservation
Service

Engineering Field Manual

Chapter 4. Elementary Soil Engineering

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Introduction

All structural measures and many land treatment measures for which SCS provides technical assistance involve the use of soil as a building material or a supporting medium. Soil engineering is the application of physical, chemical, and mechanical properties of soil to its use as a construction material and as a foundation for structures.

This chapter is about soil engineering. It includes the following major sections: (l) an explanation of basic soil concepts that relate to engineering; (2) an engineering classification and description system for soil; and (3) guides for estimating soil strength, permeability, erosion resistance, and other performance characteristics. It also discusses site investigation and presents a procedure for the preliminary embankment design of earth dams.

Soil

Soil is defined as sediments or other unconsolidated accumulations of solid particles produced by the physical disintegration and chemical decomposition of rocks. It may or may not contain organic matter.

Soil consists of the solid soil matter and void space called "soil voids" or simply "voids."

Soil Solids

The soil solids are made up of mineral particles resulting from physical disintegration of the parent rock or the minerals making up the parent rock. For example, granite often breaks down into individual particles of its minerals: feldspar, quartz, and mica.

Chemical action on rocks causes decomposition of the rocks. Water, air, and certain acids or salts will, when associated with rock minerals under favorable conditions, combine to form new chemical compounds not present in the parent rock.

Decomposition usually follows disintegration. The mineral content of the parent rock and the extent of disintegration and decomposition determine the kind of soil and the engineering properties of that soil.

The ease with which the parent rock is disintegrated and decomposed and the length of time these processes have acted determine the size of the granular soil particles. In angularity, sand and gravel particles are described as angular, subangular, subrounded, or rounded. Detailed definitions for these terms are given later in this chapter.

In shape, soil particles may be spherical, flat, elongated, or flat and elongated.

The size and shape of clay particles are determined by the chemical composition and molecular structure of each particular kind of clay.

Soil Voids

Soil voids are that portion of a soil volume not occupied by solids. In a natural state, the voids may be filled by liquid, gas, or both.

Gas in the voids is usually air. In soil engineering, air in voids is treated as being weightless. Liquid in the voids is usually water, which is considered incompressible.

Origin

Soil at a location may have been formed in place from rock or transported to that site by gravity, water, wind, ice, or some combination of these. Soil formed in place is called residual. Transported soils are described by their method of transportation.

Colluvium is soil that has been transported by gravity. This transportation may have been so slow that it is difficult to measure, or it can be nearly instantaneous. Examples are loosened particles that roll or slide down a steep slope, large masses of soil that slowly 'creep' downhill, and landslides.

Alluvium is soil that has been transported to its present location by water. *Aeolian* or eolian soil has been transported to its present location by wind. This term is derived from Aeolus, Roman god of the wind. The transportation of soil by wind and water is characterized by three processes: (1) soil particles are transported by being rolled or slid along the ground surface or by being picked up and carried in suspension; (2) particles tend to separate and deposit according to their weight (size); and (3) certain particle sizes may be in a loose arrangement and subject to compaction as they settle.

Glacial till is soil that has been gouged out of the earth's crust by ice (glaciers) at one location and dropped at another. In this process, there is usually little or no separation of particles by weight.

Transportation processes are important agents of disintegration, particularly in producing very fine particles by wearing away larger particles. An area's soil and its engineering properties are partly the result of whether and how that soil was transported and deposited.

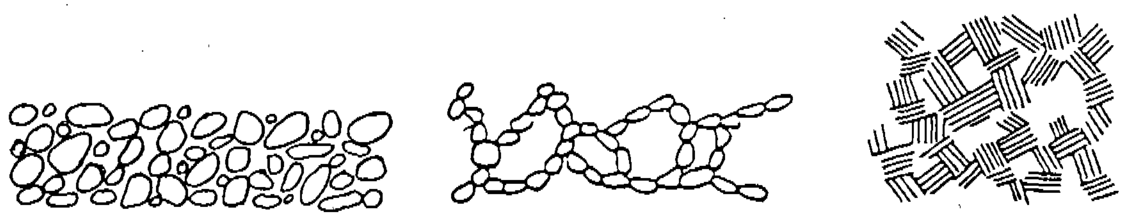
Structure

Soil structure is defined as the arrangement and grouping of soil particles in a soil mass. "Flocculent structure" describes a structure of elongated particles (usually clay particles) held together in groups or clusters of individual soil particles called "flocs," (fig. 4–1).

When not flocculated, soil particles are said to be dispersed. Such soil has a "single-grain" structure, characteristic of coarse-grained or granular soils. Most clay particles are attracted to each other by electro-chemical bonding, which causes them to flocculate and adhere or cling together. Some soils contain salts or other compounds in the pore water, creating a condition in which the soil particles are not attracted to each other. Clays in which soil particles tend to separate or repel each other are called dispersive clays. When clays have deflocculated in water they are called dispersed clays.

"Honeycomb structure" describes an arching arrangement of soil particles somewhat resembling a honeycomb in appearance. Particles are usually silt-sized; that is, relatively loose

Figure 4–1.—**Types of soil structure.**



(a) Single-grain structure

(b) Honeycomb structure

(c) Flocculent structure

(open) but stable. Soils with this type of structure are usually highly compressible and may collapse when the applied load becomes large enough to destroy the structural bonding or arching at the contact between particles.

Soil Water

Most soils contain water. Water can exist in soil in several different forms. The water in soil voids may be influenced by external or internal pressures and can have positive, neutral, or negative pressure. Some definitions pertaining to water in soil are as follows:

Hygroscopic water—The water adsorbed on the surface of soil particles as a thin film that (1) has properties substantially different from ordinary water, and (2) is removed by oven drying but not by air drying.

Capillary water—Water that is under tension in a soil due to stresses produced by menisci forming in the soil pores as water recedes into the voids from evaporation or is lost by other means. It is also the water which has been moved from one point to another through interconnected voids because of a change in capillary stress or tension.

Gravitational water—Water that is free to move through a saturated soil mass under the influence of gravity.

Water content (w) is the percentage of the weight of water to the weight of the dry solids. The term "moisture content" is sometimes used instead of "water content."

A saturated soil has its voids completely filled with water, and its water content is denoted by w_{sat}. Soil below the water table is usually considered to be saturated.

Dry soil contains only air in the voids. Drying a soil to a constant weight in an oven at a temperature of 110° ± 5° C is the standard commonly used to determine the "dry weight" or "dry mass" of a soil.

The optimum water or moisture content is the percentage of water in a soil, based on its dry weight, at which the maximum unit weight or density is obtained under a given compactive effort and is denoted by w_o. The common procedure for determining water or moisture content is to dry the soil in an oven or by other means. Most clay soils that have drained to field capacity after wetting have a water content near optimum. Dry soils require the addition of considerable water to reach optimum water content. Soils with water content between dry and saturated are termed "wet." Saturated and dry conditions represent definite water contents, whereas wet makes up the range between these two limits.

Volume–Weight Relationships

All soils are composed of solids, air, and water. In this chapter, the term "soil" includes all three components.

Figure 4–2 (sketch a) represents a definite volume of soil composed of solids and voids. Figure 4–2 (sketch b) represents the same soil with the solids and void volumes separated into their respective proportions. The total volume is always equal to the sum of the volumes of the solids and the voids.

$$V = V_s + V_v$$

Figure 4–2 (sketch c) represents the same soil volume with some water added but not enough to fill the voids completely. The soil is now composed of solids, water, and air. In this state, the volume of the voids is equal to the sum of the volumes of water and air.

$$V_v = V_w + V_a$$

The total volume is equal to the sum of the volumes of the solids, water, and air.

$$V = V_s + V_w + V_a$$

Certain volume relationships have been found to be useful in soil engineering.

Void ratio. Void ratio "e" is the ratio of the volume of the voids to the volume of the solids.

$$e = \frac{V_v}{V_s} \text{ (dimensionless)}$$

The void ratio can be equal to, greater than, or less than I and is usually expressed as a decimal.

Porosity. Porosity "n" is the percentage of the total volume that is void.

$$n = \frac{V_v}{V} \times 100 \text{ (dimensionless)}$$

Numerically, porosity can never be greater than 100 percent.

Degree of saturation. Degree of saturation, "S," is the ratio of the volume of water in the voids to the volume of the voids, expressed as a percentage.

$$S = \frac{V_w}{V_v} \times 100 \text{ (dimensionless)}$$

When the voids are completely filled with water ($V_w = V_v$), the degree of saturation equals 100 percent.

Figure 4–2 (sketch C) points out that the total weight is equal to the sum of the weights of the solids, water, and air.

$$W = W_s + W_w + W_a$$

or $W = W_s + W_w$ since the weight of the air is considered to be zero.

Water Content

An important weight ratio in soils engineering is the ratio of the weight of the water in the soil to the weight of the solids. This ratio multiplied by 100 is the percentage of water content (moisture content).

$$w = \frac{W_w}{W_s} \times 100 = \text{percentage of water content}$$

Specific gravity. The *specific gravity* (G_s) of soil solids is the ratio of the weight of a given volume of the soil solids to the weight of an equal volume of pure water. To be precise, the engineer should state the temperature of the water. More often than not, this refinement is ignored in soil engineering, even though a standard set of conditions is used in determining specific gravity.

The volume used in determining *specific gravity of solids* does not include any voids. This type of specific gravity, designated G_s, is commonly reported for sands and fines. Values usually fall between 2.5 and 2.8, and most fall near 2.65. Therefore, 2.65 is often used as an average value in qualitative evaluations. A high organic content will lead to a lower value, whereas some of the heavy minerals will give larger values.

Unit weight and density. Unit weight, γ (gamma), is defined as weight per unit volume. The total unit weight includes the weight of soil solids and water divided by the total volume, V. The equation is:

$$\gamma = \frac{W}{V}$$

Units of weight and volume must be consistent.

$$\text{Ft-lb units, } \gamma = \frac{W \text{ (lbs)}}{V \text{ (cu ft)}} = \text{pcf}$$

$$\text{cgs units, } \gamma = \frac{W \text{ (g)}}{V \text{ (cm)}^3} = \text{g/cm}^3$$

Although not technically correct, density and unit weight are often used interchangeably in soil engineering. Unit weight is represented by γ and density by ρ.

The unit weight of I cubic centimeter of distilled water at 4° C is I.0 gram. Therefore, the unit weight of distilled water at 4° C in the SI system of units is:

$$\gamma^w = \frac{1 \text{ (g)}}{1 \text{ (cm)}^3} = 1.0 \text{ gcm}^3$$

Since I.0 gm = .002205 lbs and

$$1.0 \text{ cm}^3 = .00003531 \text{ cu ft}$$

$$\gamma \frac{1.0 \times .002205}{1.0 \times .00003531} \text{ lbs/cu ft}$$

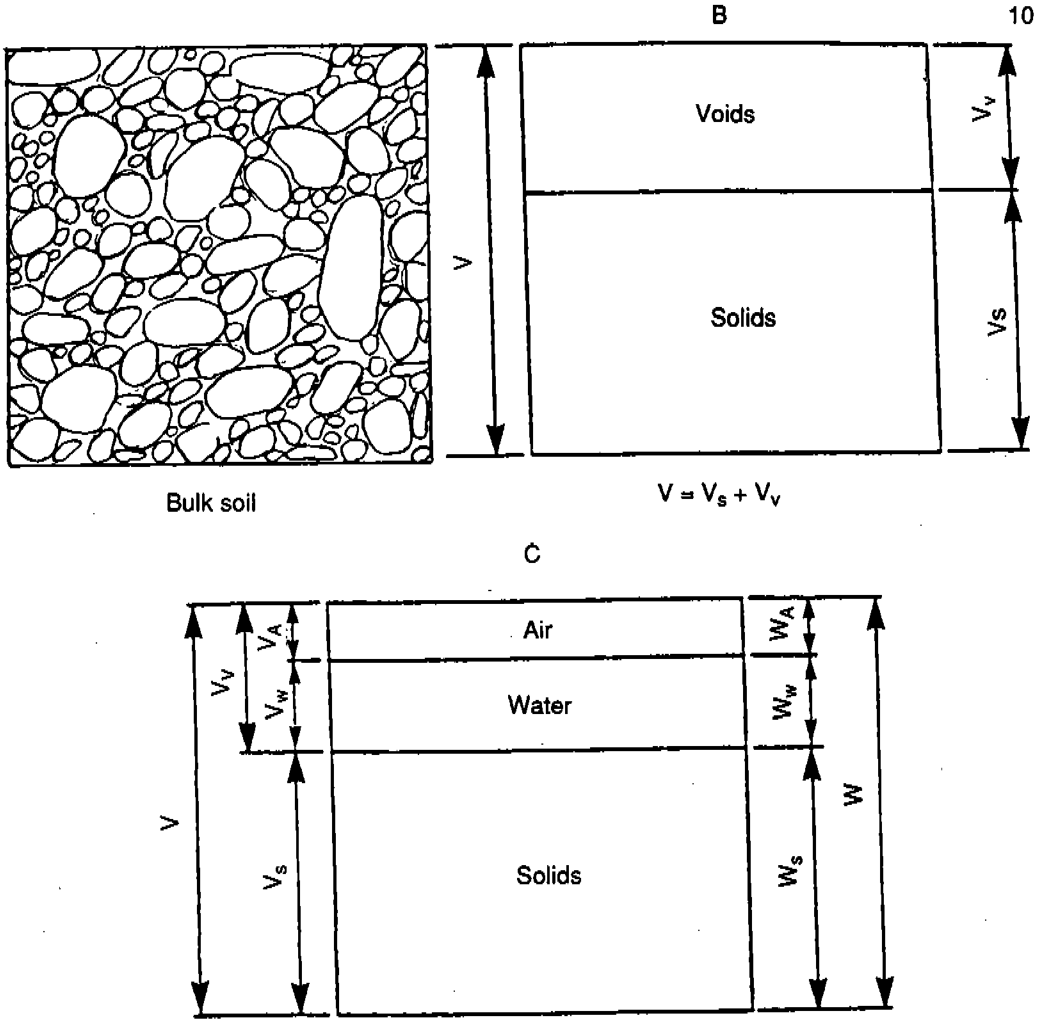
$$\therefore w = 62.4 \text{ lbs/cu ft in foot-pound units}$$

At each of four most frequently used water contents, the unit weight of soil has a standard subscript. The four may be written as follows:

$$\text{Dry unit weight, } \gamma_d = \frac{W_s}{V}, \text{ where } V_w = 0$$

$$\text{Wet unit weight, } \gamma_m = \frac{W_s + W_w + W_a}{V}, \text{ where } W_a = 0$$

Figure 4–2.—**Soil volume and weight relationships.**



Bulk Soil = Solids + Water + Air

<u>Volumes</u>	<u>Weights</u>
$V = V_s + V_w + V_a$	$W = W_s + W_w + W_a$
$V_v = V_a + V_w$	$W_a = 0$
Void ratio, $e = \frac{V_v}{V}$	Moisture content
Porosity, $n = \frac{V_v}{V}$	$w = \frac{W_w}{W_s} \times 100$ (%)

Percent saturation, $S = \frac{V_w}{V_v} \times 100$ (%)

Saturated weight, $\gamma_{sat} = \frac{W_s + W_w}{V}$, where $V_a = 0$

Submerged unit weight, $\gamma_{sub} = \gamma_{sat} - \gamma_w$

Submerged unit weight is sometimes referred to as the buoyant unit weight, γ_b.

The volume – weight relationships are summarized in table 4–I.

Atterberg Limits
As water is added to a dry plastic soil, the remolded mixture will eventually have the characteristics of a liquid. In changing from a solid to a liquid, the material first becomes a semisolid and then plastic. A Swedish scientist named Atterberg developed tests to determine the water content at which these changes take place. The points at which the changes occur are known as the Atterberg limits. The system uses standardized testing procedures to establish four states of consistency—solid, semisolid, plastic, and liquid—on the basis of water content.

Soils increase in volume as their water content increases above the shrinkage limit. This is illustrated in figure 4–3.

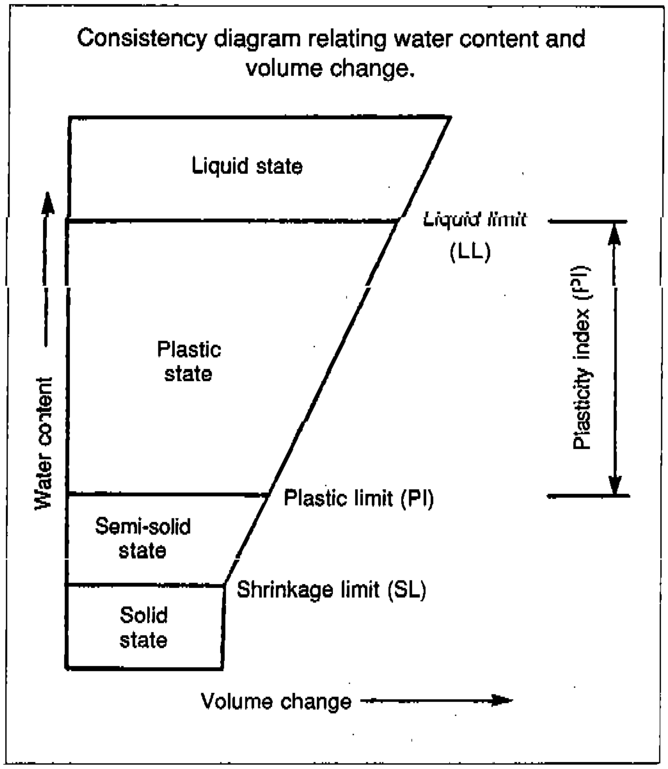
The Atterberg limits are very useful in judging the behavior of fine-grained soil or the fine-grained component of coarse-grained soils with fines. Although fines are soil particles that pass the No. 200 sieve, Atterberg limits are determined on materials that pass the No. 40 sieve. This apparent inconsistency occurs because Atterberg limits were established and measured on materials passing the No. 40 sieve many years before the No. 200 sieve was established as the largest size for fines.

Refer to figure 4–3. In the determination of Atterberg limits, the water content of minus 40 material is measured at various levels determined by prescribed test procedures. The plastic limit (PL) is the water content, by percent, at which the soil changes from a semisolid to a plastic state. The liquid limit (LL) is the water content, by percent, at which the soil water mixture changes from a plastic state to the liquid state. The difference between these two values is the range in water content at which the soil is plastic and is called the plasticity index (PI). The test procedures for liquid limit, plastic limit, and plasticity index of soils are given in ASTM designation D–4318. The test procedure for shrinkage limit is given in ASTM D–427.

In practice, the percent sign is dropped when referring to numerical values of the Atterberg limits. A material with a liquid limit of 50 percent is referred to as having a LL of 50.

The Atterberg limits are defined as:
Shrinkage limit. (SL)The shrinkage limit is the water content at which a further reduction in water does not cause a decrease in the volume of the soil mass. This defines the limit between the solid and semisolid states of consistency.

Figure 4–3.—**Atterberg limits.**



Plastic limit (PL). The plastic limit is the water content corresponding to an arbitrary limit between the plastic and semisolid states of a soil's consistency. This is the water content at which a soil will just begin to crumble when rolled into a thread approximately 3mm (1/8 in) in diameter.

Liquid limit (LL). The liquid limit is the water content corresponding to the arbitrary limit between the liquid and plastic states of a soil's consistency. This is the water content at which a pat of soil, cut by a groove 2mm wide (5/64 in), will flow together for a distance of 13mm (1/2 in) under the impact of 25 blows in a standard liquid limit apparatus.

Plasticity index (PI). The plasticity index is the numerical difference between the liquid limit and plastic limit.

PI = LL – PL

Nonplastic (NP). When the liquid limit or plastic limit cannot be determined, or if the plastic limit is equal to or greater than the liquid limit, the soil is termed "nonplastic."

