CHAPTER

4a

Construction Planning, Equipment, and Methods

Sixth Edition

GEOTECHNICAL MATERIALS, COMPACTION, AND STABILIZATION

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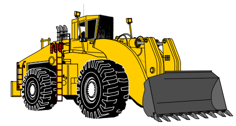

By

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ENCE 420 – Construction Equipment and Methods

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HANDLING OF MATERIALS

The actual construction process of any project is really a material-handling problem.

On heavy construction projects the major portion of the work consists of handling and processing bulk materials.

HANDLING OF MATERIALS

Therefore need:

Knowledge about the physical properties of the material being handled and of the material the machine is operating upon.

HANDLING OF MATERIALS

- Materials are used only temporarily in support of the construction activities
  - ✓ usable forms, scaffolding, shoring, and some access roads.
- Materials such as water for haul roads and fuel will be consumed.

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HANDLING OF MATERIALS

- Other materials will be permanently incorporated into the structure:
  - ✓steel, timber, concrete, asphalt, rock, and soils.
- The contractor must select the proper equipment to locate and/or process materials economically.

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HANDLING OF MATERIALS

- The decision process for matching the best possible machine to the project task requires that the contractor takes into account the following items:
  1. Properties of the material to be handled.
  2. Mechanical capabilities of the machine.

MAKING EQUIPMENT CHOICES

- Two primary material considerations:
  - ✓Total Quantity
  - ✓Size of Individual Pieces

MAKING EQUIPMENT CHOICES

- The quantity of material to be handled and the time constraints resulting from the contract or weather influence the selection of equipment as to the
  - ✓type, size, and number of machines.

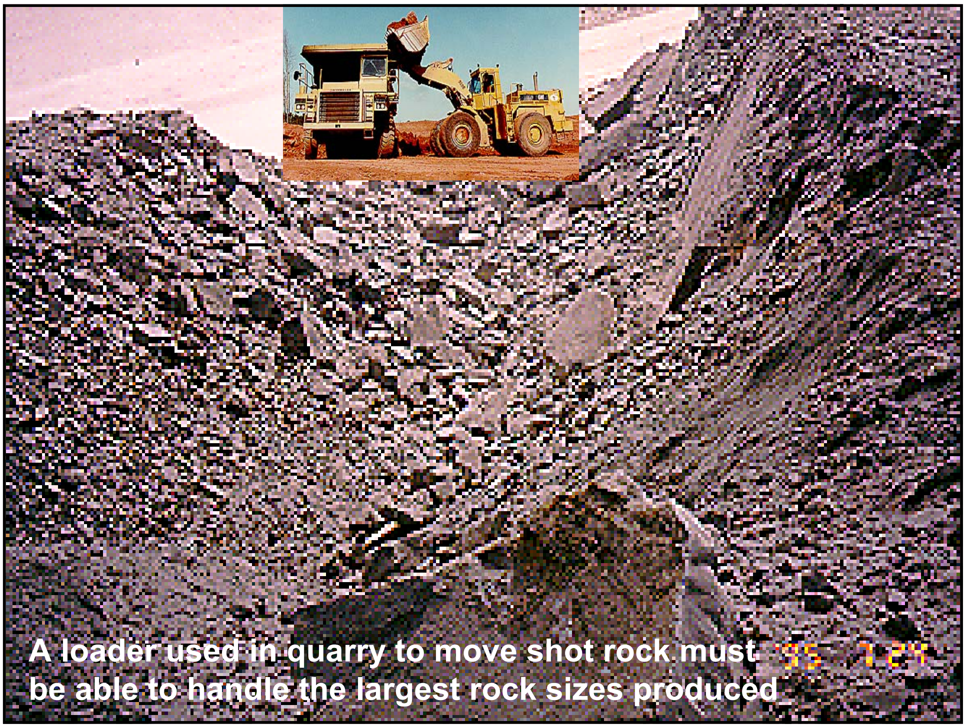
MAKING EQUIPMENT CHOICES

- Larger units generally have lower unit-production cost, but there is a trade-off in higher mobilization and fixed costs.
- The size of the individual material pieces will affect the choice of the machine size.

MAKING EQUIPMENT CHOICES

- Example:

A loader used in quarry to move shot rock must be able to handle the largest rock sizes produced



EXCAVATION

- ***Common Excavation*** **refers to ordinary earth excavation.**
- ***Rock Excavation*** **cannot be done by ordinary earth handling equipment.**
  - ✓ Rock materials must be removed by drilling and blasting or by some other methods.
  - ✓ This normally results in a considerably greater expense than earth excavation.

