Geology 229
Engineering Geology

Lecture 8

Elementary Soil Mechanics
(West, Ch. 7)

Outline of this Lecture

1. Introduction of soil properties
2. Index properties of soils
    - Soil particles
    - Phase relationship
    - Soil consistency

Definitions for SOIL

Engineering definitions:

Civil Engineering:

Soil is the earth material that can be disaggregated in water by gentle agitation.

Construction:

Soil is material that can be removed by conventional means without blasting.
similar to the definition of regolith in geological terms.

Agronomy definition:

Soil consists of the thin layers of the earth’s crust formed by surface weathering that are able to support plant life.

Soil mechanics is a fundamental subject of Geotechnical Engineering, which applies the geological knowledge into foundation engineering and highway engineering.

Soil mechanics related subjects

- **Soil classification (Ch. 8);**
- **Soil moisture (Ch. 15);**
- **Permeability/hydraulic conductivity (Ch. 15);**
- **Earthquake strong ground motion (Ch. 18).**

Elements of soil mechanics

Index properties:

Index properties mean the observable physical characteristics with significant influence on a soil's behavior. Index properties include the descriptions of:

- **Soil particles;**
- **Soil density;**
- **Phase relationships;**
- **Soil consistency;**
- **Relative density;**
- **moisture content.**

Soil particles

The description of the grain size distribution of soil particles according to their texture (particle size, shape, and gradation).

Major textural classes include:

- gravel (>2 mm);
- sand (0.1 – 2 mm);
- silt (0.01 – 0.1 mm);
- clay (< 0.01 mm).

Furthermore, gravel and sand can be roughly classified as coarse textured soils, wile silt and clay can be classified as fine textures soils.

For engineering purposes, soils can also be divided into cohesive and non-cohesive soils. Non-cohesive means the soil has no shear strength if no confinement.

Cohesive soil contains clay minerals and posses plasticity.

In engineering practice, plasticity is defined as the ability to be rolled into thin thread before breaking into pieces.

Clay is cohesive and plastic. For example, mud sticking on shoes in a rainy day when one walk in a field.

Sand is non-cohesive and non-plastic.

Particle Size Distribution

First of all, let's discuss the sieve that is the essential tool to study particle size distribution.

U.S. Standard Sieve Sizes

sieve #	Sieve opening (mm)
4	4.75
10	2.00
20	0.850
40	0.425
60	0.250
100	0.150
200	0.074

Gradation:

Gradation is a measure of the distribution of a particular soil sample. Larger gradation means a wider particle size distribution.

Well graded ⇔ poorly sorted (e.g., glacial till)

Poorly graded ⇔ well sorted (e.g., beach sand)

