Atlantic International University

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Masters in Civil Engineering

Course Objectives:

Methods of design and construction of various geotechnical engineering projects utilizing theory of soil mechanics.

Méthodes de conception et de construction de divers projets d'ingénierie géotechnique utilisant la théorie de la mécanique des sols.

Course Description:

Civil Engineering.

ORIGIN OF SOIL

SOIL-WATER RELATIONSHIP

INDEX PROPERTIES OF SOIL

CLASSIFICATION OF SOIL

SOIL STRUCTURE

ORIGIN OF SOIL

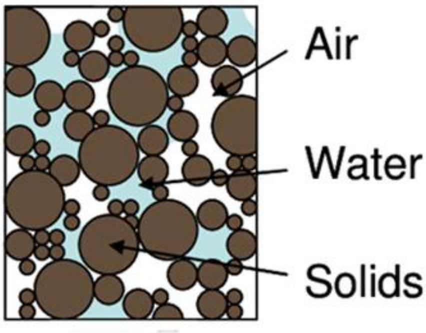
What is the soil ?

Soil is a 3 phase system :

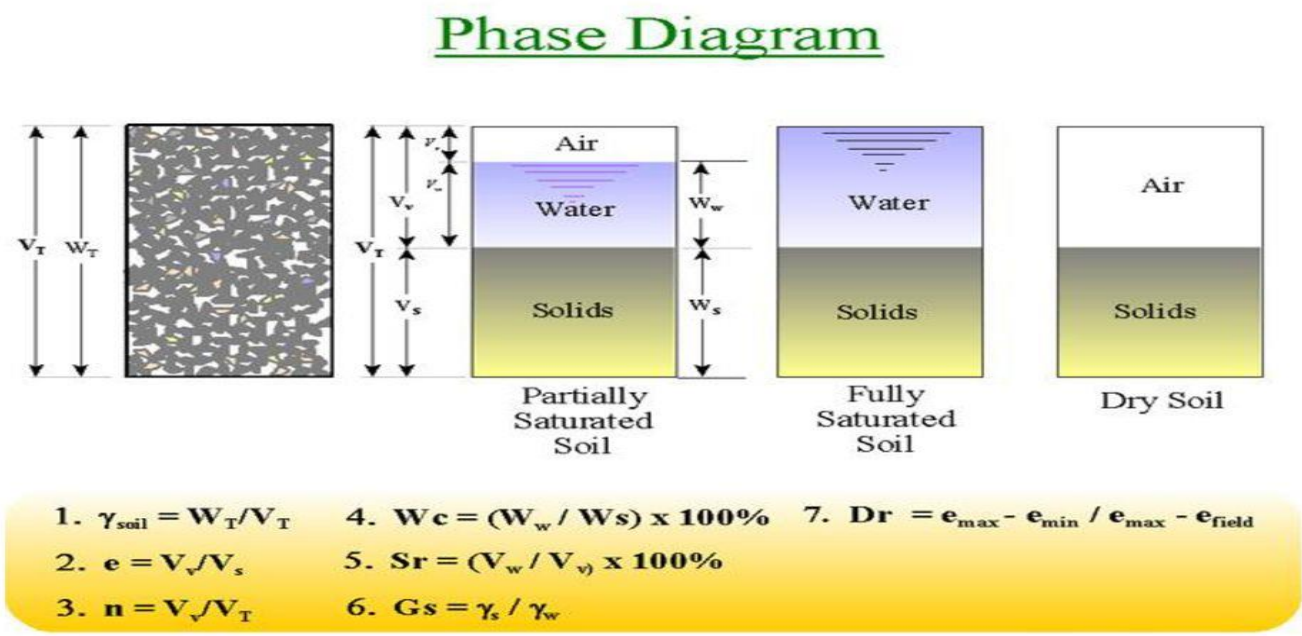
Solide

Water

Air



THERE IS KIND SOIL TWO PHASE SYSTEM

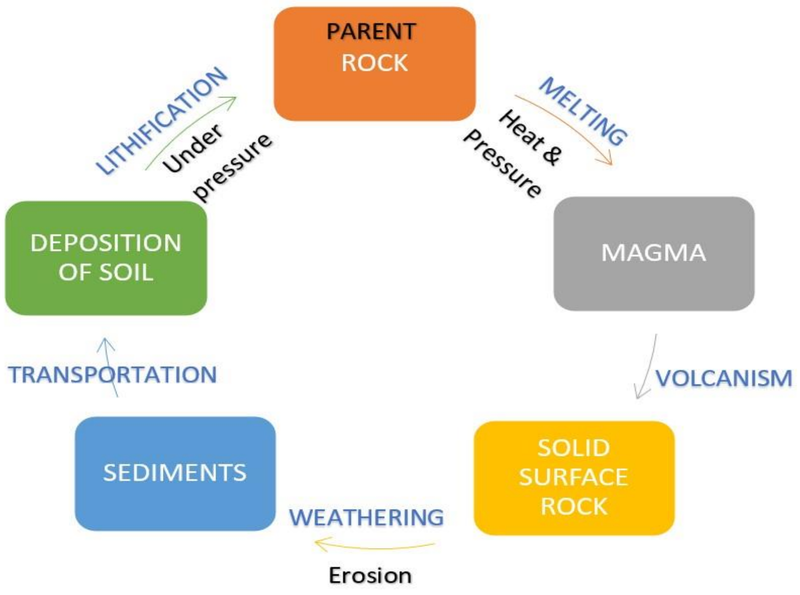


Weathering of rocks

Phisical weathering

Chemical weathering

SOIL FORMATION CYCLE



phisical process

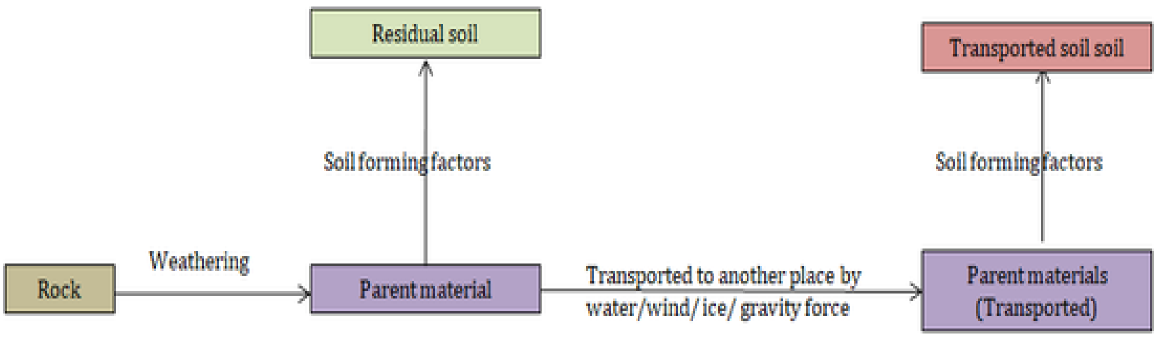
This involves the splitting of the rocks into smaller fragments.the agents of phisical process are temperature,water(rainfall),wind,ice(glaciation).