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EXCAVATION

- ***Muck Excavation*** **includes materials that will decay or produce subsidence in embankments.**
  - ✓ It is usually a soft organic material having a high water content.
  - ✓ Typically, it would include such things as decaying stumps, roots, logs, and humus.
  - ✓ These materials are hard to handle and can present special construction problems both at their point of excavation, and in transportation and disposal.

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EXCAVATION

- ***Unclassified Excavation*** **refers to the materials that cannot be defined as soil or rock.**
  - ✓ The removal of common excavation will not require the use of explosives, although tractors equipped with rippers may be used to loosen consolidated formations.

GLOSSARY OF TERMS

- The following glossary is used to define important terms that are used in discussing geotechnical materials, compaction, and stabilization:

GLOSSARY OF TERMS

- *Aggregate, course*: **Crushed rock or gravel, generally greater than 1/4 in.** in size.
- *Aggregate, fine*: **The sand or fine-crushed stone used for filling voids in coarse aggregate, Generally it is less than 1/4 in, and greater than a No.** 200 sieve in size.

GLOSSARY OF TERMS

- *ASTM*: **American Society for Testing and Materials.**
- *Backfill*: **Material used in refilling a cut or other excavation.**
- *Bank measure*: **A measure of the volume of earth in its natural position before it is excavated.**

GLOSSARY OF TERMS

- *Binder*: **Fine aggregate or other materials that fill voids and hold coarse aggregate together.**
- *Borrow pit*: **A pit from which fill material is mined.**
- *Cohesion*: **The quality of some soil particles to be attracted to like particles, manifested in a tendency to stick together, as in clay.**

GLOSSARY OF TERMS

- *Cohesive materials*: **A soil having properties of cohesion.**
- *Compacted volume*: **A measurement of the volume of a soil after it has been subjected to compaction.**
- *Grain-size curve*: ***A*** **graph showing the percentage by weight of soil sizes contained in a sample.**

GLOSSARY OF TERMS

- *Granular material*: **A soil, such as sand, whose particle sizes and shapes are such that they do not stick together.**
- *Impervious*: **A material that resists the flow of water through it is termed impervious.**

GLOSSARY OF TERMS

- *In situ*: Soil in its original or undisturbed position.
- *Lift*: A layer of soil placed on top of previously placed embankment material. The term can be used in reference to material as spread or as compacted.

GLOSSARY OF TERMS

- *Optimum moisture content*: The water content, for a given compactive effort, at which the greatest density of a soil can be obtained.
- *Pass*: A working passage (trip) of an excavating, grading, or compaction machine.

GLOSSARY OF TERMS

- *Plasticity*: The capability of being molded.
- *Rock*: The hard, mineral matter of the earth's crust, occurring in masses and often requiring blasting to cause breakage before excavation can be accomplished.

GLOSSARY OF TERMS

- *Shrinkage*. A soil volume reduction usually occurring in fine-grained soils when they are subjected to moisture.
- *Soil*. The loose surface material of the earth's crust, created naturally from the disintegration of rocks or decay of vegetation, that can be excavated easily using power equipment in the field.

PROPERTIES OF GEOTECHNICAL MATERIALS

- In analyzing problems involving earth and rock handling techniques, it is necessary to become familiar with some of the physical properties of soils and aggregates.
- The properties affect materials handling, equipment selections, and equipment production rates.

TYPES OF GEOTECHNICAL MATERIALS

- *Homogeneous* material such as steel and concrete are easy to predict their behavior.
- *Heterogeneous* material such as earths are hard to predict their behavior and properties because they are rarely uniform.

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TYPES OF GEOTECHNICAL MATERIALS

- In order to establish properties to geotechnical materials, it is necessary to classify these materials.
- Soils can be classified according to the sizes of their particles, physical properties, and their behavior.

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Generally, the soil types are found in nature in some mixed proportions. Table 4.1 presents a classification system based on combinations of soil types.