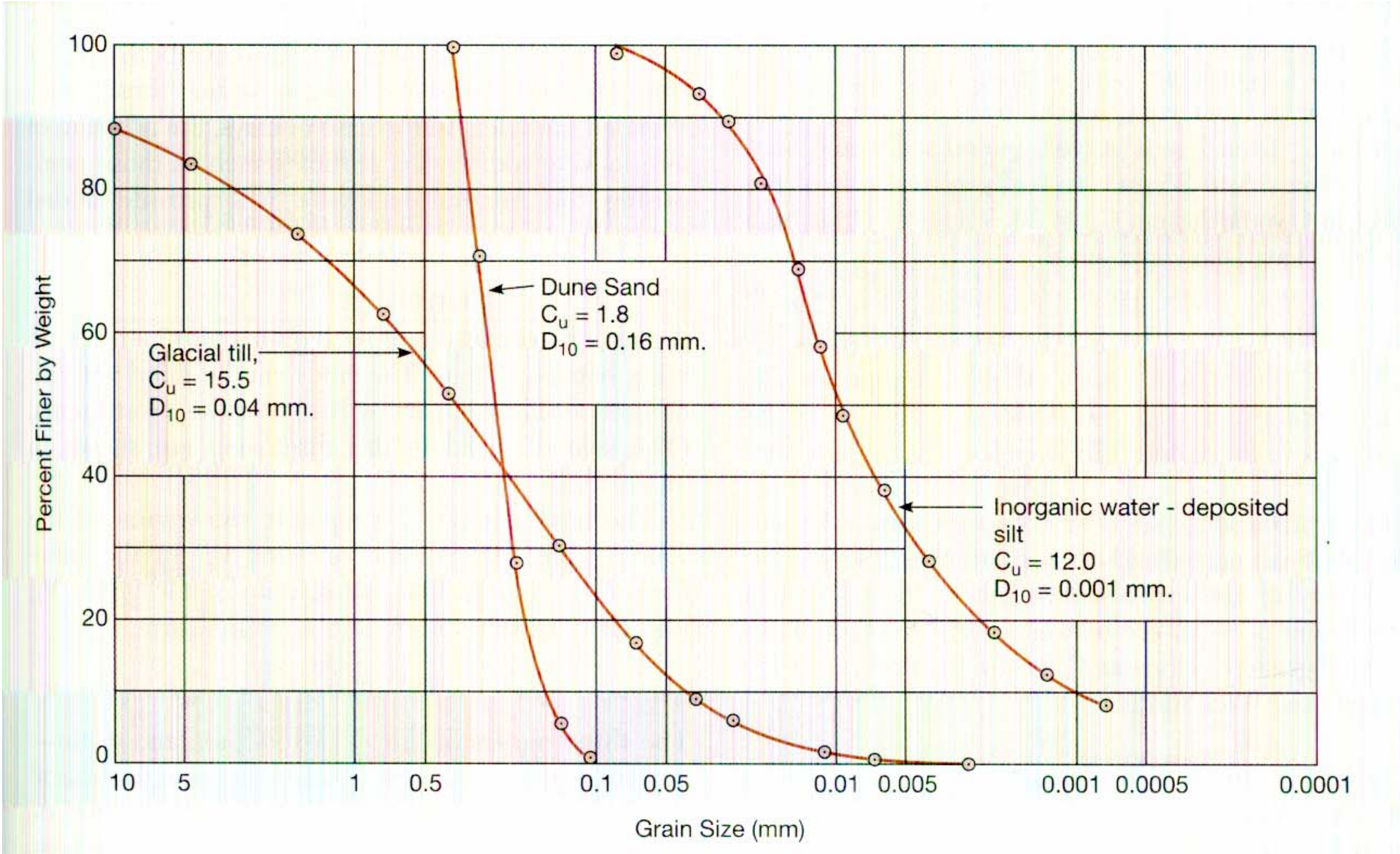
The range of grain size distribution is enormous for natural soils. E.g., boulder can be ~1 m in diameter, and the colloidal mineral can be as small as 0.00001 mm = 0.01 micron

=> It has a tremendous range of 8 orders of magnitude.

Example: If you have a soil sample with a weight of 150 g, after thorough sieving you get the following result.

sieve#	size(mm)	W(g)	%	accum%	100-accum%
4	4.750	30.0	20	20	80
20	0.850	40.0	26.7	46.7	53.3
60	0.250	50.0	33.3	79	21
100	0.150	20.0	13.3	92	8
200	0.074	10.0	6.67	98	2

The last column shows the percentage of material finer than that particular sieve size by weight.



West, Figure 7.1

There are a number of ways to characterize the particle size distribution of a particular soil sample.

D_{10}:

D_{10} represents a grain diameter for which 10% of the sample will be finer than it. Using another word, 10% of the sample by weight is smaller than diameter D_{10}. It is also called the effective size and can be used to estimate the permeability.

Hazen's approximation (an empirical relation between hydraulic conductivity with grain size)

$$k \text{ (cm/sec)} = 100 D_{10} D_{10}$$

Where D_{10} is in centimeters. It is empirical because it is not consistent in dimension (cm/sec vs cm^2).

Uniformity coefficient C_u:

$$C_u = D_{60}/D_{10}$$

where D_{60} is the diameter for which 60% of the sample is finer than D_{60}.