Chemical processes

Chemical processes lead to change in the chemical composition of rock.it involves the reaction of the rock minerals and others elements.to form another mineral

Biological processes

These processes are associated with the influence of plants ,animals on rock.



Type of soil

Transported soil

Soil is not residing over the parent rock and transported to different place by agents like wind,water,ice etc.

Residual soil

Soil resides over parent rock

Different soils

-ALLUVIAL SOIL	-BENTONITE
-LACUSTRINE SOIL	-LATERITE SOIL
-MARINE SOIL	-RED SOIL
-AEOLIN SOIL	-TUFF SOIL
-GLACIAL SOIL	-BLACK COTTON SOIL
-COLLUVIAL SOIL	-MACK
-LOESS	-PEAT
-MARL	-CUMULOSE
-TUFF SOIL	-GUMBO
	-LOAM

Organic soil contains carbon

Inorganic soil not contains carbon

- Geological Classification

Soil types may be classified on the basis of their geological origin. The origin of a soil may refer either to its constituents or to the agencies responsible for its present status.

Based on constituents, soil may be classified as:

1. Inorganic soil

2. Organic soil

Based on the agencies responsible for their present state, soils may be classified under following types:

- Residual Soils
- Transported Soils:
- Alluvial or sedimentary soils
- Aeolian soils
- Glacial soils
- Lacustrine soils
- Marine soils

Over the geological cycle, soils are formed by disintegration and weathering of rocks. These are again formed by compaction and cementation by heat and pressure.

Classification by Structure

Depending upon the average grain-size and the conditions under which soils are formed and deposited in their natural state, they may be categorized into following types on the basis of their structure:

- Soils of single-grained structure
- Soils of honey-comb structure
- Soils of flocculent structure

Classification based on grain-size

In the grain-size classification, soils are designated according to the grain-size or particle-size. Terms such as gravel, sand, silt and clay are used to indicate certain ranges of grain-sizes. Since natural soils are mixtures of all particle-sizes, it is preferable call these fractions as sand size, silt size, etc. A number of gain-size classifications have been evolved, but the commonly used ones are:

- S. Bureau of Soils and Public Roads Administration (PRA) System of U.S.A.
- International Classification, propsed at the International Soil Congress at Washington, D.C., in 1927
- Massachusetts Institute of Technology (MIT) System of Classification of U.S.A.
- Indian Standard Classification (IS: 1498-1970)

Unified soil classification system

This system was originally developed by A. Cassagrande and adopted by the U.S. Corps of Engineers in 1942 as ‘Airfield Classification’. It was later revised for universal use and redesignated as the “Unified Soil Classification” in 1957.

In this system soils are classified into three broad categories:

- Coarse-grained soils with up to 50% passing No. 200 ASTM Sieve
- Fine-grained soils with more than 50% pass No. passing No. 200 ASTM Sieve
- Organic soils

Preliminary Classification by soil types

Familiarity with common soil types is necessary for an understanding of the fundamentals of soil behaviour. In this approach, soils are described by designation such as Boulders, Gravel, Sand, Silt, Clay, Rockflour, Peat, China Clay, Fill, Bentonite, Black Cotton soil, Boulder Clay, Caliche, Hardpan, Laterite, Loam, Loess, Marl, Moorum, Topsoil and Varved Clay.

Terminology of different types of soil

A geotechnical engineer should be well versed with the nomenclature and terminology of different types of soils. The following list gives the names and salient features of different types of soil, arranged in alphabetical order.

- **Bentonite:** It is a type of clay with a very high percentage of clay mineral – montmorillonite. It is a highly plastic clay, resulting from the decomposition of volcanic ash. It is highly water absorbent and has high shrinkage and swelling characteristics.
- **Black cotton soil:** It is a residual soil containing a high percentage of the clay mineral – montmorillonite. It has very low bearing capacity and high swelling and shrinkage properties.
- **Boulders:** Boulders are the rock fragments of large size, more than 300mm in size.
- **Calcareous soil:** This type of soil contains a large quantity of calcium carbonate. Such soils effervesce when tested with weak hydrochloric acid.
- **Caliche:** It is a type of soil which contains gravel, sand and silt. The particles are cemented by calcium carbonate.
- **Clay:** It consists of microscopic and sub-microscopic particles derived from the chemical decomposition of rocks. It contains a large quantity of clay mineral. It can be made plastic by adjusting the water content. It exhibits considerable strength when dry. Clay is a fine-grained soil. It is a cohesive soil. The particle size is less than 0.002mm.
  Organic clay contains finely divided organic matter and is usually dark grey or black in colour. It has a conspicuous odour. Organic clay is highly compressible and its strength is very high when dry.
- **Cobbles:** Cobbles are large size particles in the range of 80mm to 300mm.
- **Diatomaceous earth:** Diatoms are minute unicellular marine organisms. Diatomaceous earth is a fine, light grey, soft sedimentary deposit of the silicious remains of skeletons of diatoms.
- **Dispersive clays:** These are special type of clays which defloculate in still water. Such soils erode if exposed to low-velocity water. Susceptibility to dispersion depends upon the cations in the soil pore water.
- **Dune sands:** These are wind-transported soils. These are composed of relatively uniform particles of fine to medium sand.
- **Expansive clays:** These are prone to large volume changes as the water content is changed. These soils contain the mineral montmorillonite.
- **Fills:** All manmade deposits of soil and waste-materials are called fills. These are the soil embankments raised above the ground surface. Engineering properties of fills depend upon the type of soil, its water content and the degree of compaction.
- **Gravel:** It is a type of coarse-grained soil. The particle size ranges from 4.75mm to 80mm. It is a cohesion-less material.
- **Hardpans:** H8ardpans are the types of soil that offer great resistance to the penetration of drilling tools during soil exploration. The soils are designated hardpans regardless of their particle size. These are generally dense, well-graded, cohesive aggregates of mineral particles. Hardpans do not disintegrate when submerged in water.
- **Humus:** It is a dark brown, organic amorphous earth of the topsoil. It consists of partly decomposed vegetal matter. It is not suitable for engineering works.