TABLE 1 Unified soil classification system

Symbol	Primary	Secondary	Supplementary
GW	Coarse-grained soils	Well-graded gravels, gravel-sand mixtures, little or no fines	Wide range of grain size
GP	Coarse-grained soils	Poorly graded gravels, gravel-sand mixtures, little or no fines	Predominantly one size or a range of intermediate sizes missing
GM	Gravel mixed with fines	Silty gravels and gravel-sand-silt mixtures—may be poorly graded	Predominantly one size or a range of intermediate sizes missing
GC	Gravel mixed with fines	Clayey gravels, gravel-sand-clay mixtures, which may be poorly graded	Plastic fines
SW	Clean sands	Well-graded sands, gravelly sands, little or no fines	Wide range in grain sizes
SP	Clean sands	Poorly graded sands, gravelly sands, little or no fines	Predominantly one size or a range of sizes with some intermediate sizes missing
SM	Sands with fines	Silty sands and sand-silt mixtures, which may be poorly graded	Nonplastic fines or fines of low plasticity
SC	Sands with fines	Clayey sands, sand-clay mixtures, which may be poorly graded	Plastic fines
ML	Fine-grained soils	Inorganic silts, clayey silts, rock flour, silty very fine sands	Plastic fines
CL	Fine-grained soils	Inorganic clays of low to medium plasticity, silty sandy or gravelly clays	Plastic fines
OL	Fine-grained soils	Organic silts and organic silt-clay of low plasticity	
MH	Fine-grained soils	Inorganic silts, clayey silts, elastic silts	
CH	Fine-grained soils	Inorganic clays of high plasticity, fat clays	
OH	Fine-grained soils	Organic clays and silty clays of medium to high plasticity	

TYPES OF GEOTECHNICAL MATERIALS

Symbol classification

COARSE GRAINED MATERIAL
Symbol
G—Gravel grain size from 3″ to No. 4 sieve size
S—Sand grain size from No. 4 to 200 sieve size

Subdivision
W—Well graded, little or no fines
P—Poorly graded, little or no fines
M—Concentration of silty or nonplastic fines
C—Concentration of clay or plastic fines

FINE GRAINED MATERIAL
Symbol
M—Silt very fine grain size, floury appearance
C—Clay finest grain size, high dry strength—plastic
O—Organic matter partly decomposed, appears fibrous, spongy and dark in color

Subdivision
L—Low plastic material, lean soil
H—High plastic material, fat soil

SOILS

- Soils are the principal component of many construction projects.
- Soils are used to support:
  - ✓structures - static load
  - ✓pavements for highways and airport runways - dynamic loads.
  - ✓dams and levees, as impoundment - to resist the passage of water.

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SOILS

- Some soils may be suitable for use in their natural state, whereas other, must be excavated, processed, and compacted in order to serve their purposes.

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SOILS

- Knowledge of the properties, characteristics, and behavior of different soil types is important to those persons who are associated with the design or construction of projects involving the use of soils.

PROPERTIES OF SOILS

- **Soil properties have a direct effect on**
  - ✓the ease or difficulty of handling the material.
  - ✓ the selection of equipment.
  - ✓ production rates.

TYPES OF SOILS

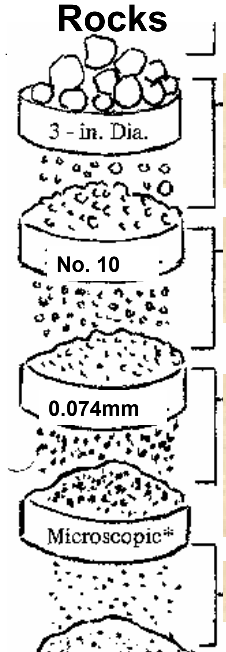
- **Soils may be classified according to:**
  - ✓The sizes of the particles of which they are composed,
  - ✓By their physical properties, or
  - ✓By their behavior when file moisture content varies.

TYPES OF SOILS

- A constructor is concerned primarily with five types of soils:
  - ✓Gravel,
  - ✓Sand,
  - ✓Silt,
  - ✓Clay,
  - ✓Organic matter,and
  - ✓Combinations of these types.

TYPES OF SOIL

Rocks



Gravel
pass 3-in, retained on No. 10

Sand
from lower limit gravel to No. 200

Silt, noncohesive
smaller than 0.074 mm but larger than 0.005 mm

Clay, cohesive

TYPES OF SOILS

- The following size limits represent those set forth by the American Society for Testing and Materials (ASTM):

TYPES OF SOILS

- ***Gravel***: is rounded or semiround particles of rock that will pass a 3-in. and be retained on a 2.0-mm No. 10 sieve. Sizes larger than 10 in. are usually called boulders.