Table 4–1.—**Volume–weight relationships**

Property			Saturated sample	Unsaturated sample	Other useful relationships			
1	2	3	4	5	6	7	8	9
Volume components	V_s	Volume of solids	$\frac{W_s}{G_s\gamma_w}$		$V-(V_a+V_w)$	$V(1-n)$	$\frac{V}{1+e}$	$\frac{V_v}{e}$
	V_w	Volume of water	$\frac{W_w}{\gamma_w}$		V_v-V_a	SV_v	$\frac{eSV}{1+e}$	eSV_s
	V_a	Volume of air	Zero	$V-(V_s+V_w)$	V_v-V_w	$(1-S)V_v$	$\frac{(1-S)eV}{1+e}$	$(1-S)eV_s$
	V_v	Volume of voids	$\frac{W_w}{\gamma_w}$	$V-\frac{W_s}{G_s\gamma_w}$	$V-V_s$	$\frac{nV_s}{1-n}$	$\frac{eV}{1+e}$	eV_s
	V	Total volume of sample	V_s+V_w	$V_s+V_w+V_a$	$\frac{W}{\gamma_d(1+w)}$	$\frac{V_s}{1-n}$	$V_s(1+e)$	$\frac{V_v(1+e)}{e}$
	n	Porosity	$\frac{V_v}{V}$		$1-\frac{\gamma_d}{G_s\gamma_w}$	$\frac{e}{1+e}$	$\frac{\gamma_d w_{sat}}{\gamma_w}$	$1-\frac{V_s}{V}$
	e	Void ratio	$\frac{V_v}{V_s}$		$\frac{G_s\gamma_w}{\gamma_d}-1$	$\frac{n}{1-n}$	$\frac{\gamma_d w_{sat}}{\gamma_w-\gamma_d w_{sat}}$	$\frac{V}{V_s}-1$
Weights for specific sample	W_s	Weight of solids	$W-W_w$		$\frac{W}{1+w}$	$G_sV\gamma_w(1-n)$	$\frac{W_wG_s}{eS}$	$V\gamma_d$
	W_w	Weight of water	$W-W_s$		wW_s	$S\gamma_wV_v$	$\frac{eW_sS}{G_s}$	$V_w\gamma_w$
	W	Total weight of sample	W_s+W_w		$W_s(1+w)$	$V\gamma_d(1+w)$		
	W_{sat}	Saturated weight of sample	$W_s+V_v\gamma_w$		$W_s(1+w_{sat})$	$V\gamma_d(1+w_{sat})$		
	W_{sub}	Submerged weight of saturated sample	$W_s-V_s\gamma_w$		$W_s\left(\frac{G_s-1}{G_s}\right)$	$V\gamma_d\left(\frac{G_s-1}{G_s}\right)$	$W_{sat}-V\gamma_w$	
Weights for sample of unit volume	γ_d	Dry unit weight	$\frac{W_s}{V_s+V_v}$	$\frac{W_s}{V_s+V_w+V_a}$	$\frac{W}{V(1+w)}$	$\frac{\gamma_m}{1+w}$	$\frac{n\gamma_w}{w_{sat}}$	$\frac{G_s\gamma_w}{1+e}$
					$G_s\gamma_w(1-n)$	$\frac{e\gamma_w}{(1+e)w_{sat}}$	$\frac{G_s\gamma_w}{1+\frac{wG_s}{S}}$	$\frac{G_s\gamma_w}{1+G_sw_{sat}}$
	γ_m	Moist unit weight		$\frac{W_s+W_w}{V}$	$\frac{W_s}{V}(1+w)$	$\gamma_d(1+w)$		
	γ_{sat}	Saturated unit weight	$\frac{W_s+V_v\gamma_w}{V}$		$\left[\frac{G_s-1}{G_sw_{sat}+1}\right]\gamma_w+\gamma_w$	$\gamma_d(1+w_{sat})$	$\gamma_d+n\gamma_w$	$\frac{(G_s+e)\gamma_w}{1+e}$
	γ_{sub}	Submerged unit weight	$\gamma_{sat}-\gamma_w$		$\left[\frac{G_s-1}{G_sw_{sat}+1}\right]\gamma_w$	$\gamma_d-(1-n)\gamma_w$	$\gamma_d-\frac{\gamma_d}{G_s}$	$\left[\frac{G_s-1}{1+e}\right]\gamma_w$
Combined relations	w	Moisture content		$\frac{W_w}{W_s}$	$\frac{W}{W_s}-1$	$\frac{eS}{G_s}$	$\frac{nS}{G_s(1-n)}$	$S\left[\frac{\gamma_w}{\gamma_d}-\frac{1}{G_s}\right]$
	w_{sat}	Saturated moisture content	$\frac{W_{sat}-W_s}{W_s}$		$\frac{n\gamma_w}{\gamma_d}$	$\frac{e\gamma_w}{(1+e)\gamma_d}$	$\frac{\gamma_w}{\gamma_d}-\frac{1}{G_s}$	$\frac{\gamma_{sat}-\gamma_d}{\gamma_d}$
	S	Degree of saturation	$\frac{V_w}{V_v}=1.0$	$\frac{V_w}{V_v}<1.0$	$\frac{W_w}{V_v\gamma_w}$	$\frac{w}{w_{sat}}$	$\frac{wG_s}{e}$	$\frac{wG_s\gamma_d}{G_s\gamma_w-\gamma_d}$
	G_s	Specific gravity	$\frac{W_s}{V_s\gamma_w}$		$\frac{\gamma_d(1+e)}{\gamma_w}$	$\frac{\gamma_d}{\gamma_w(1-n)}$	$\frac{\gamma_d}{\gamma_w-\frac{w\gamma_d}{S}}$	$\frac{W_s}{W_s-W_{sub}}$

Notes: 1. Weight of air is assumed to be zero.
2. Values of w, w_{sat}, S, and n are used as decimals.
3. w is the moisture content which corresponds to the particular W or γ being used.

Classification Using Laboratory Data
SCS uses the Unified Soil Classification System to classify soils for engineering purposes. This system is based on the identification of soils according to their particle–size, gradation, plasticity index, liquid limit, and organic matter content. ASTM D–2487 describes the Unified Soil Classification System. Gradation and particle–size are determined by sieve analyses. Plastic and liquid limits are determined by standard laboratory tests.

This system is for use on naturally occurring soils. The group names and symbols may be used to describe shale, clay stone, shells, crushed rock, and the like.

Names and Symbols
The Unified Soil Classification System uses both names or soil descriptions and letter symbols to describe a soil's properties. The symbol is based on the minus 75mm (3 in) fraction of the material. The soil name description may describe larger material.

Soils having similar engineering properties are placed in groups. Each group is designated by a name and a two–letter symbol. The most important engineering characteristic of the group is described by the first letter in the symbol, and the second most important engineering characteristic is indicated by the second letter. Some soils are given dual symbols.

The letters used as symbols and the soil properties they represent are listed below:

G – gravel C – clay O – organic

S – sand M – silt PT – peat

W – well graded H – high liquid limit

P – poorly graded L – low liquid limit

The names are mostly two-or three-word names that have modifiers when needed. The names, with their two-letter symbols are:

Coarse-grained soils

GW – well graded gravel SW – well graded sand

GP – poorly graded gravel SP – poorly graded sand

GM – silty gravel SM – silty sand

GC – clayey gravel SC – clayey sand

These names may be modified by adding "with silt," "with clay," "with organic fines," "with sand," and/or "with gravel."

Fine-grained soils

ML – silt

CL – lean clay MH – elastic silt

CH – fat clay OL or OH – organic silt

CL – ML silty clay OL or OH – organic clay

These names may be modified by adding: sandy, gravelly, with sand, with gravel.

Highly organic soils
PT – peat

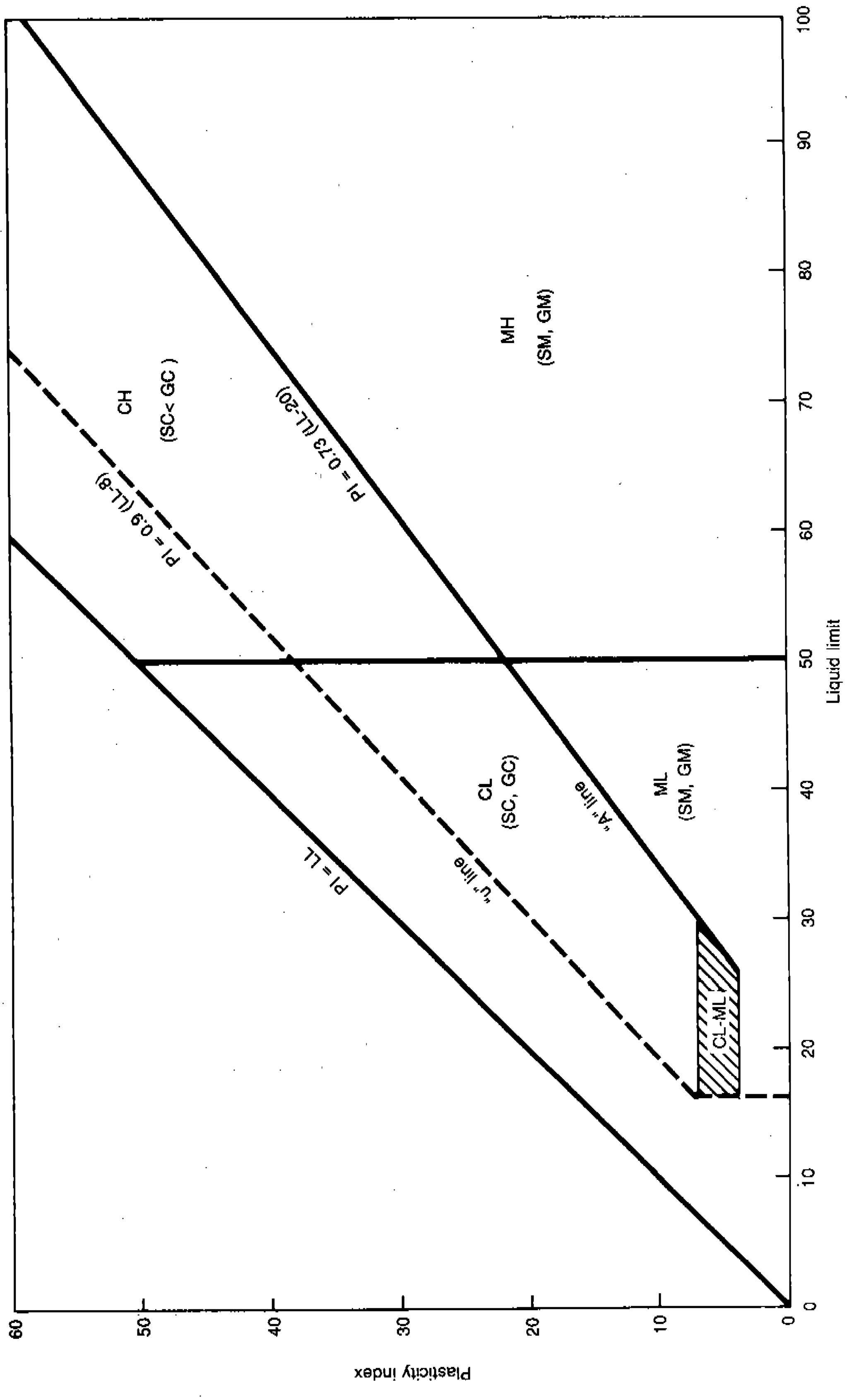
Sieve Sizes
U.S. sieve sizes are used in describing soil classes. The sieves used in the descriptions and the sizes of their openings are shown in table 4–2.

Table 4–2.—**Sieve designation and size of openings**

U.S. standard sieve sizes	Size of opening in mm	Size of opening in inches
3"	75.0	3"
3/4"	19.0	3/4"
#4	4.75	3/16"
#10	2.00	—
#40	0.425	—
#200	0.075	—

The Plasticity Chart
The plasticity chart, figure 4–4, is used to classify soil fines. It is constructed with the liquid limit (LL) as abscissa and the plasticity index (PI) as ordinate. Two lines are plotted on the chart, the A–line and the U–line. The A–line has been plotted so that it lies approximately parallel to the plot of many basic geologic materials and separates clay from silt. To find the formula for the A–line, look horizontal at PI = 4 to and along the line PI = 0.73 (LL–20). The U–line is the approximate "upper limit" for the plot of natural soils. It is used to check for erroneous data. Any test data plotting to the left or above the U–line is probably in error and should be retested for verification. The formula for the U–line is vertical from LL = 16 to PI = 7, then along the line PI = 0.9 (LL–8). The plasticity chart also has a crosshatched area above the A–line between PI's of 4 to 7 that defines an area of silty clays (CL–ML). The A–line and U–line can be extended for plotting soils with LL > 100 and PI > 60.

Figure 4–4.—**Unified Soil Classification System plasticity chart.**



Classifying Fine-Grained Soils. If soil that will pass through a 3-in sieve is passed through a No. 200 sieve, it will be divided into two portions based on particle size. The particles retained on the No. 200 sieve are sand and gravel size and are called coarse-grained. The particles passing the No. 200 sieve are termed fines.

Soils are classified as fine-grained or coarse-grained by the percentage of soil that passes the No. 200 sieve. If more than 50 percent of the soil, by dry weight, is retained on the No. 200 sieve, it is a coarse-grained soil. If 50 percent or more passes the No. 200 sieve, it is a fine-grained soil. The fine-grained soils are classified by referring to the plasticity chart. The name and verbal description include reference to the coarse fragments in the soil when applicable.

Clay or silt. Plasticity is one of the most important index properties of a fine-grained soil. Therefore, a fine-grained material is classified first according to its plasticity. The name associated with the more plastic soils is clay (C), and the name for the less plastic or nonplastic soils is silt (M).

A soil whose plot of the liquid limit and plasticity index on the plasticity chart (figure 4–4) falls on or above the A–line and has a PI of 4 or greater is classed as a fine–grained clayey soil (C). If it falls below the A–line or has a PI less than 4, the material is classified as a fine–grained silty soil (M). Silty clays (CL–ML) have PI's of 4 through 7 and fall above the A–line. This is in the crosshatched area on the plasticity chart.

Under the Unified Soil Classification System, "clay" or "clayey" and "silt" or "silty" is based on the PI and LL.

High or low liquid limit. The second most important index property in classifying a fine-grained soil is its liquid limit.

Soil that has a liquid limit of 50 or greater has a high (H) liquid limit and may be either a clay or silt. Clays with a high liquid limit are called fat clays and have the symbol CH. Silts with a high liquid limit are called elastic silts and have the symbol MH. Soil that has a liquid limit less than 50 has a low (L) liquid limit and may be either a clay or a silt. Clays with a low liquid limit are called lean clays and have the symbol CL. Silts having a low liquid limit are called silts and have the symbol ML.

Fine-grained soils with sand and/or gravel. If the soil has 15 percent or more but less than 30 percent sand and/or gravel then the words "with sand" or "with gravel" are added to the group name. Use "with sand" if the coarse-grained portion is one-half or more sand. Use "with gravel" if the coarse–grained portion is more than one-half gravel. Examples: silt with sand, ML; fat clay with gravel, CH.

If the soil has 30 percent or more sand or gravel, add the words "sandy" or "gravelly" to the group name. Examples: sandy elastic silt, MH; gravelly lean clay, CL.

Organic soils. Silts and clays that contain enough organic material to affect their engineering behavior significantly are classified as organic soils. They can be identified in the laboratory as being organic by performing liquid limit tests on both air dried and oven dried samples. If the liquid limit of the oven dried sample is less than 75 percent of the liquid limit of the air dried sample, classify the soil as organic (O). It is either a low liquid limit organic silt or clay (OL) or a high liquid limit organic silt or clay (OH) based on its air dry liquid limit and plotted position on the plasticity chart. Soils that fall on the crosshatched area of the chart are classified as organic clay (OL).

A soil composed primarily of plant tissue in various stages of decomposition is a highly organic soil and should be classified as peat (PT).

Summary of fine-grained soils. There are eight major breakdowns of fine-grained soils: clayey soil with low liquid limit, or lean clay (CL); clayey soil with high liquid limit, or fat clay (CH); silty soil with low liquid limit, or silt (ML); silty soil with high liquid limit, or elastic silt (MH); organic soil with low liquid limit, or organic clay (OL) and silt (OL); organic soil with high liquid limit, or organic clay and silt (OH); silty clay (CL–ML); and highly organic soil peat (PT).

Classifying Coarse-Grained Soils. Coarse-grained soil particles are divided into sand and gravel by passing them through a No. 4 sieve. Particles retained on the No. 4 sieve are gravel-size. Particles passing the No. 4 and retained on the No. 200 are sand-size. If more than 50 percent by dry weight of the coarse portion of a coarse-grained soil is gravel-size, the soil is classified as gravel. If 50 percent or more of the coarse fraction of a coarse-grained soil is sand-size, it is classified as sand.

Soils with less than 5 percent fines. If less than 5 percent of the total sample by dry weight is fines, the fines do not affect the soil's engineering properties for most uses. These soils are sometimes referred to as "clean sand or gravel." Only the characteristics of the coarse portion are important. The classification as sand or gravel is the material's primary characteristic.

The second most important characteristic of soil having less than 5 percent fines is its gradation (range of particle sizes). The soil may consist predominantly of one size; a mixture of coarse and fine materials with the intermediate sizes missing; or a mixture of relatively equal portions of all particle sizes. Soils in the first two groups are classified as poorly graded and those in the last group as well graded. The range of particle sizes may be obtained by making a sieve analysis. The results are plotted on a grain-size distribution graph (figure 4–5) and analyzed to determine if they meet the following criteria.

Gravels are well graded under the criteria of the Unified Soil Classification System when:

$$Cu = \frac{D_{60}}{D_{10}} \text{ is greater than 4, and}$$

$$Cc = \frac{(D_{30})^2}{D_{10} \times D_{60}} \text{ is at least 1 but not more than 3}$$

Sands are well graded when:

$$Cu = \frac{D_{60}}{D_{10}} \text{ is greater than 6, and}$$

$$Cc = \frac{(D_{30})^2}{D_{10} \times D_{60}} \text{ is at least 1 but not more than 3}$$

Where:

Cu = Coefficient of uniformity

Cc = Coefficient of curvature

D = Diameter of particles determined by a sieve or hydrometer analysis

D_{60}, D_{10}, D_{30} = Diameter of particles such that 60 percent, 10 percent, and 30 percent of the sample is smaller than that diameter. The D sizes can be determined by reading from a grain–size distribution graph opposite 60, 10, and 30 percent fines by dry weight.

Both conditions (Cu and Cc) must be met in order to have a well graded soil. If one or both of the conditions is not met, the soil is poorly graded.

Some soils can be classified by visual inspection of the grain-size distribution graph. When their plot is smooth and is concave upwards between the 10 percent and 60 percent lines they are well graded. The gravel plotted on figure 4–5 is well graded. Soils that are not well graded are poorly graded.

There are four classifications of coarse-grained soils where the fines content is less than 5 percent. They are well graded gravel (GW), poorly graded gravel (GP), well graded sand (SW), and poorly graded sand (SP). If a gravel contains more than 15 percent sand, add "with sand" to the soil name. If a sand contains more than 15 percent gravel, add "with gravel" to the soil name.

Classifications of the coarse soils described above are based on sieve analysis only.

Soils with 12 to 50 percent fines. If a soil is coarse-grained and has a fines content of more than 12 percent but less than 50 percent, the primary behavior characteristic is the same as for a clean coarse-grained soil, whether the soil is a sand or gravel. The second behavior characteristic is based on that portion of the material passing the No. 40 sieve. If this portion of the material is clayey (has a PI > 7 and plots on or above the A–line), the material is a coarse-grained soil with clayey fines (SC or GC). If it has a PI < 4 or plots below the A–line, it is a coarse-grained soil with silty fines (SM or GM). If the PI is at least 4 and not greater than 7 and plots on or above the A–line, the soil is clayey sand (SC–SM) or clayey gravel (GC–GM). If a gravel contains 15 percent or more sand, add "with sand" to the group name. If a sand contains 15 percent or more gravel, add "with gravel" to the group name.

There are four major and two minor breakdowns of coarse-grained soils where the content of fines is greater than 12 percent. They are clayey gravel (GC) or (GC–GM), silty gravel (GM), clayey sand (SC) or (SC–SM), and silty sand (SM).

Soils with 5 to 12 percent fines. Materials containing at least 5 percent but not more than 12 percent fines are given a dual classification, which consists of the symbol for the soil with less than 5 percent fines first and the symbol for soils with more than 12 percent fines second. The dual symbol means that the soil has significant engineering characteristics represented by both symbols. The classifications are: SW–SM, SW–SC, SP–SM, SP–SC, GW–GM, GW–GC, GP–GM, and GP–GC. The first symbol is obtained by classifying the soil as though it had fewer than 5 percent fines. The second symbol is obtained by classifying the soil as though it had more than 12 percent fines. The group name corresponds to the name associated with the first symbol plus "with clay" or "with silt." If a gravel contains 15 percent or more sand, add "and sand" to the group name. If a sand contains 15 percent or more gravel, add "and gravel" to the group name. Examples: well graded sand with silt (SW–SM), poorly graded gravel with clay (GP–GC). Figure 4–6 graphically represents the classification of coarse-grained soils.