The ratio of two characteristic sizes are the uniformity coefficient C_u. Apparently, larger C_u means the size distribution is wider and vice versa. C_u = 1 means uniform, all grains are in the same size, such as the case of dune sands . On the other extreme is the glacial till, for which its C_u can reach 30.

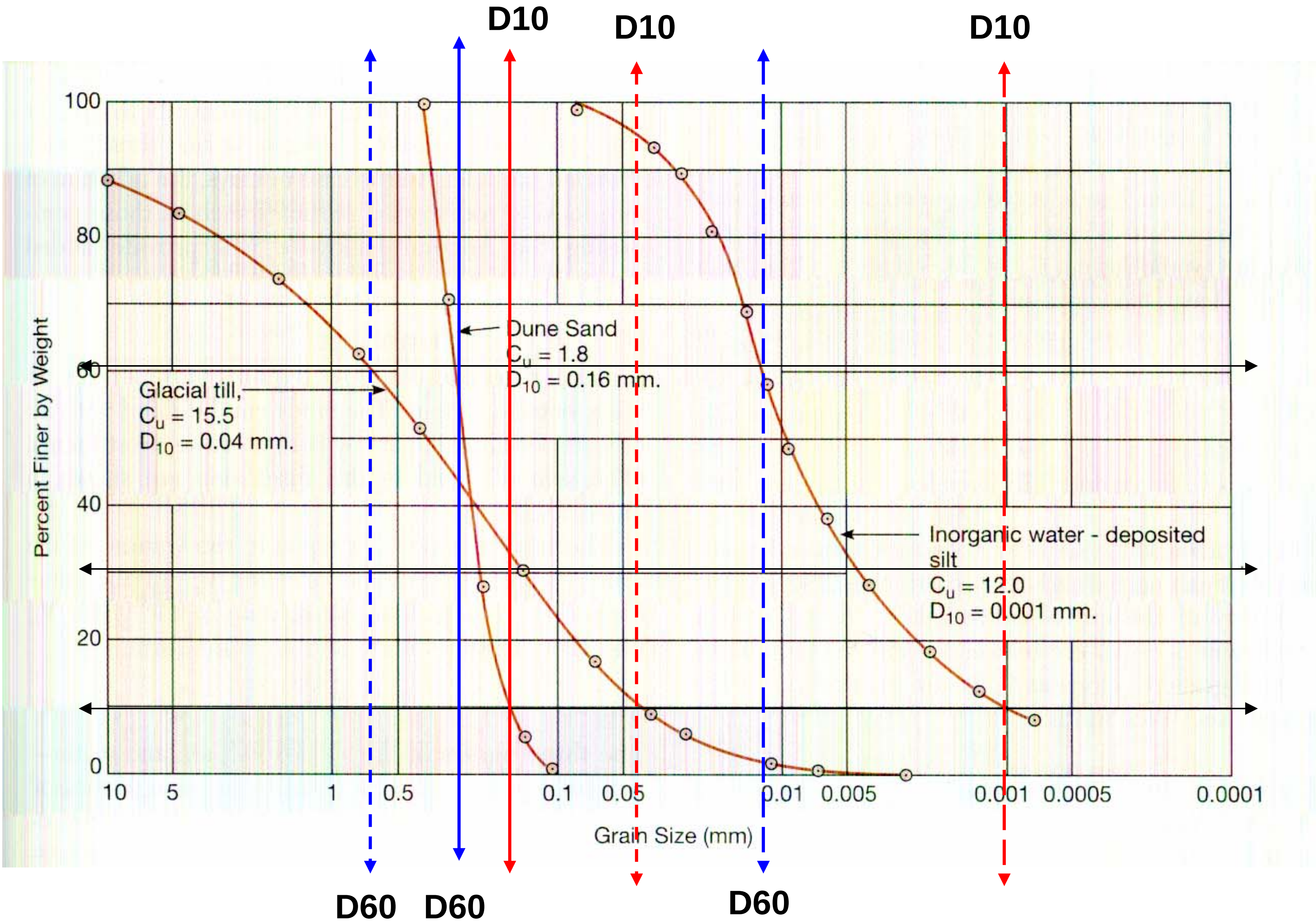
from $C_u = D_{60}/D_{10}$, then $D_{60} = C_u D_{10}$