TYPES OF SOILS

- ***Sand***: is disintegrated rock whose particles vary in size from the lower limit of gravel 2.0 mm down to 0.074 mm (No. 200 sieve). It may be classified as coarse or line sand, depending on the sizes of the grains. Sand is a granular noncohesive material.

TYPES OF SOILS

- ***Silt***: is a material finer than sand and thus its particles are smaller than 0.074 mm but larger than 0.005 mm. It is a noncohesive material that has little or no strength. It compacts very poorly.

TYPES OF SOILS

- ***Clay***: is a cohesive material whose particles are less than 0.005 mm. The cohesion between the particles gives a clay high strength when air-dried. Clay can be subject to considerable changes in volume with variations in moisture content. They will exhibit plasticity within a range of "water contents."

TYPES OF SOILS

- ***Organic matter***: is a partly decomposed vegetable matter. It has a spongy unstable structure that will continue to decompose and is chemically reactive.

TYPES OF SOILS

- Soils existing under natural conditions may not contain the relative amounts of desired types to produce the properties required for construction purposes.
- It may be necessary to obtain soils from several sources and then to blend them to use in a fill.

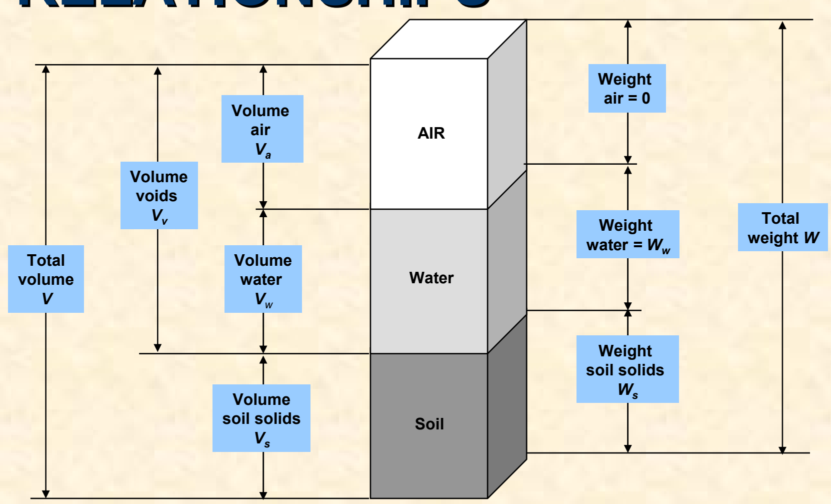
TYPES OF SOILS

- If the material in a borrow pit consists of layers of <u>different types of soils</u> the specifications for the project may require the use of excavating equipment that will dig vertically through the layers in order to mix the soil.

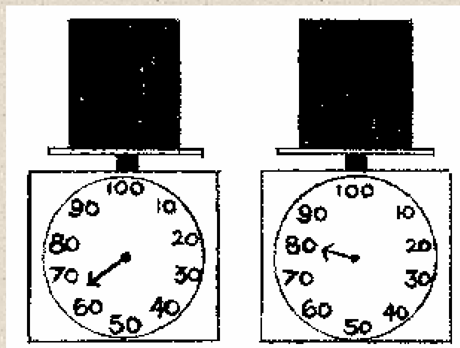
TYPES OF SOILS

- **Rock can be formed by one of the three different means:**
  - ✓Igneous rocks solidifies from molten masses
  - ✓Sedimentary rocks formed in layers settling out of water solutions.
  - ✓Metamorphic rocks are transformed from material of the first two by heat and pressure.

SOIL WEIGHT-VOLUME RELATIONSHIPS



SOIL WEIGHT-VOLUME RELATIONSHIPS



Which material has the greatest unit weight?

SOIL WEIGHT-VOLUME RELATIONSHIPS

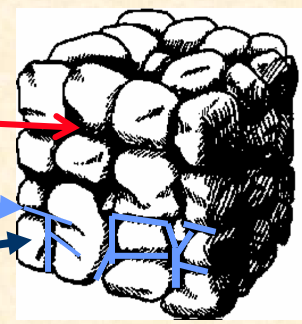
- UNIT WEIGHT

$$\textbf{Unit weight } (\gamma) = \frac{\text{total weight of soil}}{\text{total soil volume}}$$