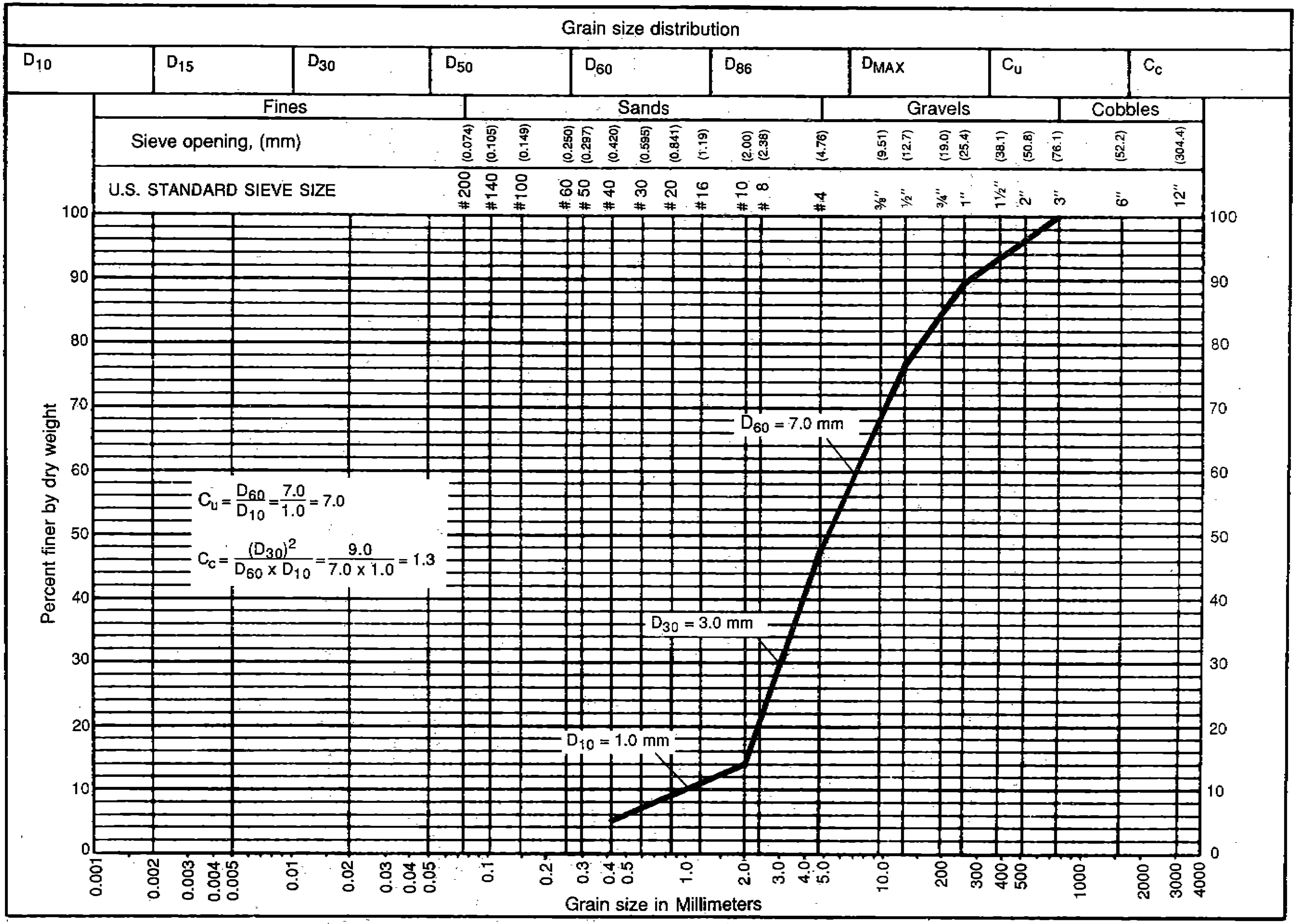
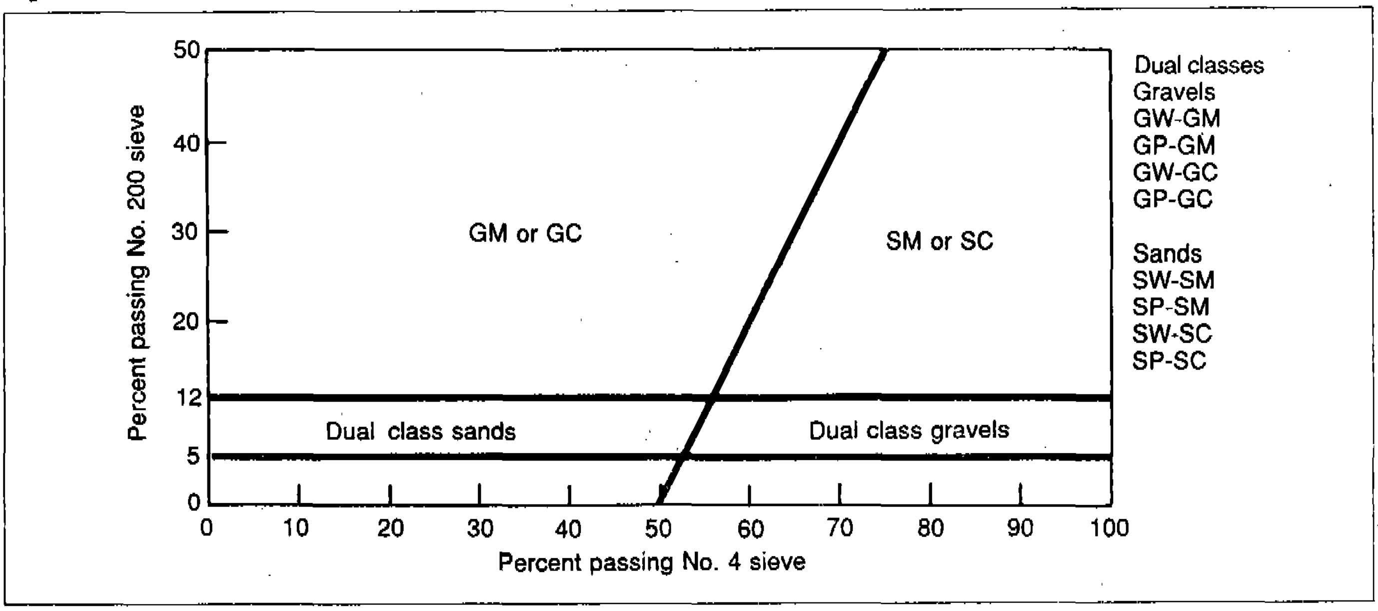


Figure 4–5.—**Grain size distribution.**

Figure 4–6.—**Classification of coarse-grained soils by gradation.**



SUMMARY. Table 4–3 gives the basic outline of the Unified Soil Classification System. The Unified Soil Classification System has several outstanding features:

1. It is simple. Technicians are normally concerned with 12 soils—four coarse-grained soils, four fine-grained soils, and four combined soils. In addition, there are four organic soils, one highly organic soil, and the dual symbol soils.

2. It provides information on important physical characteristics, such as size, gradation, plasticity, strength, brittleness, consolidation, and potential.

Interpretations based on classification must be made with care. A single classification represents a range of materials and may approach the classification of materials next to it. An example is an ML with a LL = 42 and PI = 15. This plots close to the A–line on the plasticity chart. It has characteristics closer to a CL than to a nonplastic ML (PI = 0). An ML with 49 percent sand and gravel approaches an SM or GM classification. A well graded nonplastic SM with 15 percent fines may have a high resistance to piping, whereas a poorly graded SM with 45 percent nonplastic fines and fine sands would have very low resistance to piping.

Detailed discussion and problems on the Unified Soil Classification System are given in the SCS Soil Mechanics Training Module No. 1.

Figure 4–7 shows the general relationship between the USDA textural soil classes, the Unified Soil Classifications, and the AASHTO soil classes. The classifications in the different systems are based on differing soil characteristics, and any attempt to translate between systems will be approximate at best. Design decisions should not be based on translations between systems.

This chart was prepared by using the textural classification as the basis and estimating the Unified and AASHTO classifications from the texture. Texture is based on the material passing the No. 10 sieve. The larger material, between the No. 10 and 3" sieves, is called gravel in the textural classification. The amount of gravel is indicated by adding a modifier to the texture name. When the soil contains less than 15 percent gravel, the texture is not modified. "Gravelly" indicates a gravel content of 15 percent to 35 percent. "Very gravelly" describes soil that has 35 percent to 60 percent gravel, and "extremely gravelly" is used when the gravel content is over 60 percent. Some soil survey reports have used other definitions of the modifiers. Definitions should be checked to see if they correspond to those used in this chart.

In the chart, "f" stands for fines; that is, the material that passes the No. 200 sieve.

Table 4-3.—Soil classification chart

Soil Classification Chart

Criteria for Assigning Group Symbols and Group Names Using Laboratory Tests[A]				Soil Classification: Group Symbol	Soil Classification: Group Name[B]
Coarse-Grained Soils More than 50 % retained on No. 200 sieve	Gravels More than 50 % of coarse fraction retained on No. 4 sieve	Clean Gravels Less than 5 % fines[C]	$Cu \geq 4$ and $1 \leq Cc \leq 3$[E]	GW	Well-graded gravel[F]
			$Cu < 4$ and/or $1 > Cc > 3$[E]	GP	Poorly graded gravel[F]
		Gravels with Fines More than 12 % fines[C]	Fines classify as ML or MH	GM	Silty gravel[F,G,H]
			Fines classify as CL or CH	GC	Clayey gravel[F,G,H]
	Sands 50 % or more of coarse fraction passes No. 4 sieve	Clean Sands Less than 5 % fines[D]	$Cu \geq 6$ and $1 \leq Cc \leq 3$[E]	SW	Well-graded sand
			$Cu < 6$ and/or $1 > Cc > 3$[E]	SP	Poorly graded sand[I]
		Sands with Fines More than 12 % fines[D]	Fines classify as ML or MH	SM	Silty sand[G,H,J]
			Fines classify as CL or CH	SC	Clayey sand[G,H,I]
Fine-Grained Soils 50 % or more passes the No. 200 sieve	Silts and Clays Liquid limit less than 50	inorganic	$PI > 7$ and plots on or above "A" line[J]	CL	Lean clay[K,L,M]
			$PI < 4$ or plots below "A" line[J]	ML	Silt[K,L,M]
		organic	$\frac{\text{Liquid limit – oven dried}}{\text{Liquid limit – not dried}} < 0.75$	OL	Organic clay[K,L,M,N] / Organic silt[K,L,M,O]
	Silts and Clays Liquid limit 50 or more	inorganic	PI plots on or above "A" line	CH	Fat clay[K,L,M]
			PI plots below "A" line	MH	Elastic silt[K,L,M]
		organic	$\frac{\text{Liquid limit – oven dried}}{\text{Liquid limit – not dried}} < 0.75$	OH	Organic clay[K,L,M,P] / Organic silt[K,L,M,Q]
Highly organic soils	Primarily organic matter, dark in color, and organic odor			PT	Peat

[A] Based on the material passing the 3-in. (75-mm) sieve.

[B] If field sample contained cobbles or boulders, or both, add "with cobbles or boulders, or both" to group name.

[C] Gravels with 5 to 12 % fines require dual symbols:
GW-GM well-graded gravel with silt
GW-GC well-graded gravel with clay
GP-GM poorly graded gravel with silt
GP-GC poorly graded gravel with clay

[D] Sands with 5 to 12 % fines require dual symbols:
SW-SM well-graded sand with silt
SW-SC well-graded sand with clay
SP-SM poorly graded sand with silt
SP-SC poorly graded sand with clay

[E] $Cu = D_{60}/D_{10}$ $\quad Cc = \frac{(D_{30})^2}{D_{10} \times D_{60}}$

[F] If soil contains ≥ 15 % sand, add "with sand" to group name.

[G] If fines classify as CL-ML, use dual symbol GC-GM, or SC-SM.

[H] If fines are organic, add "with organic fines" to group name.

[I] If soil contains ≥ 15 % gravel, add "with gravel" to group name.

[J] If Atterberg limits plot in hatched area, soil is a CL-ML, silty clay.

[K] If soil contains 15 to 29 % plus No. 200, add "with sand" or "with gravel," whichever is predominant.

[L] If soil contains ≥ 30 % plus No. 200, predominantly sand, add "sandy" to group name.

[M] If soil contains ≥ 30 % plus No. 200, predominantly gravel, add "gravelly" to group name.

[N] $PI \geq 4$ and plots on or above "A" line.

[O] $PI < 4$ or plots below "A" line.

[P] PI plots on or above "A" line.

[Q] PI plots below "A" line.

Figure 4–7.—**General relationships between systems used to classify soils—USDA Textural Classification, USCS, AASHTO.**

Modifier	None		Gravelly		Very Gravelly		Extremely Gravelly		SOIL PROPERTIES RELATED TO CLASSIFICATION	
% Gravel	.0 to 15%		15% to 35%		35% to 60%		60% to 90%			
USDA Texture	USCS	AASHTO	USCS	AASHTO	USCS	AASHTO	USCS	AASHTO	USCS	AASHTO
clay (c)	CH	A-7	CH	A-7	CH	A-7			High shrink-swell	f≥36%,LL≥41,PI≥11
	MH	A-7	MH	A-7	MH	A-7			Mica, Iron oxide Kaolinitic clay	f≥36% LL≥41, PI≥11
	CL	A-7	CL	A-7	CL	A-7			F≥50%, LL<50	f≥36%, LL≥41, PI≥11
			SC	A-7	SC	A-7			12%<f>50%	f≥36%, LL≥41, PI≥11
					SC	A-2-7			12% <f>50%	f≤35%, LL≥41, PI≥11
			SM	A-7	SM	A-7			12%<f<50%	f≥36%, LL≥41, PI≥11
					SM	A-2-7			12%<f<50%	f≤35%, LL≥41, PI≥11
					GC	A-7	GC	A-7	12%<f<50%	f≥36%, LL≥41, PI≥11
					GC	A-2-7	GC	A-2-7	12%<f<50%	f≤35%, LL≥41, PI≥11
					GM	A-7	GM	A-7	12%<f<50%	f≥36%, LL≥41, PI≥11
					GM	A-2-7	GM	A-2-7	12%<f<50%	f≤35%, LL≥41, PI≥11
							GW-GC	A-2-7	5%≤f≤12%	f≤35%, LL≥41, PI≥11
							GW-GM	A-2-7	5%≤f≤12%	f≥35%, LL≥41, PI≥11
Silty Clay (sic)	CH	A-7	CH	A-7	CH	A-7			High shrink swell	f≥36%, LL≥41, PI≥11
	MH	A-7	MH	A-7	MH	A-7			Mica, Iron oxide Kaolinitic clay	f≥36%, LL≥41, PI≥11
	CL	A-7	CL	A-7	CL	A-7			f≥50%, LL<50	f≥36%, LL≥41, PI≥11
					GC	A-7	GC	A-7	12%<f<50%	f≥36%, LL≥41, PI≥11
					GC	A-2-7	GC	A-2-7	12%<f<50%	f≤35%, LL≥41, PI≥11
					GM	A-7	GM	A-7	12%<f<50%	f≥36%, LL≥41, PI≥11
					GM	A-2-7	GM	A-2-7	12%<f<50%	f≤35%, LL≥41, PI≥11
							GW-GC	A-2-7	5%≤f≤12%	f≤35%, LL≥41, PI≥11
							GW-GM	A-2-7	5%≤f≤12%	f≤35%, LL≥41, PI≥11
Sandy Clay (sc)	CL	A-7	CL	A-7					f≥50%, LL<50	f≥36%, LL≥41, PI≥11
	CL	A-6	CL	A-6					f≥50%, LL<50	f≥36%, LL≤40, PI≥11
	SC	A-6	SC	A-6	SC	A-6			12%<f<50%	f≥36%, LL≤40, PI≥11
			SC	A-2-6	SC	A-2-6			12%<f<50%	f≤36%, LL≤40, PI≥11
			GC	A-6	GC	A-6			12%<f<50%	f≥36%, LL≤40, PI≥11
			GC	A-2-6	GC	A-2-6	GC	A-2-6	12%<f<50%	f≤35%, LL≤40, PI≥11
							GW-GC	A-2-6	5%≤f≤12%	f≤35%, LL≤40, PI≥11
Silty Clay Loam (sicl)	CH	A-7	CH	A-7	CH	A-7			High shrink-swell	f≥36%, LL≥41, PI≥11
	MH	A-7	MH	A-7	MH	A-7			Mica, Iron oxide Koalinitic clay	f≥36%, LL≥41, PI≥11
	CL	A-7	CL	A-7	CL	A-7			f≥50%, LL<50	f≥36%, LL≥41, PI≥11
					GC	A-7	GC	A-7	12%<f<50%	f≥36%, LL≥41, PI≥11
							GC	A-2-7	12%<f<50%	f≤35%, LL≥41, PI≥11
					GM	A-7	GM	A-7	12%<f<50%	f≥36%, LL≥41, PI≥11
							GM	A-2-7	12%<f<50%	f≤35%, LL≥41, PI≥11
							GW-G	A-2-7	5%≤f≤12%	f≤35%, LL≥41, PI≥11
							GW-GM	A-2-7	5%≤f≤12%	f≤35%, LL≥41, PI≥11

Figure 4–7.—**Continued.**

Modiifier	None		Gravelly		Very Gravelly		Extremely Gravelly		SOIL PROPERTIES RELATED TO CLASSIFICATION	
% Gravel	.0 to 15%		15% to 35%		35% to 60%		60% to 90%			
USDA Texture	USCS	AASHTO	USCS	AASHTO	USCS	AASHTO	USCS	AASHTO		
Clay	CH	A-7	CH	A-7	CH	A-7			High shrink-swell	f≥36%, LL≥41, PI≥11
Loam	MH	A-7	MH	A-7	MH	A-7			Mica, Iron oxide Koalinitic clay	f≥36%, LL≥41, PI≥11
(cl)	CL	A-7	CL	A-7	CL	A-7			f≥50%, LL<50	f≥36%, LL≥41, PI≥11
			SC	A-7	SC	A-7			12%<f<50%	f≥36%, LL≥41, PI≥11
					SC	A-2-7			12%<f<50%	f≤35%, LL≥41, PI≥11
			SM	A-7	SM	A-7			12%<f<50%	f≥36%, LL≥41, PI≥11
					SM	A-2-7			12%<f<50%	f≤35%, LL≥41, PI≥11
					GC	A-2-7	GC	A-2-7	12%<f<50%	f≤35%, LL≥41, PI≥11
					GM	A-2-7	GM	A-2-7	12%<f<50%	f≤35%, LL≥41, PI≥11
							GW-GC	A-2-7	5%≤f≤12%	f≤35%, LL≥41, PI≥11
							GW-GM	A-2-7	5%≤f≤12%	f≤35%, LL≥41, PI≥11
Sandy	CL	A-6							f≥50%, LL<50	f≥36%, LL≤40, PI≥11
Clay	SC	A-6	SC	A-6	SC	A-6			12%<f<50%	f≥36%, LL≤40, PI≥11
Loam	SC	A-2-6	SC	A-2-6	SC	A-2-6			12%<f<50%	f≤35%, LL≤40, PI≥11
(scl)					GC	A-2-6	GC	A-2-6	12%<f<50%	f≤35%, LL≤40, PI≥11
							GW-GC	A-2-6	5%<f<12%	f≤35%, LL≤40, PI≥11
							GW	A-2-6	f<5%	f≤35%, LL≤40, PI≥11
Silt	ML	A-4	ML	A-4	ML	A-4			Low or NP f	f≥36%, LL≤40, PI≤10
(si)	CL-ML	A-4	CL-ML	A-4	CL-ML	A-4			Low plastic f	f≥36%, LL≤40, PI≤10
					GM	A-4	GM	A-4	12%<f<50%	f≥36%, LL≤40, PI≤10
					GM	A-2-4	GM	A-2-4	12%<f<50%	f≤35%, LL≤40, PI≤10
							GM	A-1	12%<f<50%	f≤25%, PI≤6
							GW-GM	A-2-4	5%≤f≤12%	f≤35%, LL≤40, PI≤10
							GW-GM	A-1	5%≤f≤12%	f≤25%, PI≤6
Silt	ML	A-4	ML	A-4	ML	A-4			Low or NP f	f≥36%, LL≤40, PI≤10
Loam	MH	A-7	MH	A-7	MH	A-7			Mica, Iron oxide Koalinitic clay	f≥36%, LL≥41, PI≥11
(sil)	CL	A-6	CL	A-6	CL	A-6			f≥50%, LL<50	f≥36%, LL≤40, PI≥11
	CL-ML	A-4	CL-ML	A-4	CL-ML	A-4			Low plastic f	f≥36%, LL≤40, PI≤10
			SM	A-4	SM	A-4			12%<f<50%	f≥36%, LL≤40, PI≤10
			SM	A-7	SM	A-7			12%<f<50%	f≥36%, LL≥41, PI≥11
					SM	A-2-4			12%<f<50%	f≤35%, LL≤40, PI≤10
					SM	A-2-7			12%<f<50%	f≤35%, LL≥41, PI≥11
					SC	A-6			12%<f<50%	f≥36%, LL≤40, PI≥11
					SC	A-2-6			12%<f<50%	f≤35%, LL≤40, PI≥11
					GM	A-4	GM	A-4	12%<f<50%	f≥36%, LL≤40, PI≤10
					GM	A-7	GM	A-7	12%<f<50%	f≥36%, LL≥41, PI≥11
					GM	A-2-4	GM	A-2-4	12%<f<50%	f≤35%, LL≤40, PI≤10
					GM	A-2-7	GM	A-2-7	12%<f<50%	f≤35%, LL≥41, PI≥11
							GM	A-1	12%<f<50%	f<25%, PI≤6
					GC	A-6	GC	A-6	12%<f<50%	f≥36%, LL≤40, PI≥11
					GC	A-2-6	GC	A-2-6	12%<f<50%	f≤35%, LL≤40, PI≥11
							GW-GM	A-2-7	5%<f≤12%	f≤35%, LL≥41, PI≥11
							GW-GC	A-2-6	5%≤f≤12%	f≤35%, LL≤40, PI≥11