Coefficient of Curvature C_c

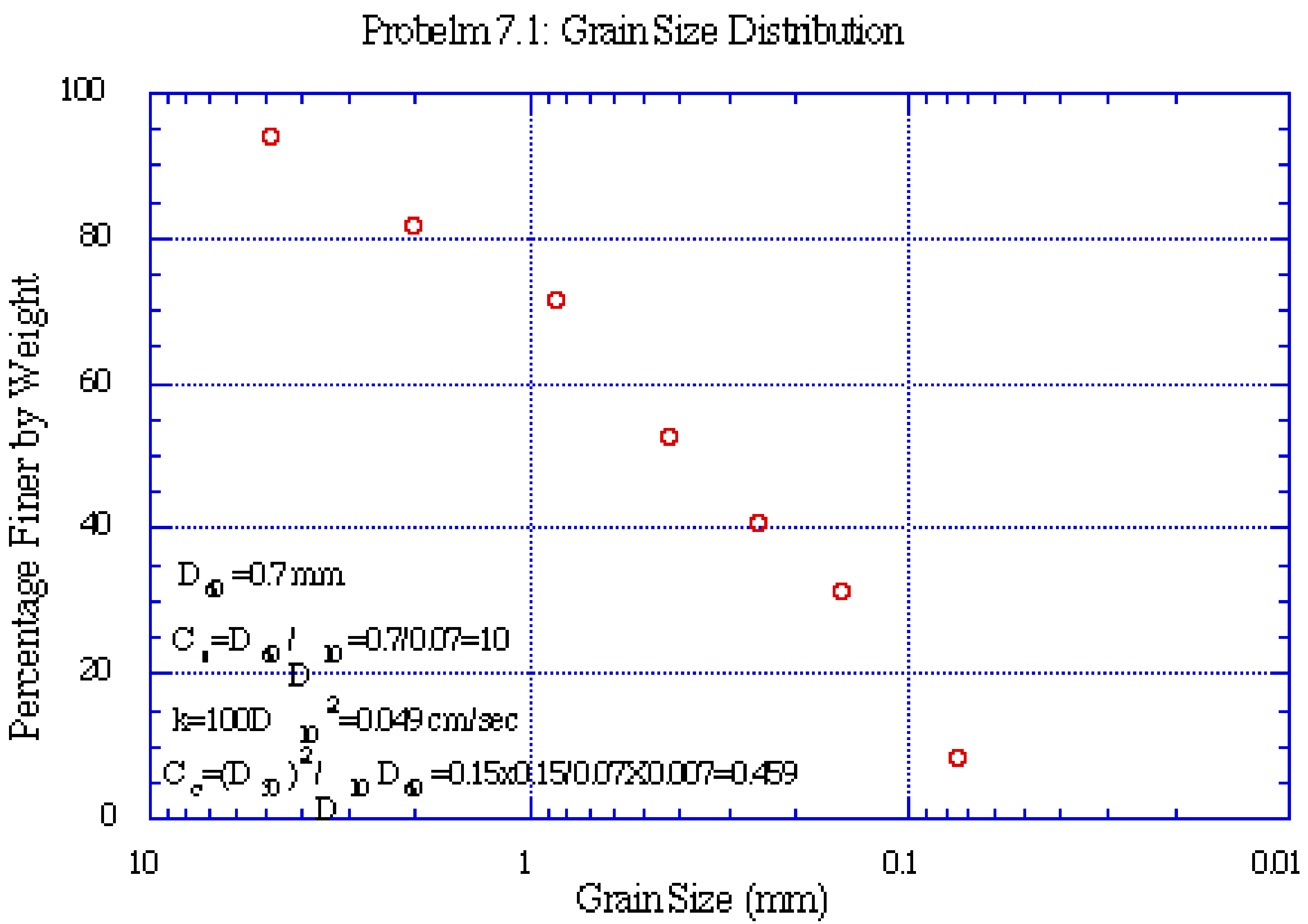
Another shape parameter, as the second moment of grain size distribution curve, is called the coefficient of curvature, and defined as