SOIL WEIGHT-VOLUME RELATIONSHIPS

Total volume includes

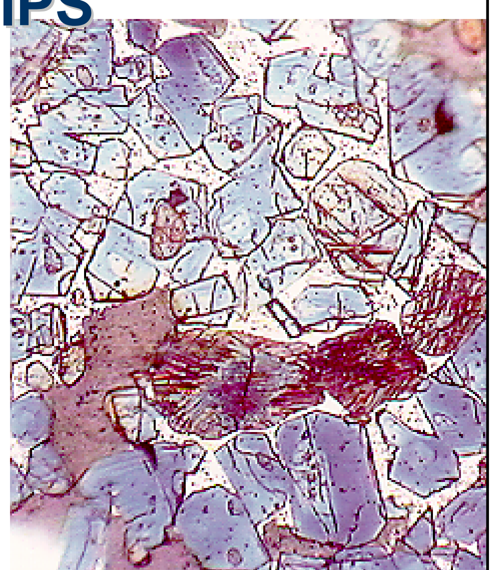
Air
Water
Solids



SOIL WEIGHT-VOLUME RELATIONSHIPS

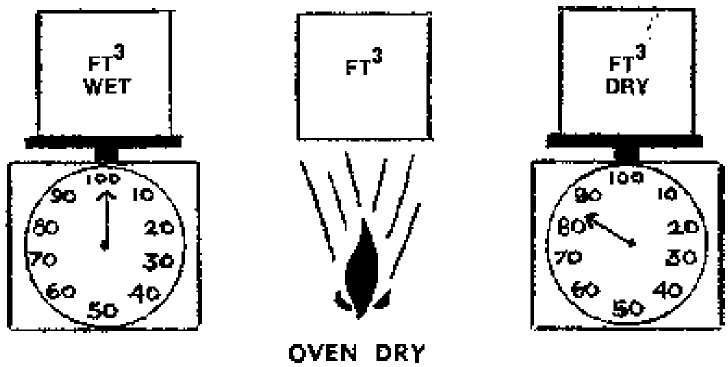
Air, Water and Solids.

That's what it looks like under the microscope.



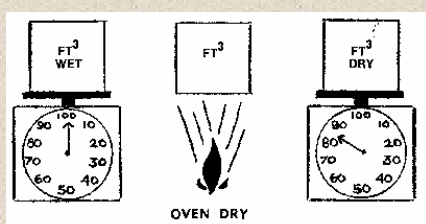
SOIL WEIGHT-VOLUME RELATIONSHIPS

γ drive off the water γ_d



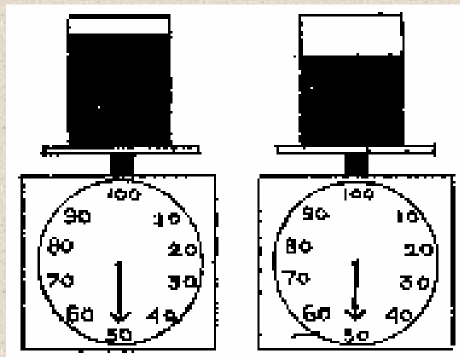
SOIL WEIGHT-VOLUME RELATIONSHIPS

- Water Content:



$$\text{Water content} = \frac{\text{Wet weight} - \text{Dry weight}}{\text{Dry weight}}$$

SOIL WEIGHT-VOLUME RELATIONSHIPS



- Same weight but different volume.

SOIL WEIGHT-VOLUME RELATIONSHIPS

Definitions:

$$\text{Unit Weight } (\gamma) = \frac{\text{total weight of soil}}{\text{total soil volume}} = \frac{W}{V} \quad (1)$$

$$\text{Dry Unit Weight } (\gamma_d) = \frac{\text{weight of soil solids}}{\text{total soil volume}} = \frac{W_s}{V} \quad (2)$$

$$\text{Water Content } (\omega) = \frac{\text{weight of water in soil}}{\text{weight of soil solids}} = \frac{W_w}{W_s} \quad (3)$$

SOIL WEIGHT-VOLUME RELATIONSHIPS

$$\text{Void Ratio } (e) = \frac{\text{volume of voids}}{\text{volume of soil solids}} = \frac{V_v}{V_s} \quad (4)$$

$$\text{Porosity } (n) = \frac{\text{volume of voids}}{\text{total soil volume}} = \frac{V_v}{V} \quad (5)$$

$$\text{Specific Gravity } (G_s) = \frac{\text{weight of soil solids}}{\text{volume of solids}}\left(\frac{1}{\text{unit weight of water}}\right) = \frac{W_s}{V_s}\frac{1}{\gamma_w} \quad (6)$$

$$\text{Degree of Saturation } (S) = \frac{\text{volume of water in voids}}{\text{volume of voids}} = \frac{V_w}{V_v} \quad (7)$$