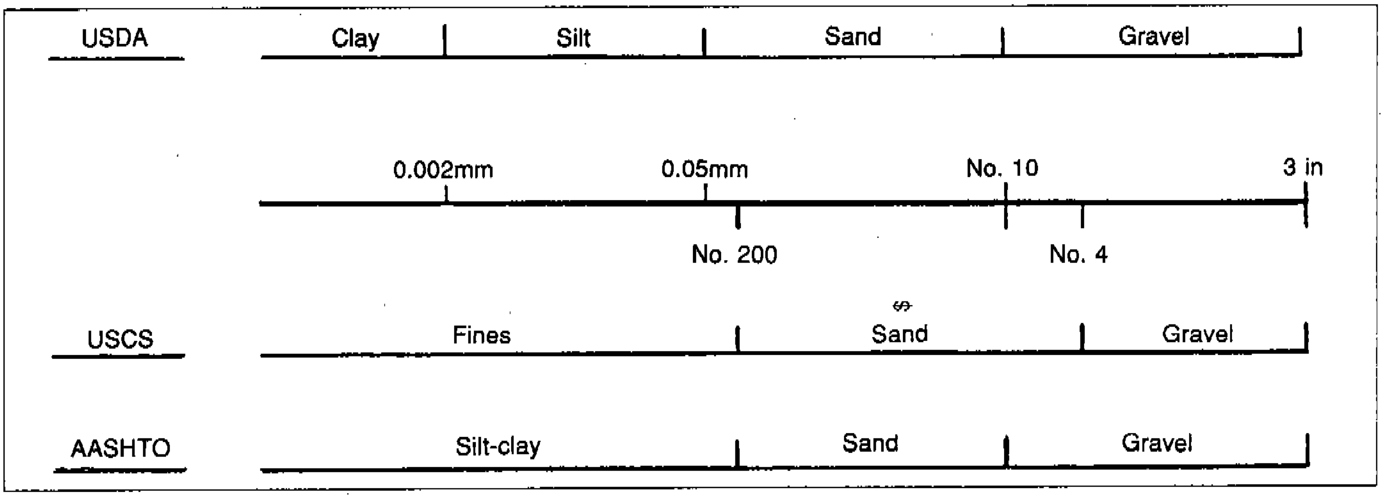
Figure 4–7.—**Continued.**

Modiifier	None		Gravelly		Very Gravelly		Extremely Gravelly		SOIL PROPERTIES RELATED TO CLASSIFICATION	
% Gravel	.0 to 15%		15% to 35%		35% to 60%		60% to 90%			
USDA Texture	USCS	AASHTO	USCS	AASHTO	USCS	AASHTO	USCS	AASHTO	USCS	AASHTO
Loam	ML	A-4	ML	A-4					Low or NP f	f≥36%, LL≤40, PI≤10
(l)	MH	A-7	MH	A-7					Mica, Iron oxide Koalinitic clay	f≥36%, LL≥41, PI≥11
	CL	A-6	CL	A-6					f≥50%, LL<50	f≥36%, LL≤40, PI≥11
	CL-ML	A-4	CL-ML	A-4					Low plastic f	f≥36%, LL≤40, PI≤10
			SM	A-4	SM	A-4			12%<f<50%	f≥36%, LL≤40, PI≤10
			SM	A-7	SM	A-7			12%<f<50%	f≥36%, LL≥41, PI≥11
					SM	A-2-4			12%<f<50%	f≤35%, LL≤40, PI≤10
					SM	A-2-7			12%<f<50%	f≤35%, LL≥41, PI≥11
			SC	A-6	SC	A-6			12%<f<50%	f≥36%, LL≤40, PI≥11
					SC	A-2-6			12%<f<50%	f≤35%, LL≤40, PI≥11
					GM	A-2-4	GM	A-2-4	12%<f<50%	f≤35%, LL≤40, PI≤10
					GM	A-2-7	GM	A-2-7	12%<f<50%	f≤35%, LL≥41, PI≥11
							GM	A-1	12%<f<50%	f<25%, PI≤6
					GC	A-2-6	GC	A-2-6	12%<f<50%	f≤35%, LL≤40, PI≥11
							GW-GM	A-2-4	5%≤f≤12%	f≤35%, LL≤40, PI≤10
							GW-GM	A-2-7	5%≤f≤12%	f≤35%, LL≥41, PI≥11
							GW-GM	A-1	5%≤f≤12%	f≤25%, PI≤6
							GW-GC	A-2-6	5%≤f≤12%	f≤35%, LL≤40, PI≤10
Sandy	ML	A-4							Low or NP f	f≥36%, LL≤40, PI≤10
Loam	CL-ML	A-4							Low plastic f	f≥36%, LL≤40, PI≤10
(sl)	CL	A-6							f≥50%, LL<50	f≥36%, LL≤40, PI≥11
	SM	A-4	SM	A-4	SM	A-4			12%<f<50%	f≥36%, LL≤40, PI≤10
	SM	A-2-4	SM	A-2-4	SM	A-2-4			12%<f<50%	f≤35%, LL≤40, PI≤10
	SC	A-6	SC	A-6	SC	A-6			12%<f<50%	f≥36%, LL≤40, PI≥11
	SC	A-2-6	SC	A-2-6	SC	A-2-6			12%<f<50%	f≤35%, LL≤40, PI≥11
					SW-SM	A-2-4			5%<f<12%	f≤35%, LL≤40, PI≤10
					SW-SC	A-2-6			5%≤f≤12%	f≤235%, LL≤40, PI≥11
					GM	A-2-4	GM	A-2-4	12%<f<50%	f≤35%, LL≤40, PI≤10
					GC	A-2-6	GC	A-2-6	12%<f<50%	f≤35%, LL≤40, PI≥11
					GW-GM	A-2-4	GW-GM	A-2-4	5%≤f≤12%	f≤35%, LL≤40, PI≤10
					GW-GC	A-2-6	GW-GC	A-2-6	5%≤f≤12%	f≤35%, LL≤40, PI≥11
							GC	A-1	f<5%	f≤25%, PI≤6
Loamy	SM	A-2-4	SM	A-2-4	SM	A-2-4	SM	A-2-4	12%<f<50%	f≤35%, LL≤40, PI≤10
Sand	SM	A-1	SM	A-1	SM	A-1	SM	A-1	12%<f<50%	f≤25%, PI≤6
(ls)			SP-SM	A-2-4	SP-SM	A-2-4	SP-SM	A-2-4	5%≤f≤12%	f≤35%, LL≤40, PI≤10
			SP-SM	A-1	SP-SM	A-1	SP-SM	A-1	5%≤f≤12%	f≤25%, PI≤6
							GM	A-2-4	12%<f<50%	f≤35%, LL≤40, PI≤10
							GM	A-1	12%<f<50%	f≤25%, PI≤6
							GW-GM	A-2-4	5%≤f≤12%	f≤35%, LL≤40, PI≤10
							GW-GM	A-1	5%≤f≤12%	f≤25%, PI≤6
							GW	A-1	f<5%	f≤25%, PI≤6

Figure 4–7.—**Continued.**

Modiifier	None		Gravelly		Very Gravelly		Extremely Gravelly		SOIL PROPERTIES RELATED TO CLASSIFICATION	
% Gravel	.0 to 15%		15% to 35%		35% to 60%		60% to 90%			
USDA Texture	USCS	AASHTO	USCS	AASHTO	USCS	AASHTO	USCS	AASHTO	USCS	AASHTO
Sand (s)	SM	A-2-4	SM	A-2-4					12%<f<50%	f≤35%, LL≤40, PI≤10
	SM	A-1	SM	A-1					12%<f<50%	f≤25%, PI≤6
	SP-SM	A-3	SP-SM	A-3					5%≤f≤112%	f≤10%, NP
	SP-SM	A-2-4	SP-SM	A-2-4	SP-SM	A-2-4	SP-SM	A-2-4	5%≤f≤12%	f≤35%, LL≤40, PI≤10
	SP-SM	A-1	SP-SM	A-1	SP-SM	A-1	SP-SM	A-1	5%≤f≤12%	f≤25%, PI≤6
	SP	A-1	SP	A-1	SP	A-1	SP	A-1	f<5%	f≤25%, PI≤6
	SP	A-3	SP	A-3					f<5%	f≤10%, NP
							GW-GM	A-2-4	5%≤f≤12%	f≤35%, LL≤40, PI≤10
							GW-GM	A-1	5%≤f≤12%	f≤25%, PI≤6
							GW	A-1	f<5%	f≤25%, PI≤6

Figure 4–8.—**Relationship between particle size and the USDA textural soil classes, the Unified Soil Classification System, and the AASHTO soil classes.**



This section tells how to classify and describe soils by visual-manual methods. The methods are similar to those in ASTM D–2488. The classification is basically the same as described in the previous section. It does contain some modifications to adapt it to the less precise visual-manual procedure as compared to laboratory methods. It must be clearly stated in the report that classification is based on visual-manual methods.

Dual and Borderline Classes
Care should be taken not to confuse the dual classifications described in the preceding section and the borderline classifications sometimes used in the field procedure. Dual symbols may be used in field classification where soils fall into the dual categories described in the preceding section. These are fine-grained soils or the fine-grained portion of coarse-grained soils falling in the crosshatched area on the plasticity chart (CL–ML), and coarse-grained soils that have 5 to 12 percent fines (SP–SM, SW–SC, GP–GM, GW–GC, etc).

Field classification includes a borderline classification category not used when classifying with laboratory data. When a soil has properties that do not distinctly place it in a specific group, it can be given a borderline symbol indicating the soil may fall into one or the other of the two groups. A borderline classification consists of two group symbols separated by a slash, for example, CL/CH, GM/SM. The slash stands for "or" (CL/CH means CL or CH). The first group symbol represents the most likely classification, or it is the classification of similar samples from the adjacent area. The group name is the name for the first symbol except for the following borderline classes and names.

CL/CH – lean to fat clay

ML/CL – clayey silt

CL/ML – silty clay

Borderline symbols should not be used indiscriminately. Every effort should be made to place the soil in a single group.

The percentages of sand, gravel, and fines are estimated to the nearest 5 percent (5%, 10%, 15%, etc). If some sand, gravel, or fines are present but are estimated to be less than 5 percent, the quantity is listed as a trace. Estimating in multiples of 5 percent results in a small change in the definition of clean sands and gravels (SW, SP, GW, GP). The field classification lists clean coarse-grained soil as having 5 percent or less fines, rather than less than 5 percent, as listed in laboratory classifications.

Apparatus needed for the tests
1. A small supply of water.
2. Pocket knife or small spatula.

Useful auxiliary apparatus:
1. A jar with a lid or a test tube with stopper.
2. Small bottle of diluted hydrochloric acid (one part 10N HCL to 3 parts of water).
3. Hand lens.

Sample size. In order to classify a soil accurately, the sample must be large enough to contain a representative percentage of each particle size. Recommended minimum sample size based on maximum particle size is given in table 4–4.

Table 4–4.—**Minimum sample size**

Maximum particle-size	Minimum sample size
5mm (3/16 in)	100 g (0.25 lb)
9.5mm (3/8 in)	200g (0.5 lb)
19mm (3/4 in)	1kg (2.2 lb)
38mm (1-1/2 in)	8kg (18 lb)
75mm (3 in)	60kg (132 lb)

Field classification
Soil should be classified using several different field tests rather than a single test. Screening and weighing of samples is not intended. Estimates of percentages of materials by dry weight may be made using visual finger techniques. With the exception of grain-size and gradation, these tests are performed on that portion of the sample smaller than the No. 40 sieve. When coarse materials that can be separated by hand are removed, the remaining material is roughly that portion passing the No. 40 sieve. Practice with materials of known percentages will be helpful in perfecting these techniques.

Highly organic soil. First determine if a soil classifies as highly organic peat (PT). Peat is composed primarily of vegetable tissue at various stages of decomposition. It has an organic odor, a dark brown to black color, a spongy consistency and a texture ranging from fibrous to formless. A soil classified as peat needs no further classification procedure. The significant items in the description still need to be completed.

Percentages of sand, gravel, and fines. If the soil is not peat, the next step in classification is to estimate the percentages of sand, gravel, and fines in the sample. The percentage is by dry weight, which differs from volume. A sample that is one-half gravel and one-half fines by volume would be about 60 percent gravel and 40 percent fines by weight because the fines have more voids and thus lower density than the gravel.

Estimates should be to the nearest 5 percent, and the percentages must total 100 percent. If some component is present but constitutes less than 5 percent of the sample, then list it as a trace. A trace does not constitute part of the 100 percent. For example: 65 percent fines, 35 percent sand with a trace of gravel.

Some suggested procedures for estimating percentages of sand, gravel, and fines are:

- Jar Method -Thoroughly shake a mixture of soil and water in a straight-sided jar or test tube, then allow the mixture to settle. Sand sizes will fall out first, in 20 to 30 seconds, and successively finer particles will follow. The proportions of sand and fines can then be estimated from their relative volumes.

- Mental Sacking - Mentally visualize the gravel-size particles placed in a sack or other container and the sand and fines in a different sack or sacks, then mentally compare the number of sacks or containers with gravel, sand, and fines.

- Inspection - Spread the sample on a flat surface and examine the particles to determine the approximate grain size. If more than 50 percent of the sample by weight has individual grains that are visible to the naked eye, the material is coarse-grained. If less than 50 percent, it is a fine-grained material.

Aggregated dry particles may appear to be sand-size grains. Saturate the sample and break these aggregates down by rubbing the wetted soil between the thumb and forefinger. Sand-size grains can be detected, as they will feel rough and gritty.

Clean sands and gravels (less than 5 percent fines) will not leave a stain on a wet hand when handled. Practicing with samples that have known percentages of sand, gravel, and fines will help in learning to estimate the percentages.

Classifying fine–grained soils
A soil is fine-grained if it contains 50 percent or more fines. The soil may be given a borderline classification if the estimated proportion of fines is 45 to 55 percent. Select a representative sample of material and remove the particles larger than the No. 40 sieve. This is about the smallest size particle that can be removed by hand. About a handful of material will be needed. Use this material to perform the dilatancy, toughness, and strength tests. These tests are illustrated in figure 4–8.

Dilatancy. Select enough material to mold into a ball about 15mm (1/2 in) in diameter. Add water, if needed, until it has a soft but not sticky consistency. Smooth the soil in the palm of one hand with the blade of a knife or spatula. Shake horizontally, striking the side of the hand against the other several times. Note the appearance of water on the surface. Squeeze the sample and note the disappearance of water.

Describe the reaction as:

None – No visible change.

Slow – Water appears slowly on the surface during shaking and does not disappear or disappears slowly when squeezed.

Rapid – Water appears quickly on the surface during shaking and disappears quickly when squeezed.

Toughness. Take the specimen from the dilatancy test, shape it into an elongated pat and roll it on a hard surface or between your hands into a thread about 3mm (1/8 in) in diameter. If it is too wet to roll, spread it out and let it dry. Fold the thread and reroll repeatedly until the thread crumbles at a diameter of 3mm (1/8 in). The soil has then reached its plastic limit. Note the pressure required to roll the thread and the strength of the thread. Circumferential breaks in the thread indicate a CH or CL material. Longitudinal cracks and diagonal breaks indicate a MH material. After the thread crumbles, lump the pieces together and knead until the lump crumbles. Note the toughness of the material during kneading. Describe the toughness of the thread as:

Low – Only slight pressure is required to roll the thread near the plastic limit. The thread and lump are weak and soft.

Medium – Medium pressure is required to roll the thread near the plastic limit. The thread and the lump have medium stiffness.

High – Considerable pressure is required to roll the thread near the plastic limit. The thread and lump are very stiff.

If a thread cannot be rolled, the soil is nonplastic.

Dry strength. Take enough material to mold into a ball about 15mm (1/2 in) in diameter. Add water, if necessary, and mold the material until it has the consistency of putty. From this material make at least three test specimens about 5mm (1/4 in) in diameter and allow them to air dry. Natural dry lumps of about the same size may be used. The natural lumps will usually have a lower strength than molded material. Do not use natural lumps that contain medium or coarse sand.

Crush the dry lumps and describe their strength as:

None – The specimen crumbles into powder with the pressure of handling.

Low – The specimen crumbles into powder with finger pressure.

Medium – The specimen breaks into pieces or crumbles into powder with considerable finger pressure.

High – The specimen cannot be broken with finger pressure, but can be broken between the thumb and a hard surface.

Very High – The specimen cannot be broken between the thumb and a hard surface.

Determine if the soil is organic or inorganic. An organic soil can be identified by its odor and its dark brown or black color. Classify inorganic soils using the criteria in table 4–5. Classify organic soils using the criteria in table 4–6.

Additional tests that may be useful in classifying fine–grained soils are as follows:

- Ribbon Test – Use a sample that has a moisture content at or slightly below the plastic limit. Form a ribbon by squeezing and working the sample between the thumb and forefinger.

  A weak ribbon that breaks easily indicates an ML soil. A hard ribbon which breaks fairly readily indicates an MH soil. A flexible ribbon with medium strength indicates a CL soil. A strong, flexible ribbon indicates a CH soil.

- Adhesion Test – Saturate some soil and let it dry on your hands. An ML soil will brush off with little effort. A CL or MH soil rubs off with moderate effort. A CH soil requires rewetting to remove it completely.

- Shine Test – In making the shine test, be sure the soil is not micaceous. Rub a small clod of moist soil with a knife blade. A reflective and shiny surface indicates high plasticity. You are seeing the shine on the surface of the clay fines.

Estimating liquid limit. Take a pat of moist soil with a volume of about 8cc (1/2 cu in) and add enough water to make the soil soft but not sticky. Rapidly add enough water to cover the outer surface. Break the pat open immediately. A positive reaction has occurred when the water has penetrated through the surface layer. If the water has penetrated, the LL is low. If the water has not penetrated, the LL is high. Visual observation of this phenomenon is much easier in direct sunlight.

Table 4–5.—**Classification of inorganic fine-grained soil**

Dilatancy	Toughness	Dry strength	Group name	Group symbol
Slow to rapid	NP or low	None to low	Silt	ML
None to slow	Low to med.	Low to medium	Elastic silt	MH
None to slow	Medium	Medium to high	Lean clay	CL
None	High	High to very high	Fat clay	CH

Table 4–6.—**Classification of organic fine-grained soil**

Dilatancy	Toughness	Dry strength	Group name	Group symbol
Slow to rapid	NP	None to low	Organic silt	OL
None to slow	Low	Low to medium	Organic clay	OL
None to slow	NP to low	None to medium	Organic silt	OH
None	Low to med.	Medium to high	Organic clay	OH

Modifiers for sand and gravel. Modifiers will be added to the soil group name of fine-grained soils to indicate the presence of sand and/or gravel.

If the soil has 15 to 25 percent sand and/or gravel, the words "with sand" or "with gravel" will be added. If sand predominates, use "with sand." If gravel predominates, use "with gravel." Examples are organic silt with sand, OL; and lean clay with gravel, CL. Notice that where percentages are estimated to the nearest 5 percent, the division between soils may be stated differently than when using laboratory data for classifying. In the preceding paragraph, instead of saying "15 percent but less than 30 percent," it says "15 to 25 percent." (25 percent is the first percentage less than 30 percent.)

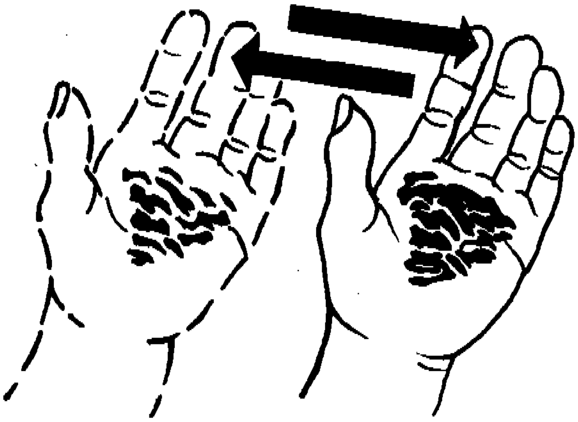
If 30 percent or more of the soil is sand or gravel, the words "sandy" or "gravelly" shall be added. Add "sandy" if there is as much or more sand than gravel. Add "gravelly" if there is more gravel than sand. Examples are gravelly fat clay, CH; and sandy organic clay, OH.

Classifying coarse-grained soils

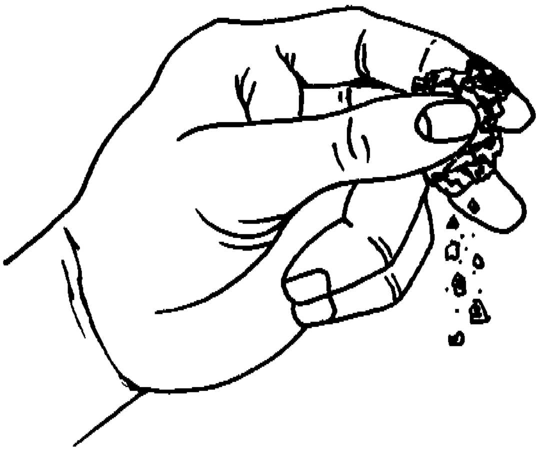
If a soil has less than 50 percent fines, it is classed as a coarse-grained soil.