- **Kankar:** It is an impure form of lime stone. It contains calcium carbonate mixed with some silicious material.
- **Laterites:** Laterites are residual soils formed in tropical regions. Laterites are very soft when freshly cut but become hard after long exposure. Hardness is due to cementing action of iron oxide and aluminium oxide. These soils are also called lateritic soils.
- **Loam:** It is a mixture of sand, silt and clay. The term is generally used in agronomy. The soil is well suited to tilling operations.
- **Loess:** It is a windblown deposit of silt. It is generally of uniform gradation, with the particle size between 0.01 and 0.05 mm. It consists of quartz and feldspar particles, cemented with calcium carbonate or iron oxide. When wet, it becomes soft and compressible because cementing action is lost. A loess deposit has a loose structure with numerous root holes which produce vertical cleavage. The permeability in the vertical direction is generally much greater than that in the horizontal direction.
- **Marl:** It is a stiff, marine calcareous clay of greenish colour.
- **Moorum:** The word moorum is derived from a Tamil word, meaning powdered rock. It consists of small pieces ofdisintegrated rock or shale, with or without boulders.
- **Muck:** It denotes a mixture of fine soil particles and highly decomposed organic matter. It is black in colour and of extremely soft consistency. It cannot be used for engineering works. The organic matter is in an advanced stage of decomposition.
- **Peat:** It is a type of organic soil having fibrous aggregates of macroscopic and microscopic particles. It is formed from vegetal matter under conditions of excess moisture, such as in swamps. It is highly compressible and not suitable for foundations.
- **Sand:** It is a coarse-grained soil, having particle size between 0.075 mm to 4.75 mm. The particles are visible to naked eye. The soil is cohesionless and pervious.
- **Silt:** It is a fine-grained soil, having particle size between 0.002 mm and 0.075 mm. The particles are not visible to naked eyes. Inorganic silt consists of bulky, equidimensional grains of quartz. It has little or no plasticity, and is cohesionless. Organic silt contains an admixture of organic matter. It is a plastic soil and is cohesive.
- **Till:** It is a type of soil formed by an unstratified deposit resulting from melting of a glacier. The deposit consists of particles of different sizes, ranging from boulders to clay. The soil is generally well-graded. It can be easily densified by compaction. Till is known as boulder-clay.
- **Top soils:** Top soils are the surface soils that support plants. They contain a large quantity of organic matter and are not suitable for foundations.
- **Tuff:** It is a fine-grained soil composed of very small particles ejected from volcanoes during its explosion and deposited by wind or water.
- **Tundra:** It is a mat of peat and shrubby vegetation that covers clayey subsoil in arctic regions. The deeper layers are permanently frozen and are called permafrost. The surface deposit is the active layer which alternately freezes and thaws.
- **Varved clays**: These are sedimentary deposits consisting of alternate thin layers of silt and clay. The thickness of each layer seldom exceeds 1 cm. These clays are the results of deposition in lakes during periods of alternately high and low waters.

SOIL-WATER RELATIONSHIP

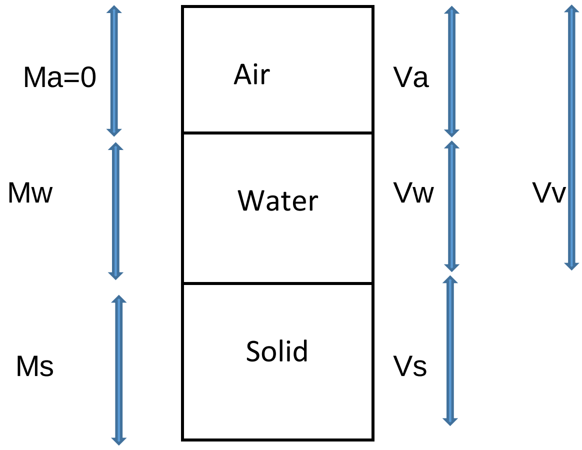
Soil definition

.soil may be defined as three phase system consisting of solid,water and air wich are intermixed with each other and whose relative proportion decides the property of soil.

Three phase system

M(masse)weight(W)

Volume



For inorganic soil

density

ƒ= 2650kg /m3

Water

ƒ= 1000kg/m3

Air

ƒ= 1.2kg/m3

volume

V= Vv+Vs =Va+Vw+Vs

Masse

M=Mv+Ms=Mw+Ms

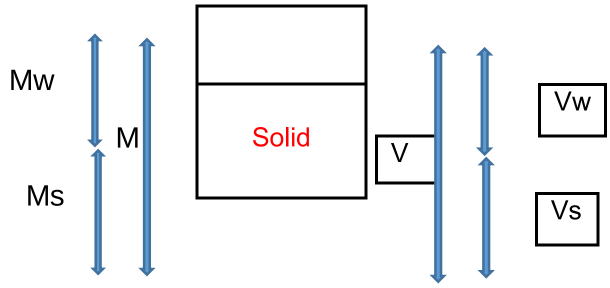
M(masse)W(weight)

M= ƒ.V

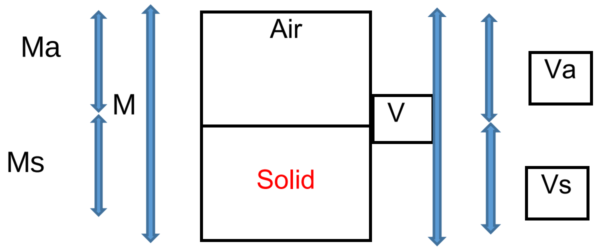
W=M.g

Two phase system

Satured soil



Dry soil



Satured soil

Mv=Mw

M=Mw+Ms

Vv=Vw

V=Vw+Vs

Dry soil

Mv=Ma

M=Ma+Ms

Vv=Va

V=Va+Vs

Water content /moisture content /%Moisture

-it is defined as amount of water present in given volume of soil .ω.ɣ.t that of solids.