$$C_c = (D_{30}\, D_{30})/(D_{10}\, D_{60})$$

A soil is thought to be well graded if the coefficient of curvature C_c between 1 and 3, with C_u greater than 4 for gravels and 6 for sands.

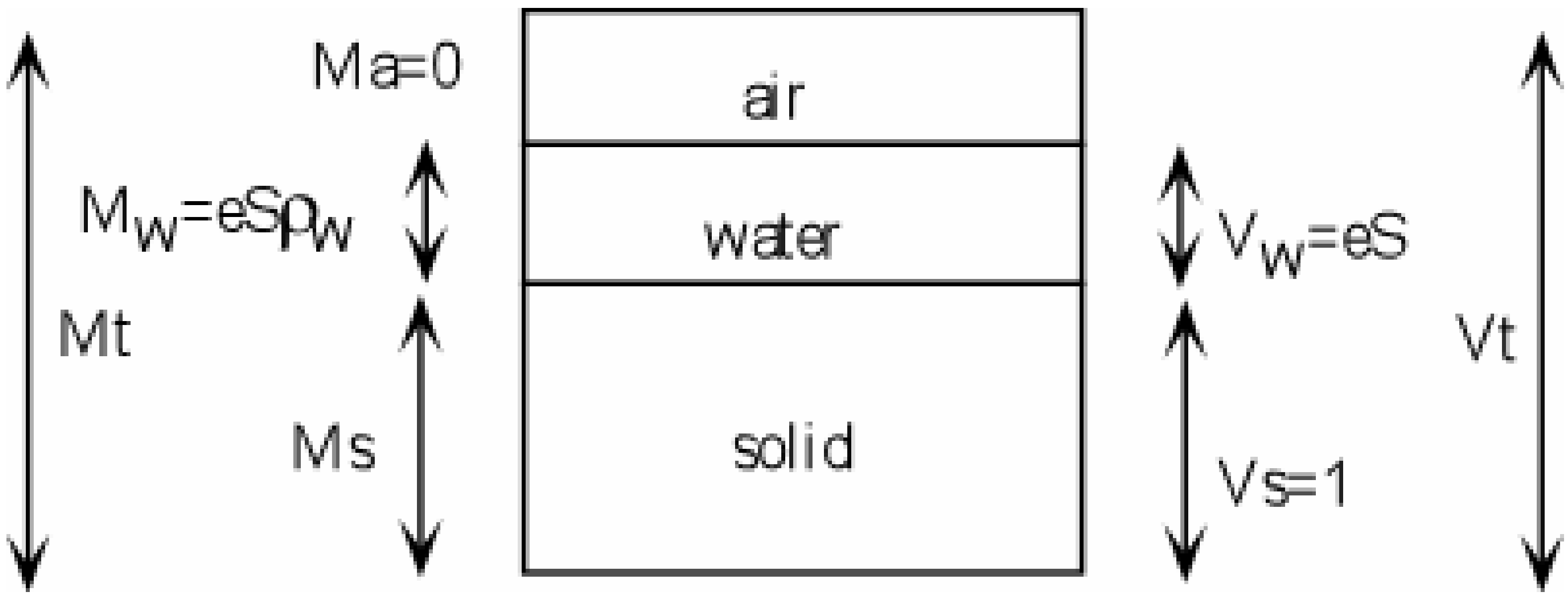


West, Figure 7.1