The soil is a gravel if the percentage of gravel is greater than the percentage of sand.

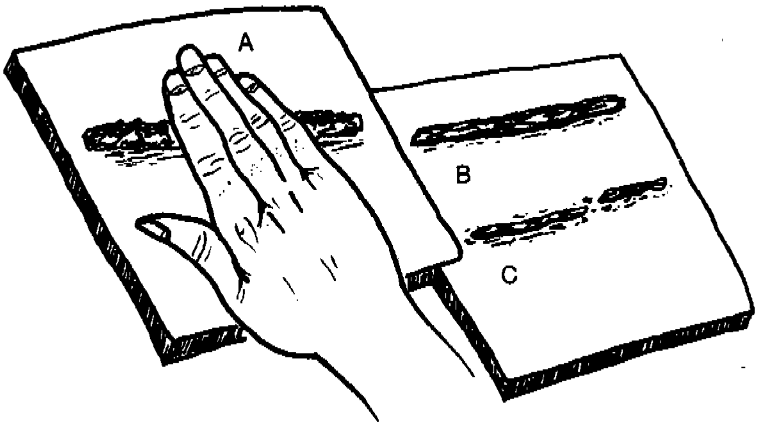
Figure 4–9.—**Dilatancy, strength, and toughness tests.**



Method of shaking
Dilatancy test



Strength test



Toughness test

A. Method of rolling thread.

B. Thread of soil above plastic limit.

C. Crumbling thread as plastic limit is reached.

After Dept. of the Army

The soil is a sand if the percentage of sand is equal to or greater than the percentage of gravel.

The soil is well graded if it has a wide range of particle sizes and a substantial quantity of all intermediate sizes.

A soil is poorly graded if it has a narrow range of particle sizes or if it has a wide range of sizes with some intermediate sizes missing (gap graded).

If the soil has 5 percent or less fines, it is a clean coarse-grained soil, of which there are four kinds:

Poorly graded sand, SP

Well graded sand, SW

Poorly graded gravel, GP

Well graded gravel, GW

If a coarse-grained soil has 15 percent or more fines, then it is a sand with fines or a gravel with fines. Classify the fines as clay or silt as described under fine-grained soils. The soil will be classified as one of the four coarse-grained soils with fines:

Silty sand, SM

Clayey sand, SC

Silty gravel, GM

Clayey gravel, GC

If a coarse-grained soil has 10 percent fines, it is given a borderline classification. The first symbol is to correspond to the symbol for clean sand or gravel (SW, SP, GW, GP) and the second to the symbol for sand or gravel with fines (SM, SC, GM, GC). The group name will correspond to the group name for the first symbol plus "with silt" or "with clay" to indicate the plasticity of the fines. Examples are: well graded sand with silt, SW–SM; and poorly graded gravel with clay, GP–GC.

If the coarse-grained soil is predominantly sand or gravel but contains 15 percent or more of the other, then the words "with sand" or "with gravel" will be added to the group name. For example: well graded sand with gravel, SW; and poorly graded gravel with sand and silt, GP–GM.

The visual–manual classifications are summarized in table 4–7.

Soil description

When a soil boring is made, a test pit dug, or a natural soil exposure examined, a log should be kept of the observations. Table 4–8 is a checklist of recommended information to be included in the log. Definitions of most of the items on the list are given in this chapter.

Table 4–8.—**Soil description checklist**

1. Project and location
   a. Test hole number and location (table 4–8)
   b. Sample number and depth of sampling
2. Group name and group symbol (table 4–7)
3. Maximum particle–size (page 4-25)
4. Percentage of cobbles and/or boulders (page 4-25)
5. Percentage gravel, sand, fines (page 4-19)
6. Particle–size range of coarse material (table 4–10)
   a. Gravel–fine, coarse
   b. Sand–fine, medium, coarse
7. Particle angularity and shape (page 4-26)—angular, subangular, subrounded, rounded
   Particle shape—flat, elongated, flat and elongated
8. Dilatancy (page 4-20)
   None, slow, rapid
9. Toughness (page 4-20)
   Low, medium, high
10. Dry strength of fines (page 4-20)
    None, low, medium, high, very high
11. Plasticity of fines (page 4-25)
    Nonplastic, low, medium, high
12. Odor – only if organic or unusual
13. Color (page 4-27)
14. Natural moisture content (page 4-27)
    Dry, moist, wet
15. Reaction with HCl (page 4-27)
    none, weak, strong
16. Consistency (page 4-27)
    Very soft, soft, firm, hard, very hard
17. Structure (page 4-27)
    Stratified, laminated, fissured, slickensided, lensed, homogeneous
18. Cementation (page 4-27)
    Weak, moderate, strong
19. Geologic name, soil series, or local name
20. Additional comments

Table 4–7.—**Field identification by visual–manual methods**

COARSE GRAINED SOIL 55% to 100% Sand and Gravel[a]	GRAVEL[b, f] % gravel greater than % sand	0, trace or 5% fines	well graded		GW	well graded gravel
			poorly graded		GP	poorly graded gravel
		10% fines	clayey fines	well graded	GW-GC	well graded gravel with clay
				poorly graded	GP-GC	poorly graded gravel with clay
			silty fines	well graded	GW-GM	well graded gravel with silt
				poorly graded	GP-GM	poorly graded gravel with silt
		15% to 45% fines	clayey fines		GC	clayey gravel
			silty fines		GM	silty gravel
	SAND[c, f] % sand equal to or greater than % gravel	0, trace or 5% fines	well graded		SW	well graded sand
			poorly graded		SP	poorly graded sand
		10% fines	clayey fines	well graded	SW-SC	well graded sand with clay
				poorly graded	SP-SC	poorly graded sand with clay
			silty fines	well graded	SW-SM	well graded sand with silt
				poorly graded	SP-SM	poorly graded sand with silt
		15% to 45% fines[e]	clayey fines		SC	clayey sand
			silty fines		SM	silty sand
FINE GRAINED SOIL 50% to 100% FINES[a, g, h]	CLAYS & SILTS with low liquid limit[d, i]	plastic fines			CL	lean clay
		low plastic fines with very low liquid limit			CL-ML	silty clay
		nonplastic & low plastic fines			ML	silt
		plastic fines with significant organics			OL	organic clay
		Non or low plastic fines with significant organics			OLL	organic silt
	CLAYS & SILTS with high liquid limit[d, i]	plastic fines			CH	fat clay
		nonplastic & low plastic fines			MH	elastic silt
		plastic fines with significant organics			OH	organic clay
		non or low plastic fines with significant organics			OH	organic silt
HIGHLY ORGANIC SOIL		primarily organic matter dark in color, organic odor			PT	peat

Footnotes for table 4–7

a. Soils that have 45%, 50%, or 55% fines may be classified with a borderline symbol, such as silty sand GM/ML, silt ML/GM.

b. If the soil contains 15% or more sand, add "with sand" to the group name.

c. If the soil contains 15% or more gravel, add "with gravel" to the group name.

d. Soils that have liquid limits near 50 may be classified with a borderline symbol, such as lean to fat clay CL/CH; silt ML/MH.

e. If the fines have significant organic matter, add "with organic fines" to the group name; for example, silty gravel with organic fines GM, clayey sand with organic fines.

f. Soils that have nearly the same percentage of sand and gravel may be given a borderline classification, such as well graded gravel with sand GW/SW.

g. If the soil has 15% to 25% sand or gravel, add "with sand" or "with gravel" to the group name, such as lean clay with sand CL; silt with gravel ML.

h. If the soil has 30% to 45% sand or gravel, add "sandy" or "gravelly" to the group name, such as gravelly organic clay OL; sandy fat clay CH.

i. Soils that fall close to the border between silt and clay may be given a borderline classification, such as silty clay CL/ML; clayey silt ML/CL.

Numbering test holes and samples. Use the following standard system of numbering test holes.

Table 4–8.—Test hole numbering system

Location	Hole Numbers
Centerline of dam	1–99
Borrow area	101–199
Emergency spillway	201–299
Centerline of principal spillway	301–399
Stream channel	401–499
Relief wells	501–599
Other	601–699
Other	701–799, etc.

Principal spillway, channel, and emergency spillway holes that are on the centerline of the dam should be given principal spillway, channel, and emergency spillway numbers rather than centerline of dam numbers. Number foundation holes in the area of the base of the dam, but not in the immediate vicinity of the centerline of the dam or appurtenances, as "other."

Samples are numbered by using the test hole number followed by a period and the sample number. Samples from test hole number 104 would be numbered 104.1, 104.2, 104.3 from the top down.

Maximum particle size. If the largest size particles are sand-size, then describe them as fine, medium, or coarse sand. If the largest particles are gravel-size, list the smallest size sieve that will pass all particles. If the largest particles are cobbles or boulders, list the maximum dimension of the largest cobble or boulder.

Percentages of cobbles and boulders. Cobbles and boulders are defined as:

- Cobbles – Particles that will pass a 12–inch square opening and will be retained on a 3–inch sieve.
- Boulders – Particles that will not pass a 12–inch square opening.

Estimate the percentage of cobbles and boulders by volume. The report should state "estimated by volume," since other percentages are by weight. Example: "estimated 10 percent cobbles (by volume), maximum size 7 inches."

Particle-size range of coarse materials. Table 4–10 gives particle-size ranges and guidelines for estimating particle sizes.

Table 4–10.—Sand and gravel sizes

Term	Particle size	Example
Gravel	75 to 4.75mm (3 to 3/16 in)	Orange to pea
1. Coarse	75 to 19mm (3 to 3/4 in)	Orange to grape
2. Fine	19 to 4.75mm (3/4 to 3/16 in)	Grape to pea
Sand	4.7t to 0.075mm (#4 to #200)	Pea to powdered sugar
1. Coarse	4.75 to 2.00mm (#4 to #10)	Pea to rock salt
2. Medium	2.00 to 0.425mm (#10 to #40)	Rock salt to table salt
3. Fine	0.425 to 0.075mm (#40 to #200)	Table salt to powdered sugar
Fines	Less than 0.075mm (#200)	

Particle angularity

- Angular – Particles have sharp edges and relatively plane sides with unpolished surfaces.
- Subangular – Particles are similar to angular but have rounded edges.
- Subrounded – Particles have nearly plane sides but have well-rounded corners and edges.
- Rounded – Particles have smoothly curved sides and no edges.

Particle shape. In particle shape, the length, width, and thickness refer to the greatest, intermediate, and least dimension.

Flat: $W/T > 3$

Elongated: $L/W > 3$

Flat and elongated particles meet criteria for both flat and elongated.

Plasticity of Fines. The plasticity of fines can be estimated with the same test as the toughness test, according to the following criteria.

- Nonplastic – A 3mm thread cannot be rolled at any water content.
- Low – The thread can barely be rolled, and the lump cannot be formed when drier than the plastic limit.
- Medium – The thread is easy to roll, and not much time is required to reach the plastic limit. The thread cannot be rerolled after reaching the plastic limit. The lump crumbles when drier than the plastic limit.
- High – Considerable time rolling and kneading is required to reach the plastic limit. The thread can be rerolled several times after it reaches the plastic limit. The lump can be formed without crumbling when drier than the plastic limit.

Figure 4-l0.—**Particle shapes.**

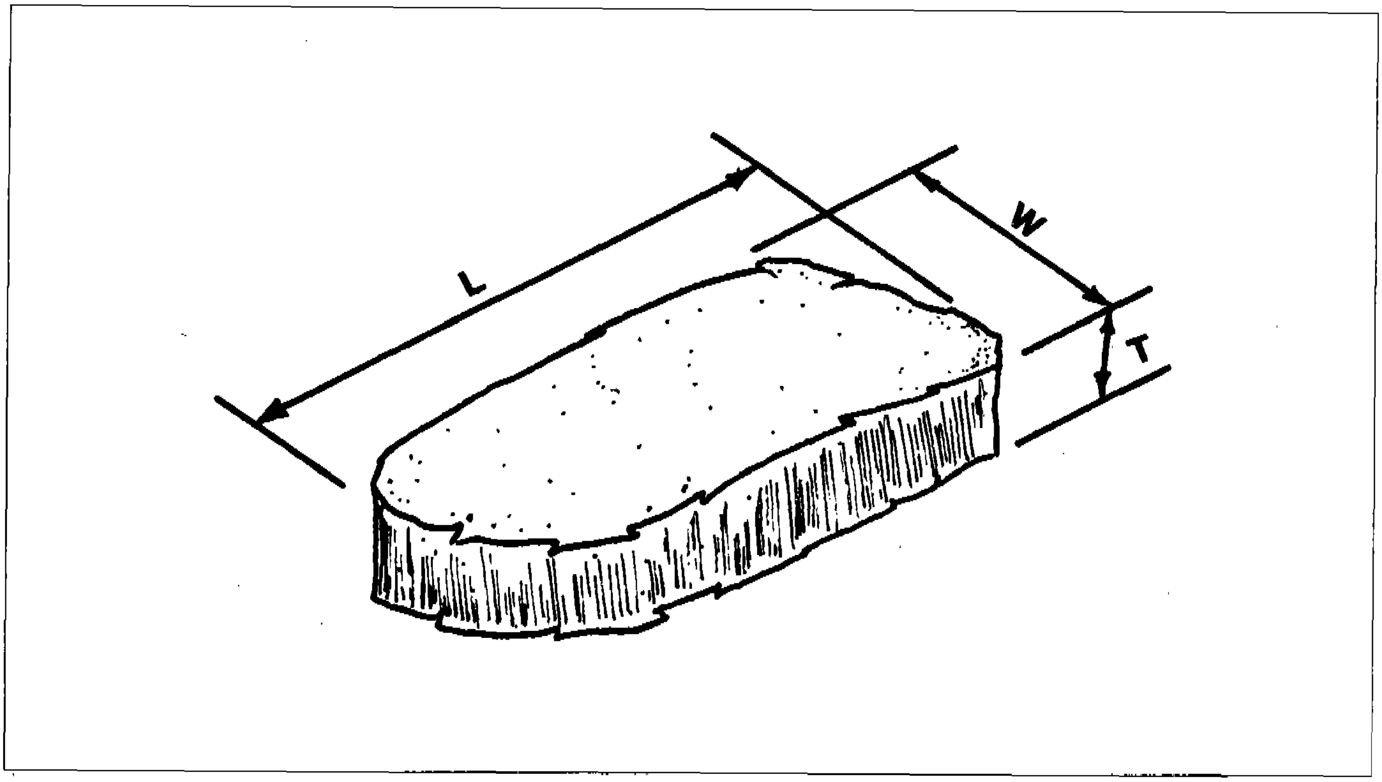
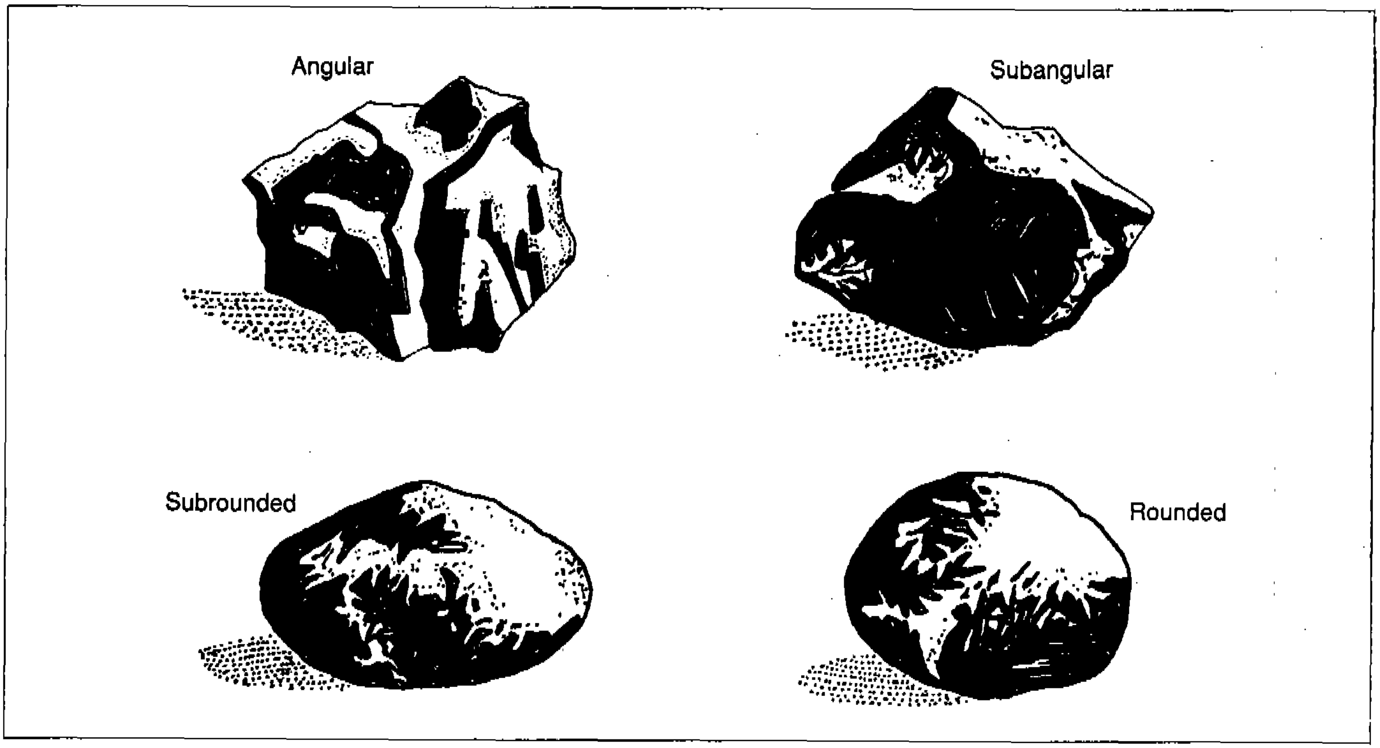


Figure 4-11.— **Flat and elongated particles.**



Color. Soil colors should be determined from moist samples. If the soil contains layers or patches of varying colors, they should be recorded along with their colors.

Natural water content

- Dry – Absence of water, dusty, dry to the touch.
- Moist – Damp but no visible water.
- Wet – Visible free water; usually soil is from below the water table.

Reaction with HCl

- None – No visible reaction.
- Weak – Some reaction with bubbles forming slowly.
- Strong – Violent reaction with bubbles forming immediately.

Consistency. Consistency is defined as the relative ease with which a soil can be deformed, either in the undisturbed or molded state. Degrees of consistency for fine-grained soils are described by the terms very soft, soft, firm, hard, and very hard. Table 4–10 gives a field identification method and estimated strength for soil consistency classes.

Structure

- Stratified – Alternating layers of varying material or color; note thickness.
- Laminated – Alternating layers of varying material or color with the layers less than 6mm thick; note thickness.
- Fissured – Breaks along definite planes of fracture with little resistance.
- Slickensided – Fracture planes appear polished or glossy, sometimes striated.
- Blocky – Cohesive soil that can be broken down into small angular lumps which resist further breakdown.
- Lensed – Inclusion of small pockets of different soils such as small lenses of sand scattered through a mass of clay; note thickness.
- Homogeneous – Same color and appearance throughout.

Cementation

- Weak – Crumbles or breaks with handling or little finger pressure.

Table 4–10.—**Field determination of consistency of fine-grained soil**

Consistency	Identification procedure	Shear strength Kg/cm^2 ($tons/ft^2$)	Blow count (blows/ft)
Very soft	Thumb will penetrate soil more than 25mm (1 in)	Less than 0.25	0 - 4
Soft	Thumb will penetrate soil about 25mm (1 in)	0.25 to 0.5	5 - 8
Firm	Thumb will indent soil about 6mm (1/4 in)	0.5 to 1.0	9 - 15
Hard	Thumb will not indent soil but soil is readily indented with thumbnail	1.0 to 2.0	15 - 30
Very Hard	Thumbnail will not indent soil	Over 2.0	Over 30

- Moderate – Crumbles or breaks with considerable finger pressure.
- Strong – Will not crumble or break with finger pressure.

Site Investigation

All construction sites need a geologic investigation. The intensity of investigation depends on design requirements, complexity of the site, and class of the structure. Detailed investigations may not be necessary for small, low-hazard structures such as farm ponds, drop structures, or chutes built in areas of generally homogeneous soil materials. For such structures, the relevant engineering characteristics of site materials need only be recognized and evaluated on the basis of experience in the area and appropriately documented.

Sites for terraces, diversions, and waterways should be checked for soil classification, thickness of topsoil, suitability of the subsoil for the intended crops, stoniness of soil, depth to bedrock, permeability, elevation and slope of the water table, and artesian pressure. In open ditch design, erosion resistance and stability of the side slopes depend on soil type and ground water conditions. Construction costs are affected by soil type, stoniness, depth to rock, and depth to water table. Foundations for dams must be checked for strength, permeability, compressibility, dispersive clays (piping), water table elevation, and depth to bedrock. The erosion resistance of the emergency spillway materials must be estimated. An adequate quantity of suitable borrow must be located. Waste storage structure sites must be investigated to ensure the integrity of the structure and to avoid pollution of ground water. A site should be checked for soil classification, permeability, depth to bedrock, and elevation of the water table. All existing and proposed wells and springs that may be affected by the structure should be located on a map.