Range

W=0 dry soil

Thers no upper limit

W ≥ 0

$$\omega\% == \frac{\frac{\text{masse}}{\text{weight of water}}}{\frac{\text{masse}}{\text{weight of solid}}}$$

=Mw/Ms or Ww/Ws

APPARENTE WATER CONTENT

Amount of water present in the soil for given volume of sample

$$\omega' = \frac{\frac{\text{masse}}{\text{weight of water}}}{\frac{\text{masse}}{\text{weight of soil}}} = \frac{Mw}{\mathrm{M}} = \frac{Ww}{\mathrm{W}}$$

Range $0 \leq \omega' \leq 1$

RELATION BETWEEN ω AND ω'

$$\omega' = \frac{Ww}{\mathrm{W}} = \frac{Ww}{\mathrm{Ws+Ww}} \times \frac{Ws}{\mathrm{Ws}} = \frac{Ww/Ws}{\mathrm{Ws/Ws+Ww/Ws}}$$

$$\boxed{\omega' = \frac{W}{1+\mathrm{W}}}$$

$\leftrightarrow \omega'(1+W)=W$

$\omega'+\omega'W=W$

$\omega'=W-\omega'W$

$\omega'=W(1-\omega')$

$$\boxed{W = \frac{w'}{(1-\mathrm{w}')}}$$

W=Ws+Ww = Ws(1+Ww/Ws)

$$\boxed{W=Ws(1+w)}$$

$$1+W = 1 + \frac{W'}{1-\mathrm{W}'}$$

$$1+W = \frac{1-W'+W'}{1-\mathrm{W}'}$$

$$\boxed{1+W = \frac{1}{1-\mathrm{W}'}}$$

Wich are more theoretical significance ?

$$\omega = \frac{Ww}{\mathrm{Ws}}$$

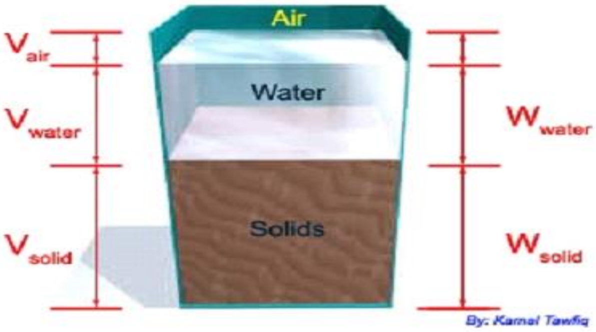
$$\omega' = \frac{Ww}{\mathrm{W}}$$

If water is added or removed from the system,Ws and W will change but Ws will be constant,so W will be more stable parameter as any change in water will indicate change in water content.

Wich are more pratical significance ?

Ws in field is difficult to determine, ω' is obtained in the field

Thephysicalstateofasoilsample



TotalVolume=$V_T = V_s + V_w + V_a$

TotalWeight=$W_T = W_s + W_w$

Porosity (n): is the ratio of void volume.

$$\mathbf{n = V_v/V_T}$$

Void Ratio (e):is the ratio of void volume to solid volume. $e = \frac{Vv}{Vs}$

now $\mathbf{n = V_v/V_T = V_v/\ V_v + V_s} = \frac{V_v/V_s}{V_v/V_s + 1} = \frac{e}{e+1}$

Note also that:

$$\mathbf{e = n / (1 - n)}$$
$$\mathbf{v = 1 / (1 - n)}$$

Note:

? ***n < 1 and is expressed as %***

? ***e may be any value greater or smaller than unity.***

Example: A soil and a void ratio of 0.872. What is the **volume of solids** of the sample?

$$e = \frac{V_v}{V_s} = \frac{V - V_s}{V_s}$$

$250 - V_s = 0.872 V_s$

$250 = 1.872\ V_s$

$V_s = 133.55$ ml

Range **e >0**

e ≠0 **Ther is no upper limit**

If e =0 ,Vv=0 is the rock, then the rock is not the soil

Degree saturation of (s):is the ratio of water volume to void volume.

$S_r = V_w/V_v$

if *S = 0* *dry soil (Vw = 0)*

S=100 *saturated soil* ($V_w = V_v$)

0 < S < 1? the soil is partially sat.

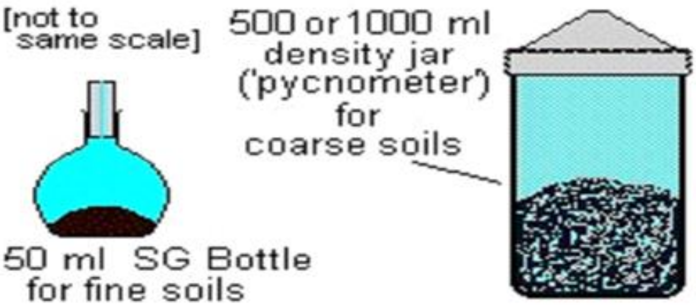
Water Content (w):is the ratio of water weight in a soil sample to the solids weight.

$$w_c = W_w / W_s$$

Specific gravity (GS): specific gravity of *soil solids* of a soil is defined as the ratio of the density of a given volume of the solids to the density of any equal volume of water at 4 ºC.

$$G_S = \frac{\text{mass of a soil grain}}{\text{mass of an equal volume of water}}$$

$$G_s = \frac{\gamma_s}{\rho_w} = \frac{M_s / V_s}{\rho_w} = \frac{M_s}{V_s \rho_w}$$



Air Content (A):is the ratio of air volume to total volume.

The **air-voids volume, V_a**, is that part of the void space not occupied by water(is the ratio of air volume to total volume).