SOIL WEIGHT-VOLUME RELATIONSHIPS

Other useful relationships can be derived:

$$\text{Void Ratio } (e) = \frac{V_v}{V_s} = \frac{V_v}{V - V_v} = \frac{\left(\frac{V_v}{V}\right)}{1 - \left(\frac{V_v}{V}\right)} = \frac{n}{1-n} \quad (8)$$

$$\text{Porosity } (n) = \frac{e}{1+e} \quad (9)$$

$$\text{Total Volume } (V) = V_v + V_s = V_a + V_w + V_s \quad (10)$$

SOIL WEIGHT-VOLUME RELATIONSHIPS

$$\text{Moist Unit Weight } (\gamma) = \frac{W}{V} = \frac{W_s + W_w}{V} = \frac{W_s\left(1 + \frac{W_w}{W_s}\right)}{V} = \frac{W_s(1+\omega)}{V} \quad \textbf{(11)}$$

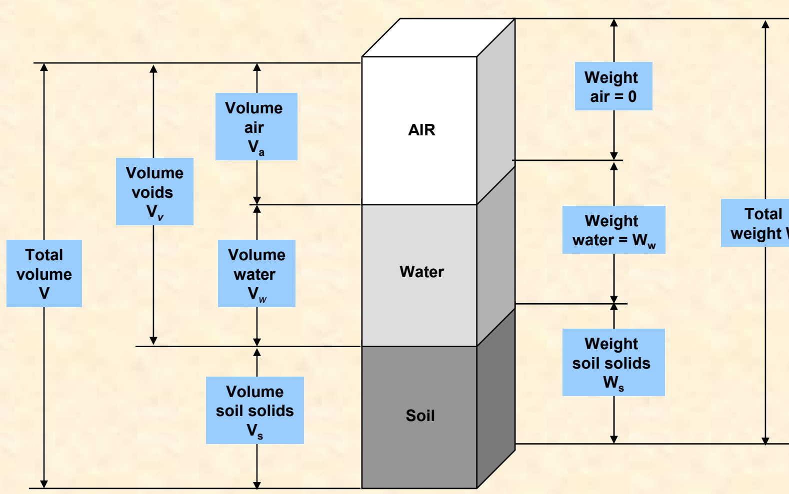
$$\gamma_d = \frac{W_s}{V} \quad \textbf{(12)}$$

From the above two equations:

$$\gamma_d = \frac{\gamma}{1+\omega} \quad \textbf{(13)}$$

$$W_s = \frac{W}{1+\omega} \quad \textbf{(14)}$$

SOIL WEIGHT-VOLUME RELATIONSHIPS



OTHER USEFUL RELATIONSHIPS

Relationships Between Unit Weight, Void Ratio, Moisture Content,and Specific Gravity

$$\gamma = \frac{W_s + W_w}{V} = \frac{G_s\gamma_w + \omega G_s\gamma_w}{1+e} = \frac{G_s\gamma_w(1+\omega)}{1+e} \quad \textbf{(15)}$$

$$\gamma_d = \frac{W_s}{V} = \frac{G_s\gamma_w}{1+e} \quad \textbf{(16)}$$

$$S = \frac{\omega G_s}{e} \quad \textbf{(17)}$$

$$\gamma_{\text{at}} \text{ (saturated unit weigth of soil)} = \frac{\gamma_w(G_s+e)}{1+e} \quad \textbf{(18)}$$

OTHER USEFUL RELATIONSHIPS

Relationships Between Unit Weight, Porosity, and Moisture Content

$$\gamma = \frac{W_s + W_w}{V} = G_s\gamma_w(1-n)(1+\omega) \quad \textbf{(19)}$$

$$\gamma_d = \frac{W_s}{V} = G_s\gamma_w(1-n) \quad \textbf{(20)}$$

$$\gamma_{\text{sat}} = [G_s(1-n)+n]\gamma_w \quad \textbf{(21)}$$

$$\omega = \frac{n}{(1-n)G_s} \quad \textbf{(22)}$$

Example 1

In its natural state, a moist soil has a volume of 0.33 ft^3 and weighs 39.93 lb. The oven dry weight of the soil is 34.54 lb. If G_s = 2.71, calculate the moisture content, moist unit weight, dry unit weight, void ratio, porosity,and degree of saturation.