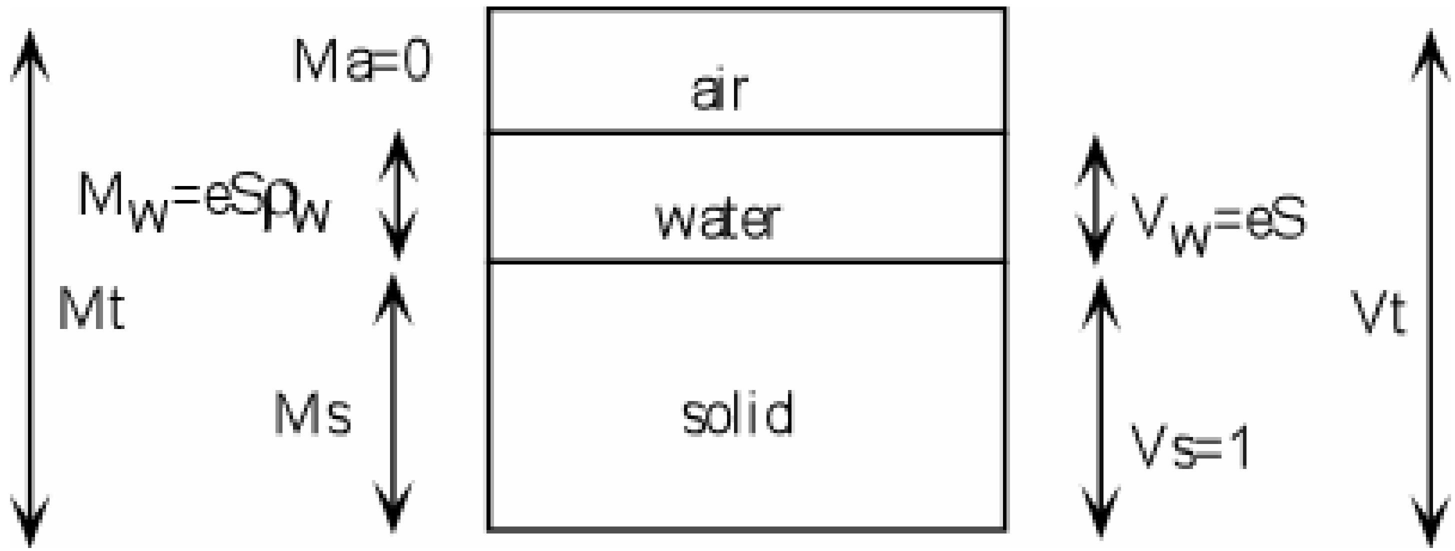
Probelm 7.1: Grain Size Distribution
Percentage Finer by Weight
Grain Size (mm)
100
80
60
40
20
0
10
1
0.1
0.01
D_{60} =0.7 mm
$C_u=D_{60}/D_{10}$ =0.7/0.07=10
$k=100D_{10}^2$=0.049 cm/sec
$C_c=(D_{30})^2/D_{10}D_{60}$ =0.15x0.15/0.07X0.007=0.459