$A_v = V_a / V$

$V_a = V_v - V_w$

$= e - e.S_r$

$= e.(1 - S_r)$

Air-voids content, A_v

A_v = (air-voids volume) / (total volume)

$= V_a / V$

$= e.(1 - S_r) / (1+e)$

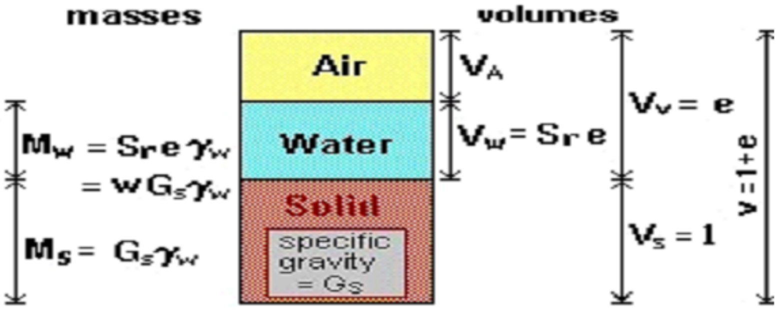
$= n.(1 - S_r)$

For a perfectly *dry* soil: $A_v = n$

For a *saturated* soil: $A_v = 0$

e in term of V, Ws, Gs

$$e=\frac{V_v}{V_s}=\frac{V-V_s}{V_s}=\frac{V}{V_s}-1=\frac{V}{\frac{W_s}{G_s\gamma_w}}-1=\frac{G_s\gamma_w V}{W_s}-1$$



Bulk (Total)density (ρt)and Dry density (ρ_d):

$$\text{Dry density, } \rho_d = \frac{\text{Mass of solids}}{\text{Total volume}} = \frac{M_S}{V} = \frac{G_s\rho_w}{1+e}$$

$$\text{Bulk density, } \rho = \frac{\text{Total mass}}{\text{Total volume}} = \frac{M_S + M_w}{V} = \frac{G_s\rho_w + S_r e\rho_w}{1+e}$$

Bulk (Total)unit weight (γt)and Dry Unit weight (γ_d):

$$\text{Dry unit weight, } \gamma_d = \frac{\text{Dry weight}}{\text{Total volume}} = \frac{W_s}{V} = \frac{G_s\gamma_w}{1+e} = 9.81\ \rho_d$$

$$\text{Unit weight, } \gamma = \frac{\text{Total weight}}{\text{Total volume}} = \frac{W_s + W_w}{V} = \frac{G_s\gamma_w + S_r e\gamma_w}{1+e} = 9.81\ \rho$$

Saturated Unit weight (γ_s):for sat .soil S= 100% =1

$$\gamma_s = \frac{e+G_s}{1+e}\gamma_w$$

submerged unit weight γ' (or **buoyant unit**

$$\gamma' = \gamma_t - \gamma_w = \frac{G_s + Se}{1+e}\gamma_w - \gamma_w = \frac{G_s - 1 - e(1-S)}{1+e}\gamma_w \text{ (for **partially saturated**)} \quad (2.11)$$

$$\gamma' = \gamma_t - \gamma_w = \frac{G_s + e}{1+e}\gamma_w - \gamma_w = \frac{G_s - 1}{1+e}\gamma_w \text{ (for **fully saturated**)} \quad (2.12)$$

Bulk in the means natural condition

1)satured soil has the bulk unit weight of 18kN/m3

2)dry soil has bulk unit weight of 16KN /m3

Satured soil has dry density of 17 KN /m3

Unit Weight of soil

the range of 26.0 to 27.0 kN/m3 or 165 to 172 lb/ft3. The total unit weight of a soil (the solidswater-air system), denoted g, is the ratio of the total weight to the total volume occupied:

$$\gamma = \frac{W}{V} = \frac{W_s + W_w}{V_s + V_w + V_a}$$

The saturated unit weight, denoted g sat, is the total unit weight that would be obtained if the air voids were lled with an equal volume of water (S = 100% and Vw = V). The dry unit weight, denoted g d, is often termed the dry density and has particular importance in eld control of soil compaction. It is the ratio of the weight of solids to the total volume:

$$\gamma_d = \frac{W_s}{V} = \frac{W_s}{V_s + V_w + V_a}$$

Note that the dry unit weight matches the weight of a single component the solids with the entire volume of solids, water, and air. It does not represent the unit weight of any component or consistent set of components, but rather provides a measure of how much solid material by weight is in the total volume of a container, such as an earthmover or a compaction mold. The buoyant unit weight or e ective unit weight, Y', is equal to the saturated unit weight minus the unit weight of water, Yw:

$$\gamma' = \gamma_{sat} - \gamma_w$$

The buoyant unit weight is sometimes used to directly calculate vertical e ective stresses below the water table instead of calculating total stresses and subtracting pore pressures.

Related Posts

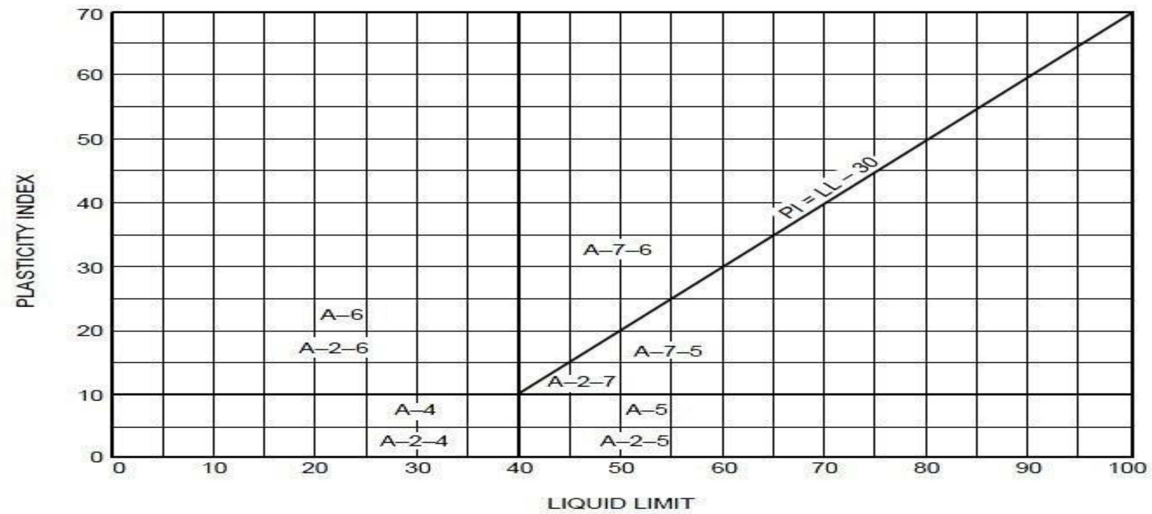


FIGURE 15.3 Plasticity chart for AASHTO Classification System. (From *Standard Specification for Transportation Materials and Methods of Sampling and Testing.* Copyright 1990 by the American Association of State Highway and Transportation Officials, Washington, D.C. Used by permission.)