$$\omega = \frac{W_w}{W_s} = \frac{W - W_s}{W_s} = \frac{39.93 - 34.54}{34.54} = 0.156 = 15.6\%$$

$$\gamma = \frac{W}{V} = \frac{39.93}{0.33} = 121.0 \text{ lb/ft}^3$$

Example 1 (continued)

$$\gamma_d = \frac{W_s}{V} = \frac{34.54}{0.33} = 104.67 \text{ lb/ft}^3$$

$$e = \frac{G_s \gamma_w}{\gamma_d} - 1 = \frac{2.71(62.4)}{104.67} - 1 = 0.62$$

$$n = \frac{e}{1+e} = \frac{0.62}{1+0.62} = 0.38$$

$$S = \frac{\omega G_s}{e} = \frac{0.156(2.71)}{0.62} = 0.682 = 68.2\%$$

Example 2

For a saturated soil, given ω = 40%, G_s = 2.71, determine the saturated and dry unit weights.

$$e = \frac{\omega G_s}{S} = \frac{(0.4)(2.71)}{1} = 1.084$$

Note: $S = 1(100\% \text{ saturation})$

$$\gamma_{\text{sat}} = \frac{(G_s + e)\gamma_{ws}}{1+e} = \frac{(2.7 + 1.084)62.4}{1+1.084} = 113.6 \text{ lb/ft}^3$$

$$\gamma_d = \frac{G_s \gamma_w}{1+e} = \frac{(2.71)(62.4)}{1+1.084} = 81.2 \text{ lb/ft}^3$$

SOIL CONSISTENCY LIMITS

- Certain limits of soil consistency were developed to differentiate between highly plastic, slightly plastic, and nonplastic materials:
  - ✓Liquid Limit (LL)
  - ✓Plastic Limit (PL)
  - ✓Plasticity Index (PI)

SOIL CONSISTENCY LIMITS

- **Liquid limit (LL)**: The water content at which a soil passes from the plastic to the liquid states. High LL values are associated with soils of high compressibility. Typically, *clays* have high LL values; *sandy soils* have low LL value.

SOIL CONSISTENCY LIMITS

- **Plastic limit (LL)**: The water content at which a soil passes from the plastic to the semisolid state. The lowest water content at which a soil can be rolled into 1/8-in. (3.2-mm) diameter thread without crumbling.

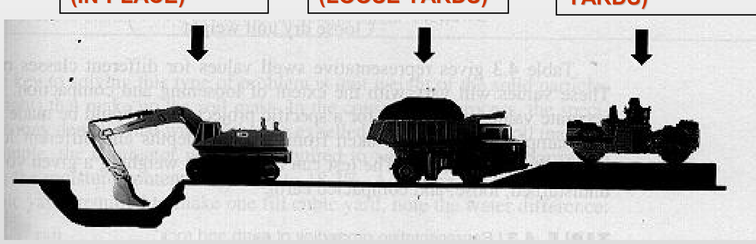
SOIL CONSISTENCY LIMITS

- ***Plasticity index (PI)***: The numerical difference between a soil's liquid limit and its plastic limit is the plasticity index. Soils with high PI values are quite compressible and have high cohesion.

$$PI = LL - PL \qquad (23)$$

VOLUMETRIC MEASURES

1.0 CUBIC YARDS NATURAL CONDITIONS (IN-PLACE) = 1.25 CUBIC YARDS AFTER DIGGING (LOOSE YARDS) = 0.90 CUBIC YARDS AFTER COMPACTION (COMPACTED YARDS)



VOLUMETRIC MEASURES

- For bulk materials volumetric measure varies with the material's position in the construction process.
- The same weight of a material will occupy different volumes as the material is handled on the project.