Phase relationship: the phase diagram



Mt: total mass
Ms: Mass of solid
Mw: mass of water
Ma: mass of air = 0

Vt: total volume
Vs: volume of solid
Vw: volume of water
Vv: volume of the void



Vt = Vs + Vv = Vs + Vw + Va

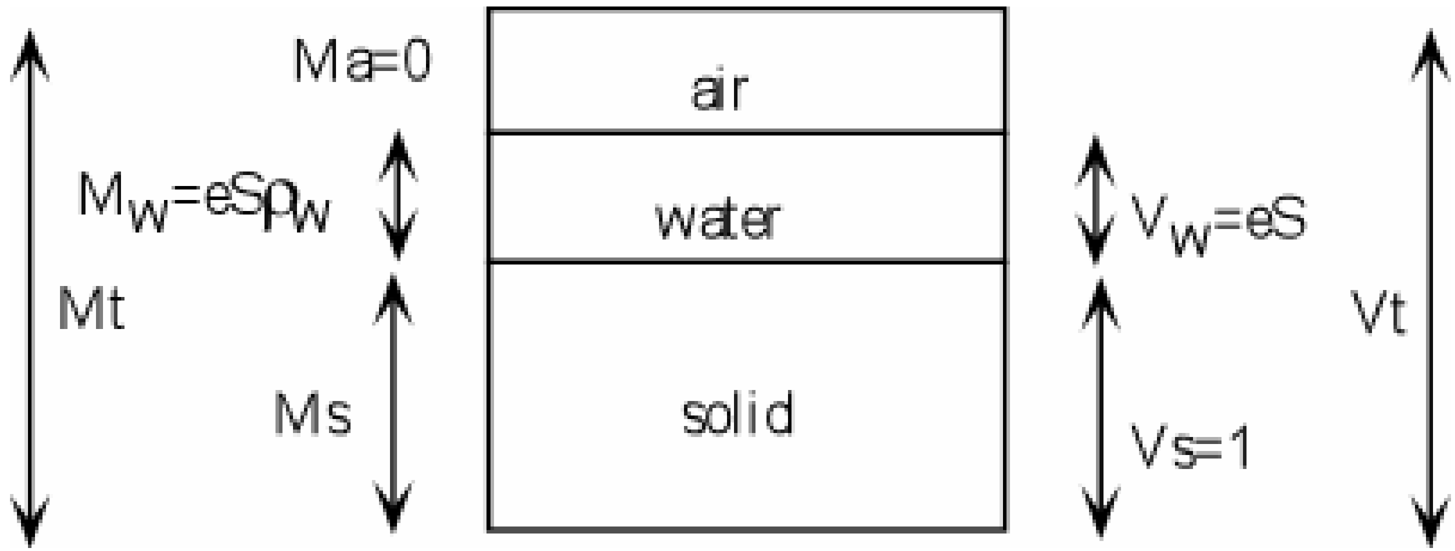
Void ratio: e = Vv/Vs

Porosity n = Vv/Vt

With the relationship of

n = e/(1+e), e = n/(1-n)

Apparently, e > n for the same phase distribution. For example, when the porosity is 0.5 (50%), the void ratio is 1.0 already.



Degree of saturation: S =Vw/Vv x 100%
Saturation is measured by the ratio of volume.

Water content: w = Mw/Ms, Mw=Vwρ_w = eSρ_w
Mw – mass of water, Ms – mass of solid
Water content is measured by the ratio of mass.
So that w can be greater than 100%.