[AASHTO Classi cation System Examples]

[Weight and Mass Relationships of soil]

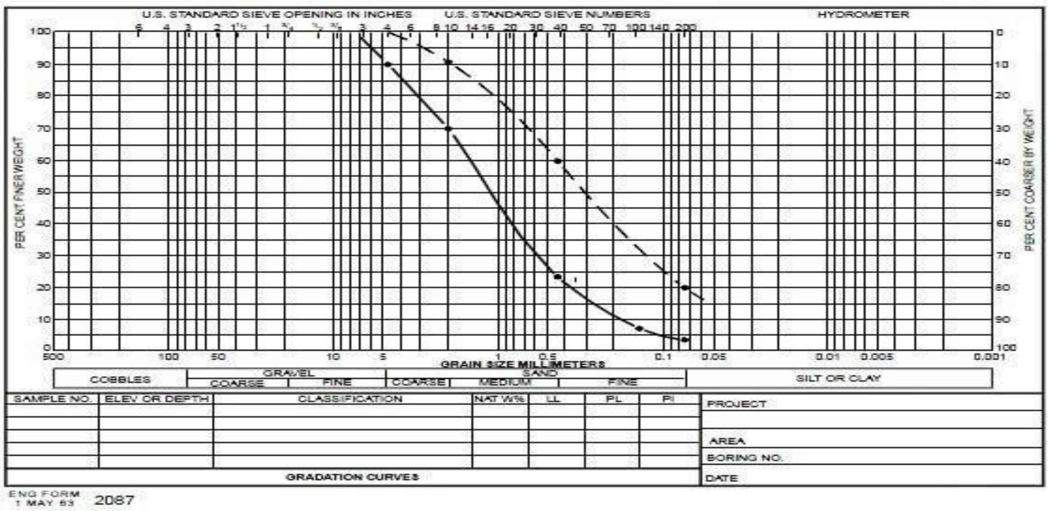


FIGURE 15.1 Typical grain size distribution curves. (From U.S. Army, 1970.)

[Atterberg Limits and Plasticity]

$$\gamma_s = G_s \gamma_w$$

$$\rho_s = G_s \rho_w$$

TRUE/ABSOLUTE SPECIFIC GRAVITY

It is th ratio of the weight of a solid of given volume to the weight of a standard fluid(water) of the same volume . it is the specific gravity of a solid. It is represent as (G).

G/GS= $= \frac{Weight\ of\ solid\ given\ soil}{\text{weight of standard fluid of same volume}}$

Standard fluid=water

G/GS= $\frac{Ws}{\text{Ww}}$

(V=Vw)

G/GS= $\frac{Ws}{\text{Ww}} = \frac{Ws.Vs}{\text{Ww.Vs}}$

G/GS= $(\frac{Ws}{\text{Vs}})\ (\frac{Vw}{\text{Ww}})$

G/GS= $(\frac{ɣs}{ɣw})\ (\frac{\rho w}{\rho w})$

-It is the ratio of unit weight of a solid(ɣs) to th unit weight of water(ɣw)

-It is the ratio of unit densityof a solid(ρs) to th unit density of water(ρw)

MASS/BULK APPARENT SPECIFIC GRAVITY

It is th ratio of the weight of a soil of given volume to the weight of a standard fluid(water) of the same volume . it is the specific gravity of a soil. It is represent as (Gm).

Gm= $= \dfrac{Weight\ of\ soil\ given\ soil}{\text{weight of standard fluid of same volume}}$

Standard fluid=water

Gm=$\dfrac{W}{\text{Ww}}$

(V=Vw)

Gm=$\dfrac{W}{\text{Ww}}=\dfrac{W.V}{\text{Ww.V}}$

Gm=($\dfrac{W}{\text{V}}$) ($\dfrac{Vw}{\text{Ww}}$)

Gm=($\dfrac{\text{ɣ}}{\text{ɣw}}$) ($\dfrac{\rho w}{\text{ρw}}$)

-It is the ratio of unit weight of a soil(ɣs) to th unit weight of water(ɣw)

-It is the ratio of unit densityof a soil(ρs) to th unit density of water(ρw)

Importante note

Density Index

The term density index ID or relative density or degree of density is used to express the relative compactness (or degree of compaction) of a natural cohesionless soil deposit.

The density index is defined as the ratio of the difference between the voids ratio of the soil in its loosest state emax and its natural voids ratio e to the difference between the voids ratios in the loosest and densest states:

$$I_D=e_{max}-ee_{max}-e_{min}.(1)$$

where

e_{max} = voids ratio in the loosest state

e_{min} = voids ratio in the densest state

e = natural voids ratio of the deposit.

This term is used for cohesionless soil only. This term is not applicable to cohesive soil because of uncertaintities in the laboratory determination of the voids ratio in the loosest state of the soil (e_{max}). When the natural state of the cohesionless soil is in its loosest form,

$e = e_{max}$ and hence ID = 0.

When the natural deposit is in its densest state, $e = e_{min}$ and hence ID = 1.

For any intermediate state, the density index varies between zero and one.