Preliminary data. First gather and record all useful soil and geologic information that is available from soils and geologic maps. This information should be recorded on a site map. Next, walk over the site, observe the surface geologic features and record them on the site map. Features that may be visible on the surface are springs, seeps, rock outcrops, boulders, slides, sinkholes, and manmade openings. Excavations, road cuts, and ditch and stream banks give opportunities to see soil and geologic profiles.

Boring program. After this work is completed, take a close look at the information that has been collected and decide what geologic questions have been answered and what questions remain. Then ask yourself what additional information is needed to answer these questions. A few borings with a hand auger may suffice, backhoe pits may be required, or a full boring and testing program with power equipment may be required to supply the needed information. The investigation is continued until all questions are answered with reasonable assurance. One should not hesitate to ask for assistance from an experienced geologist or engineer.

Geologic observations should continue throughout construction and the geologic records updated as new information is disclosed. Occasionally, new geologic information discovered during construction may require design changes.

Detailed requirements for geological investigations are given in NEH–8, Chapter 5.

Generally, borings at dam sites should be made on the centerline of the embankment and on the centerline of the principal spillway. Usually, borings are carried through all compressible and permeable strata to a relatively incompressible, impermeable base, but it is usually not necessary to go deeper than the dam is high. The number of borings required will depend on the length of the dam and the uniformity or variability of the foundation. The minimum number of borings on the principal spillway centerline usually consists of one on the intersection of the centerline of fill and the centerline of the spillway plus one each at the inlet and outlet. Other borings may be needed at a proposed drain location or to identify unusual foundation conditions.

Enough borings need to be made at the emergency spillway location to identify the materials to be excavated and to determine the erosion resistance of the soils at and below grade.

A recommended numbering system for soil borings is given in the section on soil description (table 4–9).

Ground water

Soil borings and test pits should be kept open until the ground water level has stabilized and the ground water surface elevation is measured and recorded. If a pit needs to be backfilled or a drill hole is caving, a perforated pipe should be installed and the ground water elevation measured in the pipe. It often requires 24 hours for water elevations to stabilize, and it may take weeks to months to stabilize in soils with low permeability. Where artesian pressures are encountered, a piezometer may be needed to measure the head.

It is SCS policy to backfill and tightly seal all drill holes and pits completely to prevent ground water contamination by surface water or to prevent loss of artesian pressure. Filled holes also remove hazards to livestock and equipment.

Seasonal variation in the water table should be determined by direct observation and measurement at various times during the year, or it should be estimated. Sometimes in a soil profile, the upper and lower limits of mottling are good indications of the seasonal water table fluctuation. The depth below which the soil is entirely grey usually indicates the elevation of the seasonal low water table. The depth above which the soil is primarily red, orange, or yellow usually indicates the seasonal high water table.

Estimation of Soil Performance and Performance Requirements

Estimates of soil behavior, such as its shear strength, compressibility, or permeability, can be made from the soil description and classification. These estimates are adequate to design most low hazard, low cost structures. The reasonableness of soil test results should be evaluated by comparison with estimated soil parameters.

Strength
Shear strength of soil is made up of two elements, friction and cohesion.

In its simplest form, friction is the resistance to sliding of one block of nonplastic soil against another. It is similar to and can be assumed to have the same action as the resistance of a block of wood sliding across a wooden floor. The greater the weight placed on the sliding block, the greater the force necessary to slide the block. Likewise, as load is applied to the soil or the intergranular pressure is increased, the frictional resistance or frictional shear strength increases. The friction in soil is different from simple friction because of such factors as the irregularity of the planes, interlocking of particles, and size and shape of the soil grains. The shear strength of clean sands and gravels and nonplastic silts is due to friction.

Cohesion is the result of the magnetic–like attraction of particles that is noted in one form as the plasticity and stickiness of soils. It resists the shearing of a block of soil. Cohesive strength does not increase with increased load or intergranular pressure in the soil. Highly plastic clays have mostly cohesive shear strength. Silty and sandy clays can have a combination of both cohesive and frictional strength.

Friction and cohesion increase as soil density increases. Friction increases as particle size increases and as the soil goes from poorly graded to well graded.

Over a long time period, clay soil that has mostly cohesive strength may creep like a highly viscous liquid. This is why a retaining wall for clay may tip over after 20 years even though the soil supported itself vertically while the wall was being built.

Silt–size particles are larger than clay particles and generally do not have significant cohesive attraction, as clay does. Silt particles act more like sand, having frictional strength; but being smaller, have less strength than sand.

Most soils are a mixture of sand, gravel, silt, and clay and exhibit characteristics of both cohesive and noncohesive soil. Soil usually needs more than 35 percent sand and gravel before the coarse materials significantly affect the strength characteristics.

Stable slopes for moist soils of medium or greater density can be estimated as:

Rock	1 to 1–1/2
Gravel	1–1/2 to 2:1
Sand	2:1 to 2–1/2:1
Clay	2–1/2 to 4:1
Silt	3 to 4:1

Silts and sands with water seeping from them and soft clays present difficult stability problems and should be analyzed using refined techniques on a case-by-case basis.

Permeability
Permeability is the property of a porous medium that allows water to flow through it. The porous mediums of interest are soil and rock.

Water moves through the voids between soil particles and, with few exceptions, through joints, fractures, and solution cavities in rock. In some rock, such as certain sandstones, water moves through the rock mass. The symbol for permeability is K, and it is given as a velocity through the total soil mass at a gradient of 1. The most common dimensions used for K in SCS are cm/sec and ft/day. (2830 cm/sec = 1 ft/day.)

Permeability of coarse-grained soils and fine-grained soils must be considered separately. In order to treat a soil as a coarse-grained soil when estimating permeability, it must have less than 5 percent fines, and the fines must be nonplastic. Sometimes, even 5 percent fines will clog the soil pores. The permeability of clean sand and gravel is controlled by the finest 10 to 20 percent of the soil.

Permeability of concrete sand will range from about 3.5×10^{-3} cm/sec to 3.5×10^{-2} cm/sec (10 ft per day to 100 ft per day). Gravel of the smallest particle size, about 5mm (3/16 inch), will have a permeability around 15 cm/sec (40,000 ft per day). A gravel of 5mm (3/8 inch) minimum size has a permeability around 25 cm/sec (70,000 ft per day).

The permeability of soils that have a significant content of fines depends on the characteristics of the fines. Generally, a proportion of 15 percent or more fines is enough for permeability to be controlled by the fines.

Naturally occurring soils usually form aggregates or peds. Water flows between the aggregates and through channels in the soil created by roots and burrowing animals and insects. A naturally occurring CL may range from being essentially impermeable to having as much permeability as 3.5×10^{-4} cm/sec (1 ft per day), depending on the soil structure and number and size of channels.

The permeability of a compacted soil with a significant content of fines depends on the soil gradation and plasticity, the moisture content at compaction, and the amount of compaction. When the soil is compacted dry, the aggregates remain intact, and water flows between them in a manner similar to the way it flows in sand. When the soil is compacted wet, the aggregates are flattened and molded together, creating a solid mass of much lower permeability. The optimum moisture content from the standard Proctor compaction test can be used as the estimated division between dry and wet compaction. Soils that have a significant fines content and are compacted 2 percent dry of optimum can be expected to have a permeability of 10 to 1,000 times that of the same soil compacted 2 percent wet of optimum.

Other things being equal, the greater the soil density, the lower its permeability. However, the greatest influence on permeability of soils having a significant content of fines is the moisture content during compaction.

Compressibility

Compressibility is the property of a soil that pertains to its susceptibility to decrease in volume when subjected to load. Volume change is the result of changes in pore volume, soil grains being essentially incompressible. Organic matter in the soil may be highly compressible.

Other commonly used terms related to compressibility are *consolidation, settlement, collapse,* and *compaction.*

Consolidation is the gradual reduction in soil volume resulting from an increase in compressive stress. It consists of *initial* consolidation, which is a comparatively sudden reduction in volume resulting from the expulsion and compression of gas; *primary* consolidation, which results principally from a squeezing out of water and is accompanied by a transfer of load from the soil water to the soil solids; and *secondary* consolidation, resulting principally from the adjustment of the internal structure of the soil mass after initial consolidation.

Settlement is the displacement of a structure due to the compression and deformation of the underlying soil.

Compaction is the densification of a soil by means of mechanical manipulation.

Collapsible soils are low density soils that have considerable strength when dry or moist. They lose strength and undergo sudden compression when they are saturated. Some will collapse under their own weight when saturated; others, only when loaded.

Collapsible soil foundations cause problems when they are saturated after being loaded by a structure. Examples are settlement of a dam foundation resulting in cracking of the dam when stored water saturates the foundation; settlement and cracking of an irrigation ditch dike or lining when seepage from the ditch saturates the foundation; or settlement of a building when the foundation soil is saturated with water from a downspout or leaks in water or sewer pipes.

Collapsible soils usually occur as alluvial fans in subhumid to arid areas. Low density soils above the water table in this situation should be suspected of being collapsible. They can be identified by consolidation testing of undisturbed samples. In testing, samples are loaded in a moist condition, then saturated. Collapsible soils will show sudden settlement upon wetting.

Bearing capacity

The allowable bearing capacity of a soil is the maximum average load per unit area of a footing that will not produce failure by rupture of the supporting soil or produce excessive settlement. Bearing capacity depends not only on the soil, but on the footing size, shape, and depth and on the maximum settlement the structure can take without excessive damage. Bearing capacity is most often controlled by settlement.

Bearing capacity of the soil is seldom a problem for light farm structures except on obviously soft, low density or low strength soils. When settlement problems occur, they are usually the result of building on two soils with different settlement characteristics, such as undisturbed soil and loose backfill.

Relatively heavy, rigid structures, such as concrete manure tanks, must be set on strong uniform foundations to avoid differential settlements that can cause cracking.

Many local building codes contain values of maximum allowable soil pressure for foundation design. They are based on experience. Values are also found in engineering and building construction handbooks. These maximum allowable values are called presumptive bearing pressures. They should be used only for small, low cost structures.

Compaction

One method of treating soil to improve its characteristics is by compaction. Compacted soil should be thought of as a different material from the soil in its natural state. Increasing a soil's density by compaction increases soil strength and decreases compressibility. Other things being equal, increasing soil density by compaction will decrease permeability. However, trying to achieve low permeability in a fine-grained soil by compacting it to a high density can be a mistake. High densities require soil moisture near or below optimum. Low permeability requires compaction moisture above optimum. The moisture content at the time of compaction is more important than density in determining permeability. This is discussed further in the section on permeability.

Some adverse effects of compacting soil are as follows: compaction creates a potential for increased swelling in some fine-grained soils; compacting backfill against a retaining wall increases soil pressures against that wall; compaction usually makes a soil less suitable for plant growth; and compaction increases the potential for soil cracking as a result of differential movement.

When samples of a dry soil are moistened and then compacted and subsequent samples are moistened and compacted, so that each sample has a higher moisture content than the last, the soil will increase in density with increasing moisture until a "maximum density" at an "optimum moisture" is reached. After that, increases in moisture will result in a decrease in dry density. There is an optimum moisture content for each soil and a compaction method at which maximum density will be obtained.

The type of test described above is known as a Proctor density test or a moisture-density test. The SCS usually uses the moisture-density test described in ASTM D–698. The test sets reference soil densities and moisture contents for soil testing and compaction control.

The most important items to control when compacting soil are soil moisture, lift thickness, compaction equipment type and weight, and number of equipment passes.

Proctor density tests are the best way to determine the best placement moisture content for fine-grained soils. Soils that must flex without cracking should be placed at moisture contents above optimum. At locations where cracking is not important, soil can be placed from about 2 percent below to 2 percent above optimum. Embankments in arid or semi-arid areas that may crack from deep drying need special consideration.

Some guidelines that can be used in the field to estimate correct moisture where testing is not feasible are:

1. If the embankment becomes firm and hard, the moisture content is probably too low. Equipment should sink into the soil a few inches.
2. The soil should have enough moisture so that, when formed into a ball, it will not break if struck sharply with a pencil.
3. For most soils, optimum moisture is a little below the plastic limit.

The moisture content of clean gravel and coarse sand have very little effect on their compaction characteristics. Moist fine sand has a very low density when dumped into place. A moisture content near saturation will make compaction easier. Dirty sands act much like fine-grained soils with similar plasticity.

Maximum lift thickness in order to obtain satisfactory compaction depends primarily on the equipment used for compaction, assuming the equipment is suitable for the soil. Table 4–11 can be used as a guide for lift thickness.

Rock size should be limited to 2/3 of the loose lift thickness so that the rock will fit within the compacted lift thickness.

For efficient compaction, the equipment must be suitable for the soil type. Clean sands and gravels need vibratory compactors. Small, hand-guided plate vibrators are available for confined areas. Track tractors are also effective in compacting clean coarse-grained soils. They should be operated as fast as practical so they will produce vibrations.

Plastic soils need sheepsfoot or tamping rollers. Rubber-tired rollers are good for wet plastic soils, low plastic, and nonplastic fine soil.

Erosion resistance

Resistance of soil to *sheet erosion* has been evaluated in the development of the Universal Soil Loss Equation. The soil erodibility factor was given the symbol K. The erodibility factor K should *not* be used to evaluate a soil's erosion resistance to flow in a channel (diversions, waterways, drainage or irrigation channels, floodways, emergency spillways).

Procedures to evaluate a soil's resistance to water flow are given in Technical Release No. 25, Design of Open Channels, and Technical Release No. 52, A Guide for Design and Layout of Earth Emergency Spillways.

Soils resist erosion during channel flow in two ways:
(l) Coarse–grained soils, such as sand and gravel, resist movement by the weight of individual particles. Other things being equal, the heavier a particle, the greater its resistance to movement. Platy, elongated, and low–density particles are moved more easily than equidimensional and denser

Table 4–11.—**Maximum lift thickness for compaction equipment**

Equipment	Maximum loose lift thickness inches	cm
Hand compactor (mechanical)	4	10
Track tractor	6	15
Small plate vibrator	8	20
Sheepsfoot roller	9	25
Rubber-tired roller	12	30
Rubber-tired equipment	18	45
Vibratory roller	24	60

particles. In TR–25, figure 6–2, a clean coarse-grained soil's resistance to erosion is evaluated on its D75 size, the size at which 75 percent by weight of the soil particles are smaller. (2) Fine-grained soils resist erosion as a mass held together by the cohesion between particles. TR–25, figure 6–2, rates erosion resistance on the basis of a soil's Plasticity Index (PI) and Unified classification. The higher the PI, up to 20, and the more clayey the soil, the greater its erosion resistance. A CL with PI = 20 has greater erosion resistance than a CL with PI = 15. A CL with PI = 15 has greater erosion resistance than an ML with PI = 15. The erosion resistance of fine-grained soils also increases with increased density. Density is indicated by void ratio in figure 6–2, TR–25. A decreasing void ratio indicates increasing density.

Coarse-grained soils that have cohesive fines resist erosion by both the weight of the sand or gravel particles and the cohesion of the fines. Coarse-grained soils with noncohesive fines have about the same erosion resistance as clean coarse-grained soil. Some very dense soils, such as dense glacial tills, have a high erosion resistance even though their particle-size and cohesiveness would not indicate so. A feeling for the relative erosion resistance of soils in your area can be gained by close observation of the performance of waterways, diversions, streams, and other channels.

Table 4–12 presents a generalized listing of soils with the more erosion resistant soils listed first and the least resistant last.

Earth pressures

It is important that retaining walls be backfilled in the manner (to the height and with the materials) that were assumed in the design. What might seem like a small change in the backfill could double the load on a wall. The following discussion explains some of the factors that determine earth loads on walls.

Soil resting against the side of a wall exerts a force on the wall that acts in a nearly horizontal direction. The size of the force depends on the kind of soil, its moisture content, the wall movement, time since backfilling, and the wall height and length.

Table 4–12.—**Comparative erosion resistance of soils**

Most resistant	
Large gravel	GW, GP
Clayey gravel	GC
Highly plastic clay and clayey sand	CH, SC
Clays, silty gravel	CL, GM
Silts, silty sand, organic silts	MH, OH, ML, SM, OL
Least resistant	

The soil force against a wall (figure 4–12(a)) results from a tendency of the wedge of soil JKL to slide down the slope JL. The wedge of soil is restrained by both the wall and friction and cohesion along JL. If the soil is saturated, then a water load (figure 4–12(b)) represented by the triangle MNO is added to the soil load. Since water has no shear strength, the total water load must be resisted by the wall. However, there is a reduction in the soil portion of the load under saturated conditions because only the buoyant weight of the soil is acting against the wall.

Combined soil-water load is large, and only specially designed reinforced concrete walls can withstand the pressure. Walls should have good drains to prevent buildup of water pressures where possible.

Lowest forces on a wall can be obtained by backfilling with dumped gravel. Forces from dumped sand are only slightly larger. The wall must be able to move slightly or deflect slightly; and the sand or gravel section must be free draining and be of a minimum size or larger, as shown in figure 4–13. Outlets must be provided for water collected in the sand and/or gravel backfill.

The horizontal pressure at any point A will be 0.3 to 0.4 times the weight of soil above point A for dumped sand or gravel.

Compaction of backfill will increase pressures because compaction forces are "locked into" the soil. Also, compaction tends to move the wall during backfilling rather than after backfilling, when movement will reduce soil pressure.

Soil with clayey fines will stand vertically at the time of excavation. This would indicate that clayey soils would produce very low horizontal pressures against walls. However, when wet, clayey soils may "creep" over a long time period and gradually build up high soil pressures. Over time, pressures from clay soils will reach from 0.8 to 1.0 times the weight of overlying soil. Pressures of compacted clay backfill may be greater than 1.

Figure 4–12.—**Earth pressures against walls.**

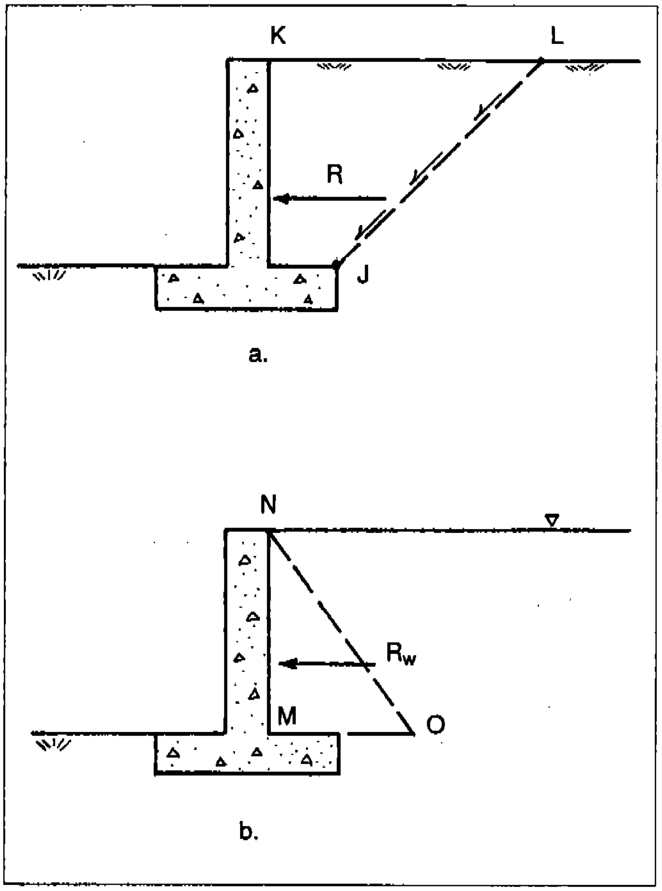
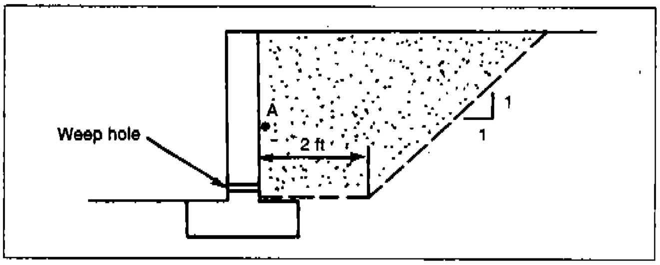


Figure 4–13.—**Minimum sand or gravel section.**



Cracking

The primary cause of failure of SCS embankments is cracking and piping. A crack in an embankment becomes a flow path for water. Flow through the crack may erode the sides, creating a void through the dam. Cracking may be caused by either or both of two physical actions.

Cracking may be caused by soil shrinkage that results from drying. The finest-grained materials have the highest cracking potential. Plasticity is an indirect measurement of cracking potential because higher plasticity is associated with finer materials and clay minerals. Fine-grained nonplastic materials will shrink, but shrinkage will be less than in plastic materials.

Foundation materials subject to shrinkage cracking should be protected from drying while they are exposed. This may be done with sprinkling, covering, or delaying final grading until backfill can start. The fill surface must also be protected from drying between lifts. Once an area has dried and cracked, it should be loosened by discing and then moistened and compacted.