VOLUMETRIC MEASURES

Soil volume is measured in one of three states:

Bank Cubic Yard (bcy):	1 cu yd of material as it lies in the *natural* state
Loose Cubic Yard (lcy):	1 cu yd of material after it has been disturbed by a loading process
Compacted Cubic Yard (ccy):	1 cu yd of material in the compacted state, also referred to as a net in-place cubic yard

SHRINKAGE AND SWELL FACTORS

$$\text{Shrinkage Factor} = \frac{\text{Compacted Dry Unit Weight}}{\text{Bank Dry Unit Weight}} = \frac{\gamma_{Cd}}{\gamma_{Bd}} \quad (24)$$

$$\text{Shrinkage \%} = \frac{\text{Compacted Unit Weight - Bank Unit Weight}}{\text{Compacted Unit Weight}} \text{X}\,100 \quad (25)$$

$$\text{Swell Factor} = \frac{\text{Loose Dry Unit Weight}}{\text{Bank Dry Unit Weight}} = \frac{\gamma_{Ld}}{\gamma_{Bd}} \quad (26)$$

$$\text{Swell \%} = \left(\frac{\text{Bank Unit Weight}}{\text{Loose Unit Weight}} - 1\right) \text{X}\,100 \quad (27)$$

SWELL VALUES FOR DIFFERENT CLASSES OF EARTH

Table 2

Material	Bank weight lb/cu yd	Bank weight kg/m³	Loose weight lb/cu yd	Loose weight kg/m³	Percent swell	Swell factor
Clay,dry	2,700	1,600	2,000	1,185	35	0.74
Clay, wet	3,000	1,780	2,200	1,305	35	0.74
Earth, dry	2,800	1,660	2,240	1,325	25	0.80
Earth, wet	3,200	1,895	2,580	1,528	25	0.80
Earth and gravel	3,200	1,895	2,600	1,575	20	0.83
Gravel, dry	2,800	1,660	2,490	1,475	12	0.89
Gravel, wet	3,400	2,020	2,980	1,765	14	0.88
Limestone	4,400	2,610	2,750	1,630	60	0.63
Rock, well blasted	4,200	2,490	2,640	1,565	60	0.63
Sand, dry	2,600	1,542	2,260	1,340	15	0.87
Sand, wet	2,700	1,600	2,360	1,400	*15*	0.87
Shale	3,500	2,075	2,480	1,470	40	0.71

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Example 3

An earth fill, when completed, will occupy a net volume of 187,000 cu yd. The borrow material which will be used to construct this fill is a stiff clay. In its "bank" condition, the borrow material has a wet unit weight of 129 lb per cu ft (γ), a moisture content (ω) of 16.5 %, and an in-place void ratio (e) of 0.620. The fill will be constructed in layers of 8-in. depth, loose measure, and compacted to a dry unit weight (γ_d) of 114 lb. per cu ft at a moisture content of 18.3%.

Compute the required volume of the borrow pit excavation.

$$\text{Borrow}: \quad \gamma_d = \frac{\gamma}{1+\omega} = \frac{129}{1+0.165} = 111\ \text{lb/ft}^3$$

$$\text{Fill (given)}: \quad \gamma_d = 114\ \text{lb/ft}^3$$

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Example 3 (continued)

Fill:

$$\text{Volume of Fill } (V_F) = \left(187{,}000\ \text{yard}^3\right)\left(\frac{27\ \text{ft}^3}{1\ \text{yard}^3}\right) = 5{,}049{,}000\ \text{ft}^3$$

$$\text{Weight of Fill } (W_F) = \left(5{,}049{,}000\ \text{ft}^3\right)\left(\frac{114\ \text{lb}}{1\ \text{ft}^3}\right) = 575{,}586{,}000\ \text{lb}$$

Borrow:

$$\text{Weight of Borrow} = V_B\left(\frac{111\ \text{lb}}{\text{ft}^3}\right)$$

Example 3 (continued)

Note: Weight of Fill = Weight of Borrow

Hence:

$$575{,}586{,}000\text{ lb} = V_B\left(\frac{111\text{ lb}}{\text{ft}^3}\right)$$

$$\Rightarrow \text{Volume of Borrow } (V_B) = \frac{575{,}586{,}000\,\cancel{\text{lb}}}{111\,\cancel{\text{lb}}}\text{ft}^3 = 5{,}185{,}460\text{ ft}^3$$

$$= \underline{192{,}054\text{ cu yd}}$$

Alternatively (Simpler Approach):

$$\text{Shrinkage Factor} = \frac{\text{Compacted Dry Unit Weight}}{\text{Bank Dry Unit Weight}} = \frac{114}{111} = 1.03$$

$$\text{Volume of Borrow } (V_B) = (\text{Shrinkage Factor})(\text{Volume of Fill}) = \frac{114}{111}\left(187{,}000\text{ yard}^3\right) = \underline{192{,}054\text{ cu yd}}$$