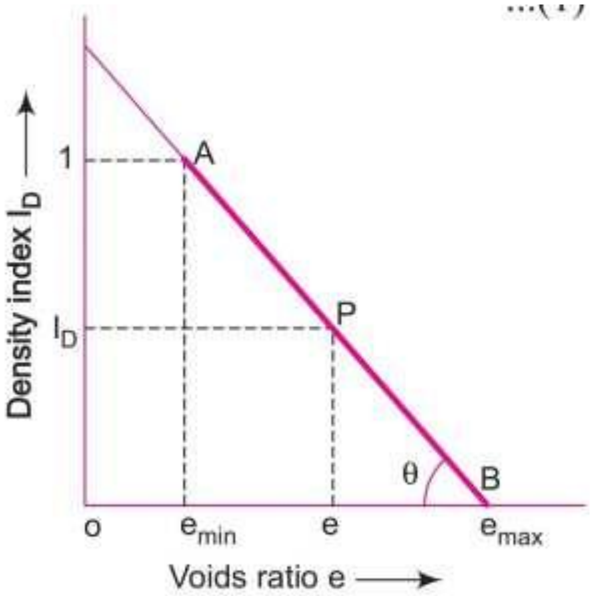
Equation 1, defining density index, can be easily derived by noting the fact that the density index is a function of voids ratio expressed by:

ID = f (e) …(i)

Relationship between density index and void ratio relationship

This relationship between ID and e may be represented graphically, as shown in fig.

…(i)



Learn Density Index, relative compaction, density index and void ratio relationship,charectristics of granular soils in dense and loose states,Relative density

The slope of the straight line AB, representing the relationship between ID and e is given by

$$\tan\theta = 1 e_{max} - e_{min}$$

$$\cot\theta = (e_{max} - e_{min}) \ldots (ii)$$

Now, for an intermediate value e we have,

$(e_{max} – e)$ = ID cotθ or

$$ID = e_{max} - e \cot\theta \ldots (iii)$$

Substituting the value of cotθ from equation ii, we get

$$I_D = e_{max} - e e_{max} - e_{min}$$

From fig., we observe that when e = e_{max}, ID = 0 and when e = e_{min}, ID = 1. Now from equation, we have

$$e = G\gamma_w \gamma_d - 1$$

$$e_{max} = G\gamma_w \gamma_{d,min} - 1$$

$$e_{min} = G\gamma_w \gamma_{d,max} - 1$$

$$[I_D = \gamma_d - \gamma_{d,min} \gamma_{d,max} - \gamma_{d,min}][\gamma_{dmax} \gamma_d]$$

The above equation gives density index in terms of densities.
Density index is also expressed in terms of porosity as follows.

$$I_d = (n_{max} - n)(1 - n_{min})(n_{max} - n_{min})(1 - n)$$

where,
Ɣd = in-situ dry density;

η = in-situ porosity.
Ɣd, max = maximum dry density or dry density corresponding to most compact state.
Ɣd, min = minimum dry dnsity or dry density corresponding to most loosest state.
ηmax = maximum porosity at loosest state;
ηmin = minimum porosity at densest state.

Charactristics of granular soils in dense and loose states

gives the maximum and minimum voids ratio, porosity and dry unit weight of some typical granular soils.

[table id = 10\]

Relative density

gives the characteristics of density of granular soils on the basis of relative density.

[table id=11 /]

Relative Compaction (RC)

Degree of compaction is also sometimes expressed in terms of an index called relative compaction (RC) defined as follows:

$$R_C = \gamma_d \gamma_{damas}$$

where,

Ɣd,max is the maximum dry density from compaction test.

In recent years, the use of the above index has become a generally accepted practice for judging the measure of compaction of both coarse-grained as well as cohesive soils. Since Ɣd = Ɣs (1 + e),in general, we have

$$R_C = 1 + e_{min} 1 + e$$

Relative compaction (RC) can also be expressed in terms of relative density (ID) as follows

$$R_C = R_0 1 - I_D (1 - R_0$$

where,

$$R_0 = Y_{d,min} Y_{d,max}$$

and RC and ID are in fraction form.

Lee and Singh (1971) give the following approximate relation between RC and ID

RC = 80 + 0.2 ID

(where both RC and ID are in percent form) When the soil is in looset form, ID = 0, which gives minimum value of RC as 80% from equation . When the soil is in densest form, ID = 100% corresponding to which RC = 100% from equation Thus, relative compaction varies from 80% to 100% according to equation.

Higher the relative density, denser is the soil mass. Table-2 below shows different state of compactness of soil with respect to relative density.

Table.2. Soil Classification based on Relative Density

Relative Density	State of Compactness
0-15	Very loose
15-35	Loose
35-65	Medium Dense
65-85	Dense
85-100	Very Dense

Exercice with solution

Example 1: Determine unit weights, water content, based on known volume and weight (English units)

Given: (English units)

- Volume of soil mass: 1 ft^3.
- Weight of soil mass at moist condition: 100 lbs
- Weight of soil after dried in oven: 80 lbs

Requirements:

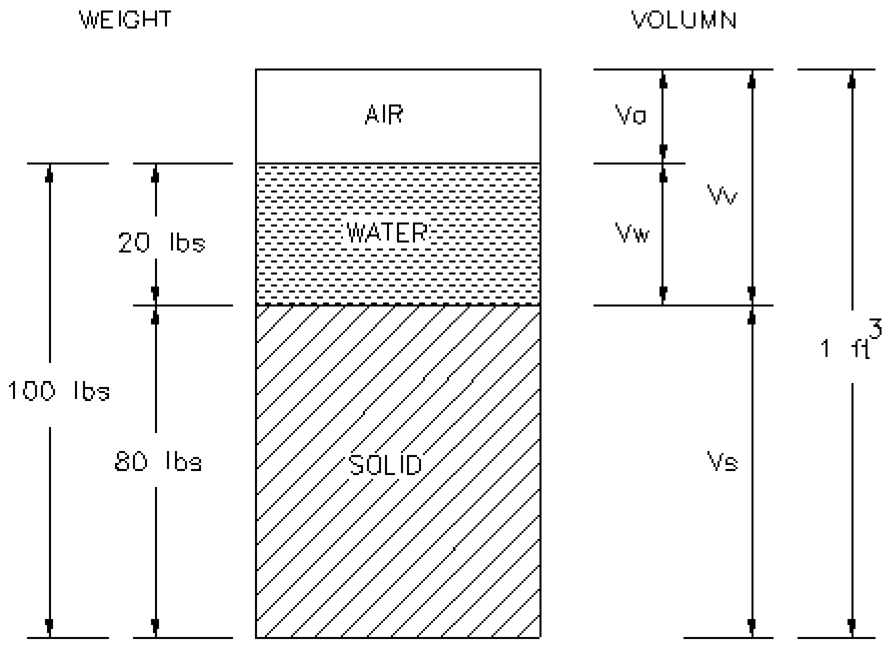
Determine moist unit weight of soil, dry unit weight of soil, and water content.