Cracking may be caused by embankment movement as a result of either foundation settlement or differential embankment settlement caused by steep changes in the foundation grade. Usually, 1:1 abutment or trench side slopes are flat enough to prevent excessive differential settlement.

Failure due to cracking also depends on deformability of the soil and its ability to heal itself. Deformability without cracking is a result of both a soil's plasticity and its water content. Adding compaction moisture above optimum helps in controlling cracking caused by settlement.

Shrink–Swell

Highly plastic soils under low load have a high swell potential when water content increases. Swelling potential may be estimated from the plasticity index of a soil. Soils with a plasticity index greater than 20 usually have a medium to high swell potential; soils with a PI greater than 35 usually have a very high swell potential. Swelling greatly reduces the strength of soils.

Table 4–13 may be used to estimate volume change on the basis of its SL and PI.

If possible, soils that have a high shrink-swell potential should be placed in the lower and interior zones of an embankment where moisture change will be restricted and where loads will restrain swelling.

Table 4–13.—**Volume change potential**
(Adapted from Holtz and Gibbs 2:9)

Volume Change	Shrinkage Limit	Plasticity Index
Probably low	12 or more	0 - 15
Probably moderate	10 - 12	15 - 30
Probably high	0 - 10	30 or more

Frost Heave

Soil movement caused by frost action is responsible for much damage each winter to roads, streets, buildings, and other improvements. Damage is caused by movement as the soil freezes and by loss of bearing capacity when it thaws.

As soil freezes, water moves from unfrozen soil to the freezing area, building ice lenses which cause the soil to expand. Three conditions are necessary for ice lenses to form: (1) freezing soil, (2) a source of water, and (3) a permeable, fine-grained soil that will transmit water by capillary action. Frost heave can be controlled by controlling any one of the three conditions.

The water source is usually the water table. Sometimes the water source is infiltrating surface water. When the water source is the water table, a common control measure is drainage to lower the water table. The water table should be lowered to 6 to 8 ft below the ground surface.

A second method of control is to place a soil barrier between the ground water and the freezing soil. This may be a zone of clean gravel that will not transmit water by capillarity or a zone of compacted clay that has such low permeability that it will not transmit enough water during the winter to create a problem. In some cases, ridged foam insulation is used under paving or around foundations to prevent ground freezing. Good drainage under paving will reduce damage during thawing.

Dispersive Clay Soils

Some clay soils disperse in the presence of water and take on a single-grained structure. Because of this, they are highly erodible and pipeable. Terraces, diversions, dikes, and dams constructed with dispersed clays will have severe surface erosion and may internally erode through cracks in the embankment or foundation. Waterways and channels built in dispersed clays may suffer severe erosion.

Nonplastic and low plastic (PI of 4 or less) silts and fine sands are highly erosive by nature and should not be confused with dispersed clays.

Dispersed clays have long been associated with arid and semi-arid regions. More recently, dispersed clays have been identified in many sections of this country and a number of foreign countries.

Dispersed clays can sometimes, but not always, be recognized in cuts where construction activity has removed the surface soil or where the underlying soil has been used in fills. They have a characteristic erosion pattern consisting of narrow, deep, parallel gullies and vertical and horizontal tunnels or jugs. Suspect soils can be tested for dispersion by a soil mechanics laboratory. Soil samples collected for dispersion testing should be sealed in moisture-proof bags to preserve their natural moisture. The crumb test, a simple field test, may be used to identify some dispersive clays and to select samples for laboratory testing.

Dispersed clays should not be used in construction if an economical alternative borrow source can be found.

If dispersed clays are used, they should be protected from drying and cracking with a covering of erosion resistant soil. Erosion of dispersed clay has been successfully controlled by treatment with hydrated lime. Treatment technique and rate should be developed by testing in a soil mechanics laboratory. Internal erosion can be controlled by a properly designed sand filter.

Behavior characteristics of soils. The following charts (figure 4–14) contain soil performance interpretations based on their Unified classification. These are generalizations and should not be used as a basis for design.

Figure 4–l4.—**Unified classification and properties of soils.**

	IMPORTANT PROPERTIES						
			Workability as	Permeability			
Typical Names	Shear Strength	Compress-ibility	Construction Material	When Compacted	K Cm. Per Sec.	K Ft. Per Day	Unified Soil Classes
Well graded gravels, gravel-sand mixtures, little or no fines.	Excellent	Negligible	Excellent	Pervious	$K > 10^{-2}$	$K > 30$	GW
Poorly graded gravels, gravel-sand mixtures, little or no fines.	Good	Negligible	Good	Very Pervious	$K > 10^{-2}$	$K > 30$	GP
Silty gravels, gravel-sand-silt mixtures.	Good to Fair	Negligible	Good	Semi-pervious to Impervious	$K = 10^{-3}$ to 10^{-6}	$K = 3$ to 3×10^{-3}	GM
Clayey gravels, gravel-sand-clay mixtures.	Good	Very Low	Good	Impervious	$K - 10^{-6}$ to 10^{-8}	$K = 3 \times 10^{-3}$ to 3×10^{-5}	GC
Well graded sands, gravelly sands, little or no fines.	Excellent	Negligible	Excellent	Pervious	$K > 10^{-3}$	$K > 3$	SW
Poorly graded sands, gravelly sands, little or no fines.	Good	Very Low	Fair	Pervious	$K > 10^{-3}$	$K > 3$	SP
Silty sands, sand-silt mixtures.	Good to Fair	Low	Fair	Semi-pervious to Impervious	$K = 10^{-3}$ to 10^{-6}	$K = 3$ to 3×10^{-3}	SM
Clayey sands, sand-clay mixtures.	Good to Fair	Low	Good	Impervious	$K = 10^{-6}$ to 10^{-8}	$K = 3 \times 10^{-3}$ to 3×10^{-5}	SC
Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity.	Fair	Medium to High	Fair	Semi-pervious to Impervious	$K = 10^{-3}$ to 10^{-6}	$K = 3$ to 3×10^{-3}	ML
Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.	Fair	Medium	Good to Fair	Impervious	$K = 10^{-6}$ to 10^{-8}	$K = 3 \times 10^{-3}$ to 3×10^{-5}	CL
Organic silts and organic silty clays of low plasticity.	Poor	Medium	Fair	Semi-pervious to Impervious	$K = 10^{-4}$ to 10^{-6}	$K = 3 \times 10^{-3}$ to 3×10^{-3}	OL
Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.	Fair to Poor	High	Poor	Semi-pervious to Impervious	$K = 10^{-4}$ to 10^{-6}	$K = 3 \times 10^{-1}$ to 3×10^{-3}	MH
Inorganic clays of high plasticity, fat clays.	Poor	High to Very High	Poor	Impervious	$K = 10^{-6}$ to 10^{-8}	$K = 3 \times 10^{-3}$ to 3×10^{-5}	CH
Organic clays of medium to high plasticity, organic silts.	Poor	High	Poor	Impervious	$K = 10^{-6}$ to 10^{-8}	$K = 3 \times 10^{-3}$ to 3×10^{-5}	OH
Peat and other highly organic soils	Not Suitable for Construction						Pt

Figure 4–14.—**Unified classification and properties of soils — Continued.**

EMBANKMENTS								
Compaction Character-istics	Standard Procter Unit Density (Lbs. per cu. ft.)	Type of Roller Desirable	Relative Characteristics: Perme-ability	Relative Characteristics: Compress-ibility	Resistance to Piping	Ability to Take Plastic Deformation Under Load Without Shearing	General Description & Use	Unified Soil Classes
Good	125-135	Crawler tractor or steel wheeled & vibratory	High	Very Slight	Good	None	Very stable, pervious shells of dikes and dams.	GW
Good	115-125	Crawler tractor or steel wheeled & vibratory	High	Very Slight	Good	None	Reasonably stable, pervious shells of dikes and dams.	GP
Good with close control	120-135	Rubber-tired or sheepsfoot	Medium	Slight	Poor	Poor	Reasonably stable, not well suited to shells but may be used for impervious cores or blankets.	GM
Good	115-130	Sheepsfoot or rubber-tired	Low	Slight	Good	Fair	Fairly stable, may be used for impervious core.	GC
Good	110-130	Crawler tractor & vibratory or steel wheeled	High	Very Slight	Fair	None	Very stable, pervious sections, slope protection required.	SW
Good	100-120	Crawler tractor & vibratory or steel wheeled	High	Very Slight	Fair to Poor	None	Reasonably stable, may be used in dike with flat slopes.	SP
Good with close control	110-125	Rubber-tired or sheepsfoot	Medium	Slight	Poor to Very Poor	Poor	Fairly stable, not well suited to shells, but may be used for impervious cores or dikes.	SM
Good	105-125	Sheepsfoot or rubber-tired	Low	Slight	Good	Fair	Fairly stable, use for impervious core for flood control structures.	SC
Good to Poor. Close control essential	95-120	Sheepsfoot	Medium	Medium	Poor to Very Poor	Very Poor	Poor stability, may be used for embankments with proper control. *Varies with water content.	ML
Fair to Good	95-120	Sheepsfoot	Medium	Medium	Good to Fair	Good to Poor	Stable, impervious cores and blankets.	CL
Fair to Poor	80-100	sheepsfoot	Medium to Low	Medium to High	Good to Poor	Fair	Not suitable for embankments.	OL
Poor to Very Poor	70-95	Sheepsfoot	Medium to Low	Very High	Good to Poor	Good	Poor stability, core of hydraulic fill dam, not desirable in rolled fill construction.	MH
Fair to Poor	75-105	Sheepsfoot	Low	High	Excellent	Excellent	Fair stability with flat slopes, thin cores, blanket & dike sections.	CH
Poor to Very Poor	65-100	Sheepsfoot	Medium to Low	Very High	Good to Poor	Good	Not suitable for embankments.	OH
Do Not Use for Embankment Construction								Pt

Figure 4–14.—**Unified classification and properties of soils — Continued.**

CHANNELS		FOUNDATION					Unified Soil Classes
Long duration to constant flows.		Foundation soils, being undisturbed, are influenced to a great degree by their geologic origin. Judgment and testing must be used in addition to these generalizations.				TENTATIVE FOR TRIAL USE ONLY	
RELATIVE DESIRABILITY		RELATIVE DESIRABILITY					
					Requirements for Seepage Control		
Erosion Resistance	Compacted Earth Lining	Bearing Value	Seepage Important	Seepage Not Important	Permanent Reservoir	Floodwater Retarding	
1	—	Good	—	1	Positive cutoff or blanket	Control only within volume acceptable plus pressure relief if required.	GW
2	—	Good	—	3	Positive cutoff or blanket	Control only within volume acceptable plus pressure relief if required.	GP
4	4	Good	2	4	Core trench to none	None	GM
3	1	Good	1	6	None	None	GC
6	—	Good	—	2	Positive cutoff or upstream blanket & toe drains or wells	Control only within volume acceptable plus pressure relief if required.	SW
7 if gravelly	—	Good to poor depending upon density	—	5	Positive cutoff or upstream blanket & toe drains or wells	Control only within volume acceptable plus pressure relief if required.	SP
8 if gravelly	5 erosion critical	Good to Poor depending upon density	4	7	Upstream blanket & toe drains or wells	Sufficient control to prevent dangerous seepage piping.	SM
5	2	Good to Poor	3	8	None	None	SC
—	6 erosion critical	Very Poor; susceptible to liquefication	6, if saturated or pre-wetted	9	Positive cutoff or upstream blanket & toe drains or wells	Sufficient control to prevent dangerous seepage piping.	ML
9	3	Good to Poor	5	10	None	None	CL
—	7 erosion critical	Fair to Poor; may have excessive settlement	7	11	None	None	OL
—	—	Poor	8	12	None	None	MH
10	8 volume change critical	Fair to Poor	9	13	None	None	CH
—	—	Very Poor	10	14	None	None	OH
—	—	REMOVE FROM FOUNDATION					Pt

Scope

This section presents a method for selecting a structurally sound preliminary embankment design by means of a qualitative evaluation of soil characteristics, site topography, and foundation conditions. It presents an orderly approach to the concurrent evaluation of the many factors that influence embankment stability. The validity of conclusions reached by this method depends on the competence of the site investigation, the adequacy of the testing program, and the soundness of the designer's judgment. Design practices based on quantitative soil tests, such as analyses of slope stability, seepage, and settlement, are not discussed herein; however, they are necessary to the design of large dams, and such analyses will logically follow the selection of a preliminary design. In the case of small earth dams that have low hazard potential and whose magnitude or importance do not justify extensive investigation or testing programs, the conclusions reached by this method may constitute final design. For these small dams, the method presented herein should be regarded as the minimum analysis required for adequate design.

General

An earth dam embankment must be designed to be stable for any force condition or combination of force conditions that may reasonably be expected to develop during the life of the structure. Other than overtopping caused by inadequate spillway capacity, the three most critical conditions that may cause failure of the embankment are as follows:

1. Differential settlement within the embankment or its foundation caused by variation of materials, variation of height of embankment, or compression of foundation strata. This may cause the formation of cracks through the embankment that are roughly parallel to the abutments. These cracks could concentrate seepage through the dam and lead to failure by internal erosion.

2. The development of seepage through the embankment and foundation. This condition may cause piping within the embankment or foundation or both.

3. The development of shearing stresses within the embankment and foundation due to weight of the fill. If the magnitude of the shearing stresses exceeds the strength of the materials, sliding of embankment or foundation may occur, resulting in the displacement of large portions of the embankment.

Embankment stability

The stability of an embankment depends on a number of factors, the most important of which are discussed below. Each of these factors must be considered in the development of the embankment design. The finished design must include all features necessary to overcome any detrimental influence which may be exerted by any or all of these factors.

1. *Physical characteristics of the fill materials.* The classification of soils for engineering uses has already been discussed. These are summarized in table 4–14. Relative characteristics of compacted fill materials are presented in table 4–15.

2. *Configuration of the site.* Since, in a natural site, the height of the embankment varies considerably throughout its length, the total settlement of any given section of the embankment will differ from that of the sections immediately adjacent to it. The width of the gap and slope of the abutments profoundly influence the degree of differential settlement between adjacent sections of the embankment. The narrower the gap and the steeper the abutments, the more critical is the problem of differential settlement.

3. *Foundation materials.* The character and distribution of foundation materials must be considered from the standpoint of shear strength, compressibility, and permeability. In some cases, the shear strength of the foundation may govern the choice of embankment slopes. Permeability and stratification of the foundation may govern the choice of zoning plan and drainage features. In many cases, foundations contain compressible soils which settle under the weight of the embankment even though their shear strength is satisfactory. When such settlement occurs in the foundation, the embankment settles. This settlement is rarely uniform over the basal area of the embankment. Therefore, fill materials used on such sites must be sufficiently plastic to deform without cracking.

   Relative characteristics of the various soil groups pertinent to foundation evaluation are presented in table 4–16. Table 4–16 is not presented as a general solution to all foundation problems, but it may be used as an aid to evaluate foundation conditions. A foundation composed of homogeneous soil is simple to evaluate; however, such a condition is rarely found in natural soil deposits. The more usual condition is a stratified deposit composed of layers of several soil types. The number of possible combinations of materials and arrangements of materials within a deposit is so great as to render a general solution impossible. The geologic history of the site, the extent of stratification, and the order in which materials occur within the stratification are of great significance in determining the suitability of the foundation. A complex stratified foundation containing plastic or compressible soil should be investigated by an experienced engineer or geologist.

Figure 4-15.—**Embankment types.**

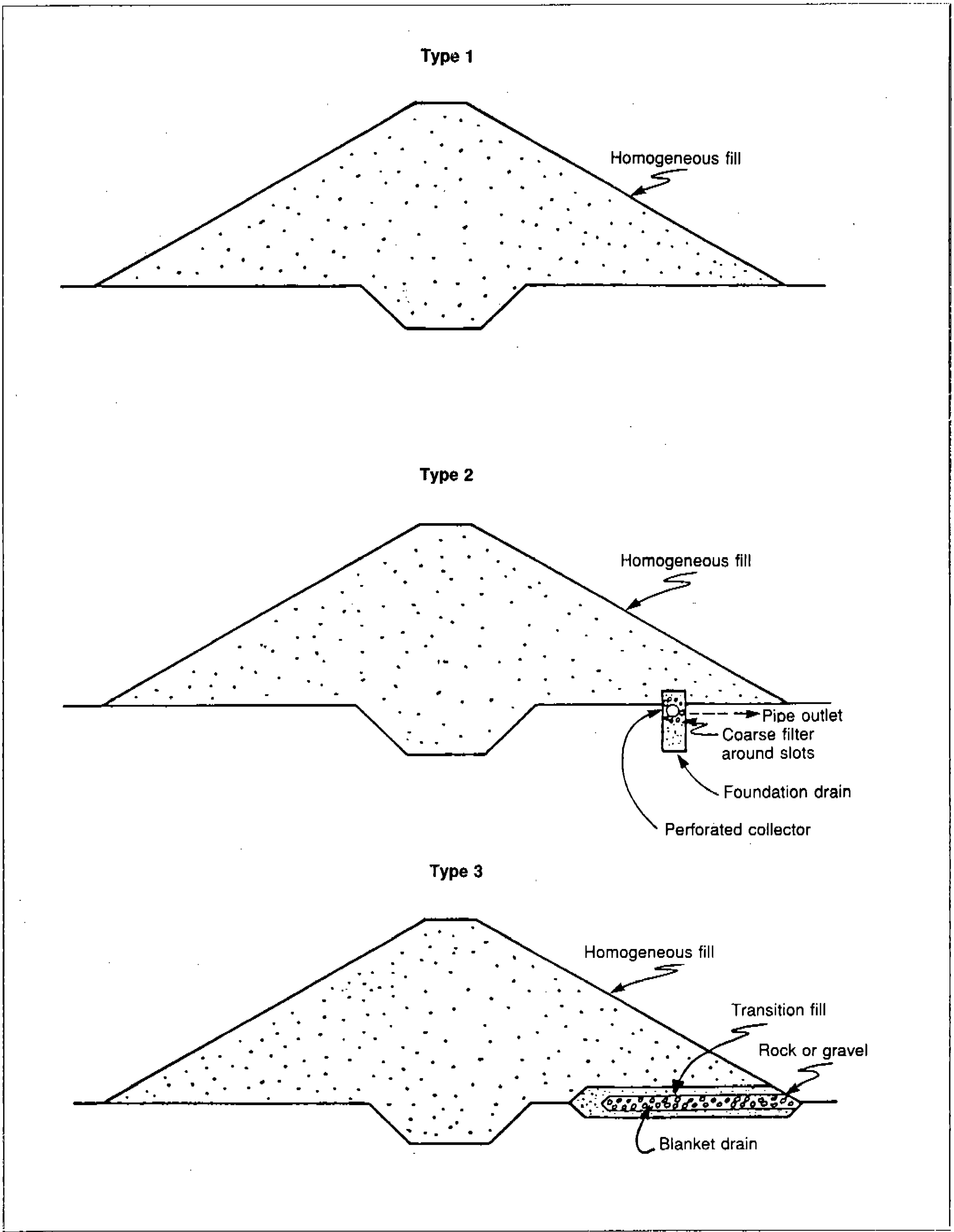
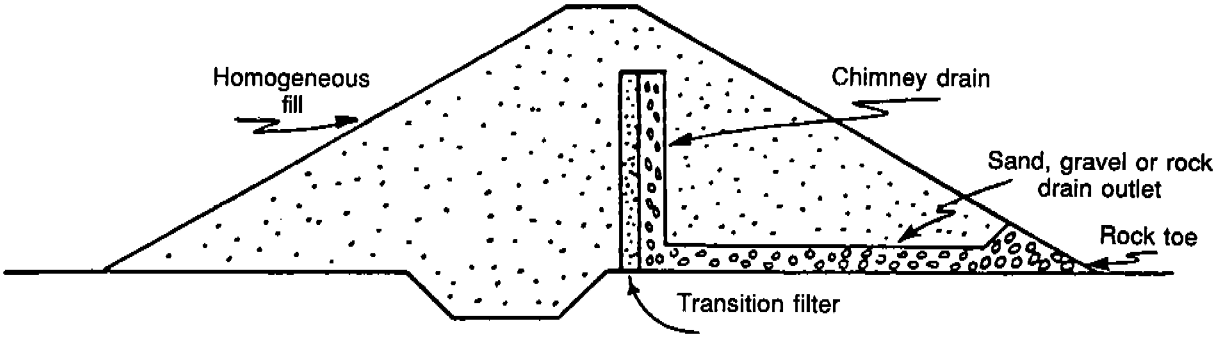
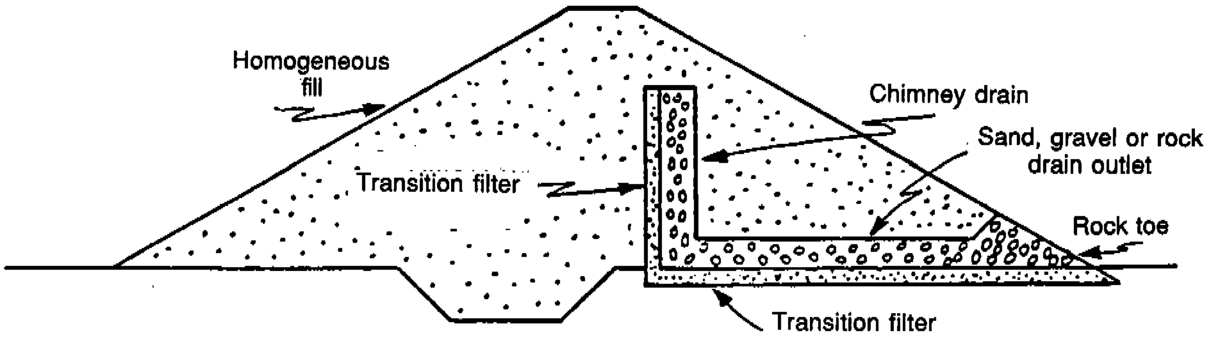


Figure 4-15.—**Embankment types — Continued.**

Type 4



Type 5



Type 6

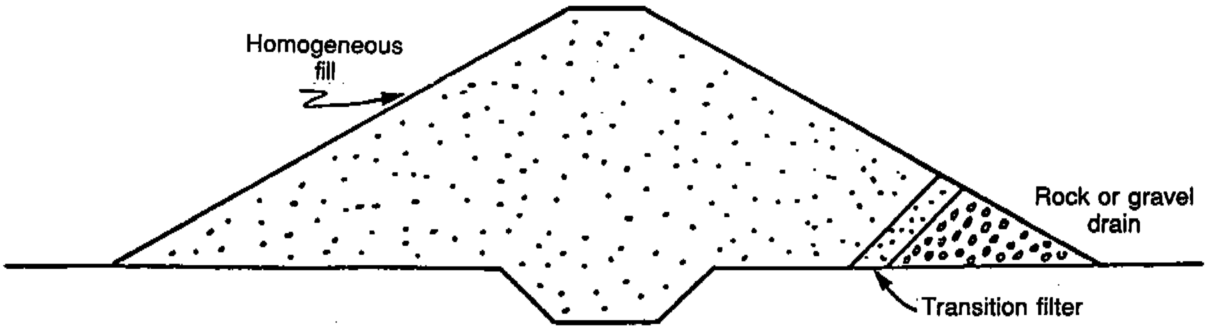


Figure 4-15.—**Embankment types — Continued.**

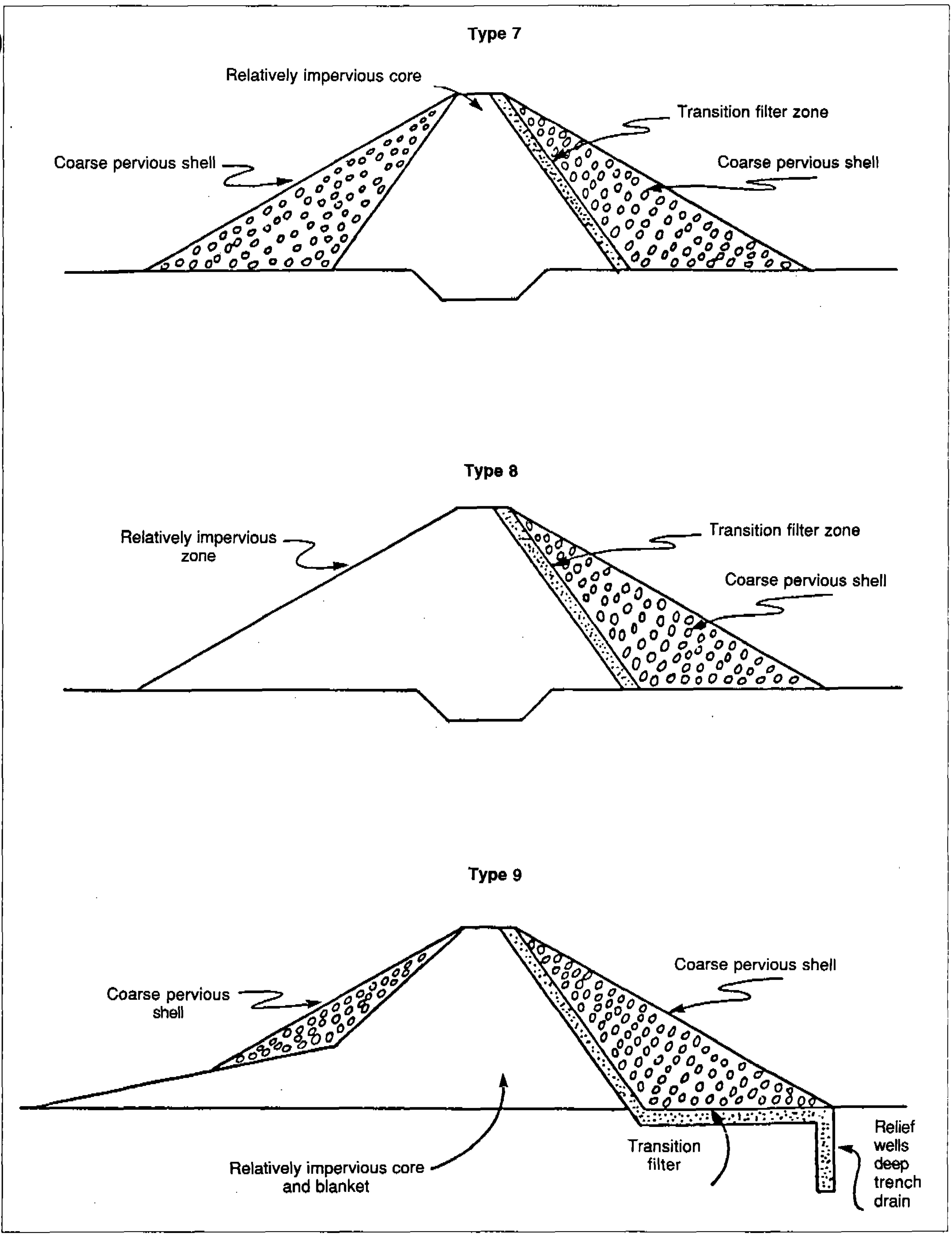
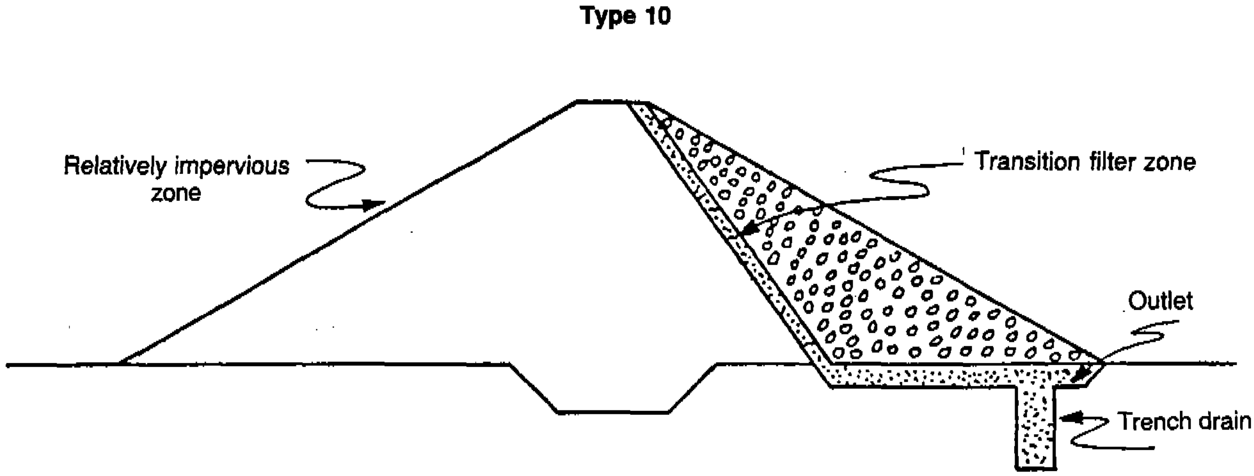


Figure 4-15.—**Embankment types — Continued.**



4. *Embankment zoning.* The stability of embankment slopes and the seepage pattern are greatly influenced by the zoning of the embankment. The position of the saturation line within a homogeneous earth dam is theoretically independent of the type of soil used in the embankment. Unless drainage is provided, this saturation line intersects the downstream slope at a point above the toe. In many cases, the quantity of seepage is so slight that it does not affect the slope's stability; however, in some cases the saturation of the toe will cause sloughing or serious reduction of shear strength in the downstream section of the embankment. It is desirable to include a toe drain in the design of most homogeneous dams. Dams founded on pervious foundations or constructed of materials that exhibit susceptibility to piping and cracking should always be protected by adequate toe drainage. Toe drains may be constructed of sand, gravel, or rock, depending on the nature of the fill material. Whenever a rock toe drain is installed, a graded filter should be placed between the fill and the drain. In many cases, a 12–inch layer of well graded stream run sandy gravel will satisfy this requirement. Filter design criteria are presented in Soil Mechanics Note No. 1.

   Where suitable materials are available it is desirable to design a zoned embankment in which the upstream and downstream thirds of the embankment are composed of coarse-grained pervious soils. The downstream pervious shell serves to lower the line of saturation in the same manner as does a toe drain and increases the total shear resistance of the embankment. The upstream pervious shell protects the embankment from failure due to stresses caused by rapid drawdown of the reservoir. Also, this type of zoning usually results in the placement of the more shear-resistant materials in the outer embankment zones.

5. *Fill placement.* The type of compaction control required to produce a fill of adequate density depends on the nature of the soil to be used in the embankment. Soils that indicate susceptibility to piping and cracking must be placed at a carefully controlled moisture content and compacted to a density determined by laboratory compaction tests. The most effective types of compaction equipment for various soil types are indicated in table 4–15.

Required design date

In order to develop a sound embankment design, the designer must have the following information:

1. Report of detailed foundation investigation (usually included in geological report).

2. Report of available quantities of fill materials, by type (usually included in geological report).

3. Report of characteristics of fill materials and foundation materials (materials testing laboratory report).

4. Topographic survey of the site (from preliminary investigation report).

Selection of embankment type

Table 4–18 and figure 4–15 (4 sheets) have been prepared for use as aids to evaluation of the factors discussed herein. Figure 4–15 illustrates 10 conventional basic embankment types, each of which is best applicable to a specific combination of site, foundation, and soil conditions. Table 4–17 presents a method by which an experienced engineer may evaluate site and foundation conditions. This evaluation, combined with the information derived from tables 4–16, 4–17, and 4–18, will enable him or her to select the proper embankment design type of means of table 4–19.

Table 4-14.—Working classification of soils for use as fill materials for rolled earth dams

Working Classification of Soils for Use as Fill Materials for Rolled Earth Dams

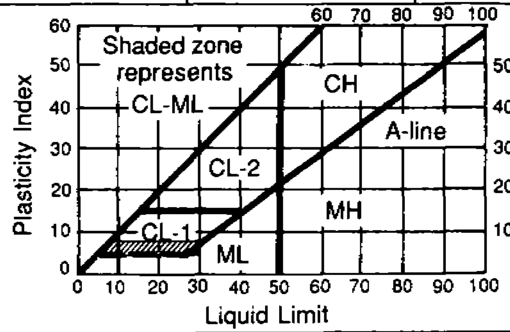
Major Divisions			Symbol	Typical Name	Laboratory Classification Criteria			Behavior
Coarse Grained Soils d_{50} > No. 200 Mesh (0.074 mm)	Sands and Gravels	Clean	GW	Well graded gravel; sandy gravels	Determine percentages of gravel and sand. Depending on percentage of fines (200 mesh), coarse grained soils are classified as follows: Less than 5%—GW, GP, SW, SP More than 12%—GC, GM, SC, SM 5% to 12%—Borderline cases	$C_u>4$; $1\leq Cc\leq 3$	$Cu = \frac{d_{60}}{d_{10}}$ $Cc = \frac{d_{30}^2}{d_{10}\, d_{60}}$	I
			GP	Poorly graded gravels; sandy gravels		C_u4 or $1>Cc>3$		
			SW	Well graded sands; gravelly sands		$C_u>6$; $1\leq Cc\leq 3$		
			SP	Poorly graded sands; gravelly sands		C_u6 or $1>Cc>3$		
		With Clay Fines	GC	Clayey gravels; sandy, clayey gravels		Atterberg limits above A-line		II
			SC	Clayey sands; gravelly, clayey sands		Atterberg limits above A-line		
		With Silt Fines	GM	Silty gravels; sandy, silty gravels		Atterberg limits below A-line		III
			SM-1	Coarse silty sands		(#100 sieve) $d_{50} \geq 0.15$ mm	Atterberg limits below A-line	
			SM-2	Fine silty sands		(#100 sieve) $d_{50} < 0.15$ mm		IV
Fine Grained Soils $d_{50} \leq$ No. 200 Mesh (0.074 mm)	Silts and Clays	LL < 50	ML	Silts; rock flour; ash; very fine silty sands; sandy, clayey silts				
			CL-1	Clays of low plasticity; silty clays; sandy, gravelly clays (PI < 15)				V
			CL-2	Clays of medium plasticity; silty, sandy, or gravelly clays (PI ≥ 15)				VI
		LL ≥ 50	CH	Clay of high plasticity; fat clay				VII
			MH	Elastic silts; micaceous and diatomaceous silt				VIII
		Organic	OL	Organic silts and clays	Same as ML	$\frac{\text{LL (oven dry soil)}}{\text{LL (air dry soil)}} < 0.75$		IX
			OH	Organic silts and clays	Same as MH			

Table 4–I5.—**Characteristics of compacted fill materials**

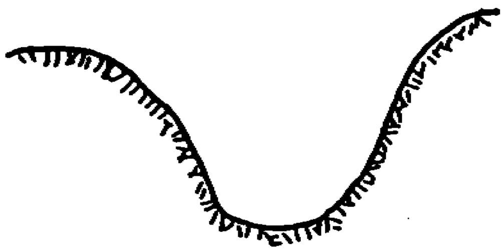
Behavior Group	Relative Resistance to Failure (1) Greatest to (6) Least			Relative Characteristics		
	Shearing	Piping	Cracking	Permeability	Compressibility	Compaction
1	2	3	4	5	6	7
I	1	—	—	High	Very Slight	Good; crawler tractor; steel-wheeled roller.
II	3	3	4	Low	Slight	Fair; sheepsfoot roller; rubber-tired roller.
III	2	5	3	Medium	Slight	Good; rubber-tired roller; sheepsfoot roller.
IV	3	6	6	Medium	Slight to Medium	Good to poor; sheepsfoot roller; close control essential.
V	4	4	5	Low	Medium	Good to fair; sheepsfoot roller; close control essential.
VI	5	2	2	Low	Medium to High	Good to fair; sheepsfoot roller; rubber-tired roller.
VII	6	1	1	Low	High	Fair to poor; sheepsfoot roller.
VIII	6	Variable	Variable	Medium-Low	Very High	Poor to very poor; sheepsfoot roller.
IX	6	Variable	Variable	Medium-Low	Very High	Very poor; not suitable for embankments.

Table 4–I6.—**Characteristics of foundation materials**

Group Symbol	Characteristics Influencing Embankment Design				Seepage Control Requirements
	Shear Strength	Sensitivity to Shock	Compressibility [2]	Permeability	
1	2	3	4	5	6
GW	High	None	Very Slight	High	Positive Cutoff
GP	High	None	Very Slight	High	Positive Cutoff
GM	High	None	Very Slight	Medium-Low	Toe Trench to None
GC	High	None	Slight	Low	None
SW	High	None	Very Slight	High	U.S. Blanket & Toe Drainage; cutoff
SP	Usually High [2]	High for loose fine sand	Very Slight	High	U.S. Blanket & Toe Drainage; cutoff
SM	Usually High [1]	High for loose fine sand	Very Slight	Medium	U.S. Blanket & Toe Drainage; cutoff
SC	High	None	Slight	Low	None
ML	Medium	High for loose silts	Medium	Medium	Toe Trench
CL	Medium	None	Medium	Medium-Low	None
OL	Low	None	High	Low	None
MH	Low	High for loose silts	Very High	Low	None
CH	Medium to Low [2]	None	Usually Very High	Low	None
OH	Low	None	Very High	Low	None
Pt	Very Low	None	Very High	Very High	Remove from foundation

Table 4-17.—Evaluation of site and foundation conditions

Site Classification

Site Configuration[1]	Site Type
 1. Relatively broad gap. 2. Gently sloping abutments.	Type A
 1. Relatively narrow gap. 2. Steep abutments.	Type B

Foundation Classification

General Characteristics[2]		Foundation Type
Compressibility	Permeability[3]	
None to Very Slight	Impervious	1a
	Pervious	1b
Slight	Impervious	2a
	Pervious	2b
Medium	Impervious	3a
	Pervious	3b
High	—	4

Notes:
[1]Determined from topographic survey.
[2]Determined from report of geological investigation and laboratory testing.
[3]Relative to that of the embankment.

Table 4–18.—Selection of basic design type

Site Type	Foundation Type	Type of Embankment Design Required				
		Homog. Section Materials Group	Design Type	Zoned Section Shell	Zoned Section Core	Design Type
	1a	II, V, VI, VII, VIII	1	I, III, IV	II, V, VI, VII, VIII	7 or 8
A	1a	III, IV	4 or 6	I	III, IV	7 or 8
	1b	II, V, VI, VII, VIII	2 or 3	I, III, IV	II, V, VI, VII, VIII	9 or 10
A	1b	III, IV	5	I	III, IV	10
	2a	II, V, VI, VII	1	I, III, IV	II, V, VI, VII	7 or 8
A	2a	III, IV, VIII	4 or 6	I	III, IV, VIII	7 or 8
	2b	II, V, VI, VII	2 or 3	I, III, IV	II, V, VI, VII, VIII	9 or 10
A	2b	III, IV, VIII	5	I	III, IV	10
	3a	V, VI, VII	1, 4 or 6	I, III, IV	V, VI, VIII	7 or 8
A	3a	II, III, IV, VIII	4 or 6	I	II, III, IV, VIII	7 or 8
	3b	V, VI, VII	2 or 3	I, III, IV	V, VI, VII	9 or 10
A	3b	II, III, IV, VIII	5	I	II, III, IV, VIII	10
4		Evaluate from test data on undisturbed samples only!				

Site Type	Foundation Type	Type of Embankment Design Required				
		Homog. Section Materials Group	Design Type	Zoned Section Shell	Zoned Section Core	Design Type
	1a	II, V, VI, VII	1	I, III, IV	II, V, VI, VII	7 or 8
B	1a	III, IV, VIII	4 or 6	I	III, IV, VIII	7 or 8
	1b	II, V, VI, VII	2 or 3	I, III, IV	II, V, VI, VII	9 or 10
B	1b	III, IV, VIII	5 or 6	I	III, IV, VIII	10
	2a	II, VI, VII	1 or 6	I, III, IV, V	II, VI, VII	7 or 8
B	2a	III, IV, V, VI, VIII	4 or 6	I	III, IV, V, VI, VIII	7 or 8
	2b	II, VI, VII	2 or 3	I, III, IV, V	II, VI, VII	9 or 10
B	2b	III, IV, V, VI, VIII	5 or 6	I	III, IV, V, VI, VIII	10
	3a	VI, VII	1, 4 or 6	I, III, IV, V	VI, VII	7 or 8
B	3a	II, III, IV, V	4	I	II, III, IV, V	7 or 8
	3b	VI, VII	2 or 3	I, III, IV, V	VI, VII	9 or 10
B	3b	II, III, IV, V	5	I	II, III, IV, V	10
	4	Evaluate from test data on undisturbed samples only!				

References

Below is a list of references that give additional information on soil engineering.

I. Soil Conservation Service, Soil Mechanics Notes.

SM Note No. I, Guide for determining the gradation of sand and gravel filters.
SM Note No. 2, Light weight piston sampler for soft soils and loose sands.
SM Note No. 3, Soil mechanics considerations for embankment drains.
SM Note No. 4, Preparation and shipment of undisturbed core samples.
SM Note No. 5, Flow net construction and use.
SM Note No. 6, Glossary, symbols, abbreviations, and conversion factors.
SM Note No. 7, The mechanics of seepage analysis.
SM Note No. 8, Soil mechanics testing standards.
SM Note No. 9, Permeability of selected clean sands and gravels.
SM Note No. I0, The static cone penatrometer: the equipment and using the data.
(Additional Soil Mechanics Notes are being prepared. January, I988.)

2. National Engineering Handbooks.

NEH 008, Engineering geology.
NEH 0I8, Ground water geology.

3. Technical Releases.

TR 026, The use of soils containing more than 5 percent rock larger than the no. 4 sieve.
TR 027, Laboratory and field test procedures for control of density and moisture of compacted earth embankments.
TR 028, Clay minerals.
TR 07I, Rock materials field classification procedure.

4. ASTM D–2487, Classification of soils for engineering purposes.

5. ASTM D–2488, Description and identification of soils (visual–manual procedure).

6. Terzaghi and Peck. Soil mechanics in engineering practice.

7. Sowers, George F. Introductory soil mechanics and foundations: geotechnical engineering.

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