Problem solving technique:

1. Moist unit weight g_t= W_t / V_t (W_t = 100 lbs, V_t=1 ft^3, are given)
2. Dry unit weight, g_d = W_s / V_t (Weight of solid is weight of soil after dried in oven ,Ws = 80 lbs, V_t=1 ft^3, are given)
3. Water content, w (%) = W_w/W_s (W_s = 80 lbs , weight of water, W_w not known)
4. Find weight of water, from phase relationship diagram, W_w = W_t – W_s.

Solution:

1. Moist (total) unit weight, g_t = W_t / V_t = 100/1 = 100 pcf (lbs/ft^3)
2. Dry unit weight, g_d = W_s / V_t = 80/1= 80 pcf (lbs/ft^3).
3. Weight of water = 100-80=20 lbs
4. Water (Moisture) content: w (%) = W_w/W_s ´ 100 (%) = 20/80x100% = 25%



Example 2: Determine unit weights, water content, based on known volume and weight (SI units)

Given: (SI units)

- Volume of soil mass: 0.0283 m^3.
- Weight of soil mass at moist condition: 45.5 kg
- Weight of soil after dry in oven: 36.4 kg

Problem solving technique:

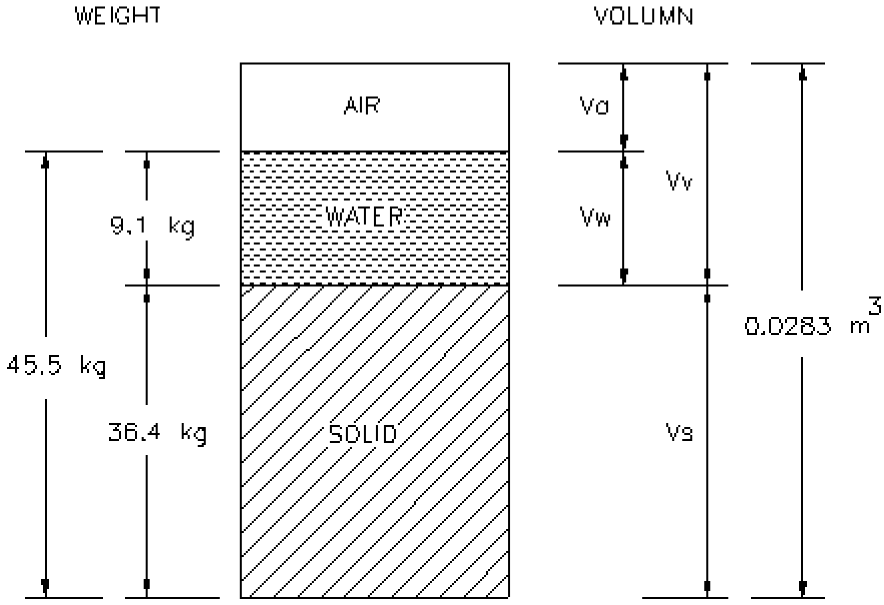
1. Moist unit weight $g_t = W_t / V_t$ (both value are given)
2. Dry unit weight, $g_d = Ws / V_t$ (both value are given)
3. Water content, w (%) = W_w/W_s (Weight of solid is weight of soil after dried in oven is given, weight of water not known)
4. Find weight of water, from phase relationship diagram, $W_w = W_t – W_s$.

Requirements:

Determine moist unit weight of soil, dry unit weight of soil, and water content.

Solution:

1. Moisture (total) unit weight, $g_t = W_t / V_t$ = 45.5/0.0283 = 1608 kg/m3 = 1.608 g/cm3
2. Dry unit weight, $g_d = Ws / V_t$ = 36.4/0.0283= 1286 kg/m^3=1.286 g/cm^3
3. Weight of water = 45.5-36.4=9.1 lbs
4. Water (Moisture) content: w (%) = W_w/W_s ´ 100 (%) = 9.1/36.4x100% = 25%



Example 3: Determine void ratio, porosity, and degree of saturation based on known volume, weight, and specific gravity (English units)

Given: (English units)

- Volume of soil mass: 1 ft^3.
- Weight of soil mass at moist condition: 125 lbs
- Weight of soil after dry in oven: 100 lbs
- Specific gravity of solid = 2.65

Requirements:

Determine void ratio, porosity, and degree of saturation

Problem solving technique:

1. Void ratio, $e = V_v/V_s$ (Vv, Vs, not given)
2. Find $V_s = W_s/g_s$ (Ws = 100 lbs, gs is not given)
3. Find $g_s = G_s g_w$ (Gs is given, g_w =62.4 lbs/ft^3 is a know value)
4. Find $V_v = 1-V_s$ (e can be calculated)
5. Porosity, $n = V_v/V_t$ (V_v from step 4, Vs from step 2)
6. Degree of saturation, $S = V_w/V_v$ (V_v from step 4, need to find V_w)
7. $V_w = W_w/g_w$ (W_w, not given, g_w=62.4 lbs/ft3)
8. Find $W_w = W_t - W_s$ (Both W_t, W_w are given)

Solution:

1. Solid unit weight, g_s = $G_s g_w$=2.65*62.4=165.4 lbs/ft^3
2. Volume of solid, V_s = W_s/g_s = 100/165.4=0.6 ft^3
3. Volume of void = V_t – V_s = 1 –0.6=0.4 ft^3
4. Void ratio, e = V_v/V_s = 0.4/0.6=0.66
5. Porosity, n = V_v/V_t = 0.4/1 = 0.4
6. Weight of water = 125-100=25 lbs
7. Volume of water, V_w = W_w/g_w = 25/62.4=0.4 ft^3
8. Degree of saturation, S = V_w/V_v = 0.4/0.4x100% = 100%.