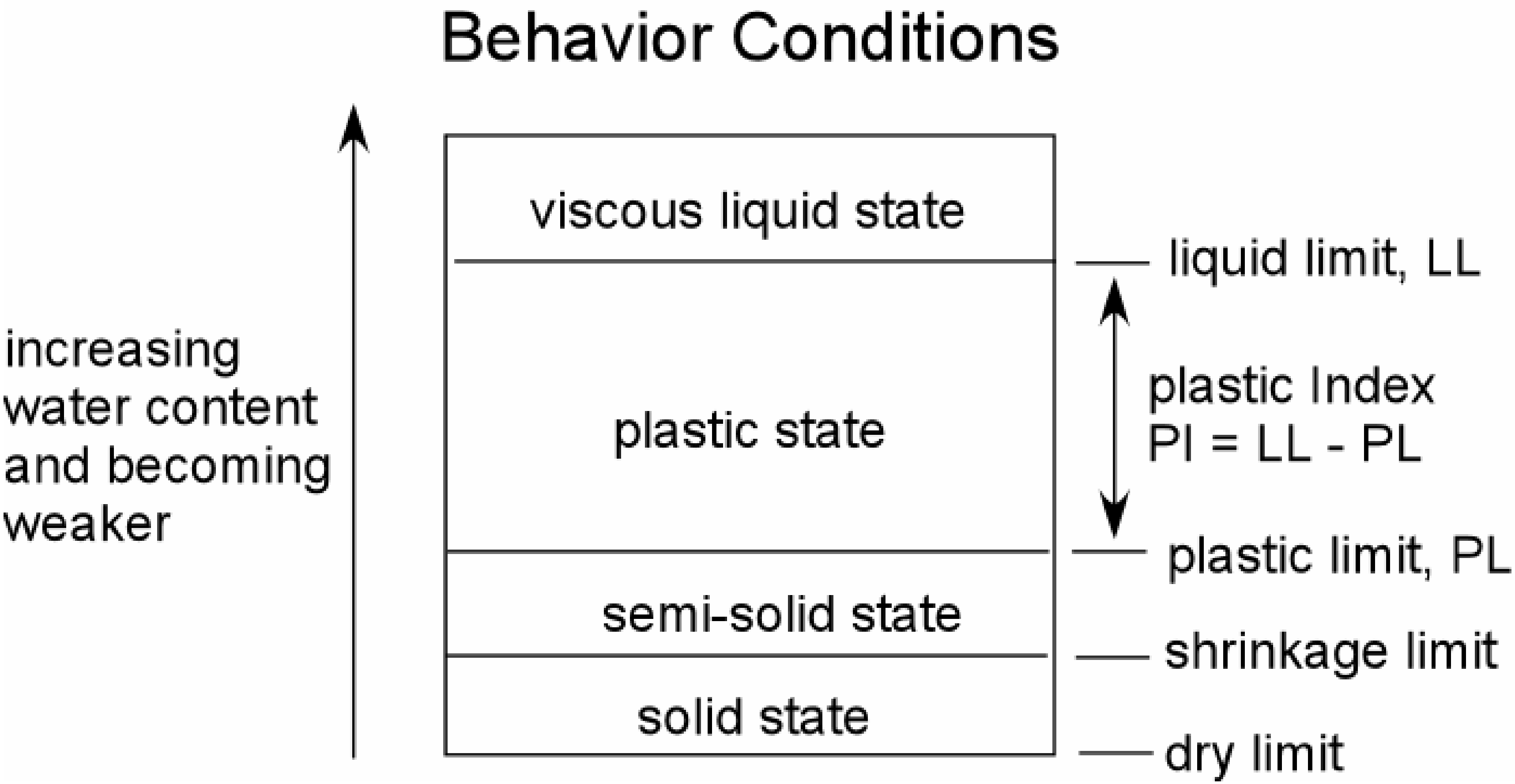
Soil Consistency

Soil consistency is defined as the relative ease with which a soil can be deformed use the terms of soft, firm, or hard.

Consistency largely depends on soil minerals and the water content.

Atterberg limits are the limits of water content used to define soil behavior. The consistency of soils according to Atterberg limits gives the following diagram.

Consistency of Soils



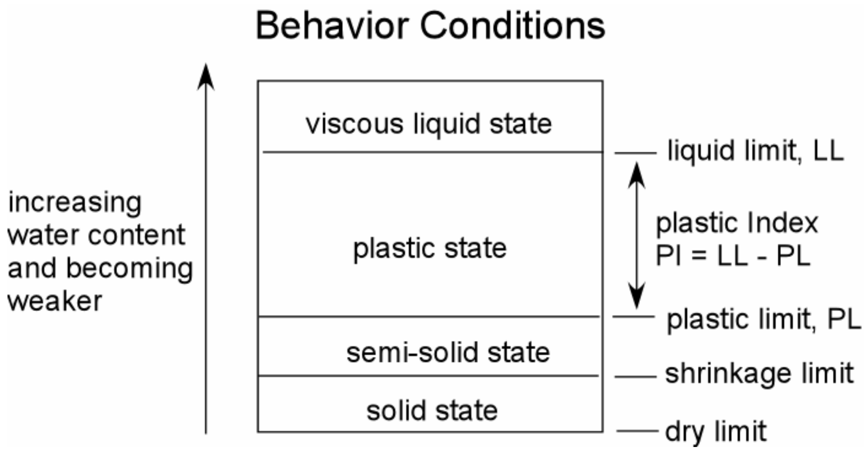
LL: The lowest water content above which soil behaves like liquid, normally below 100.

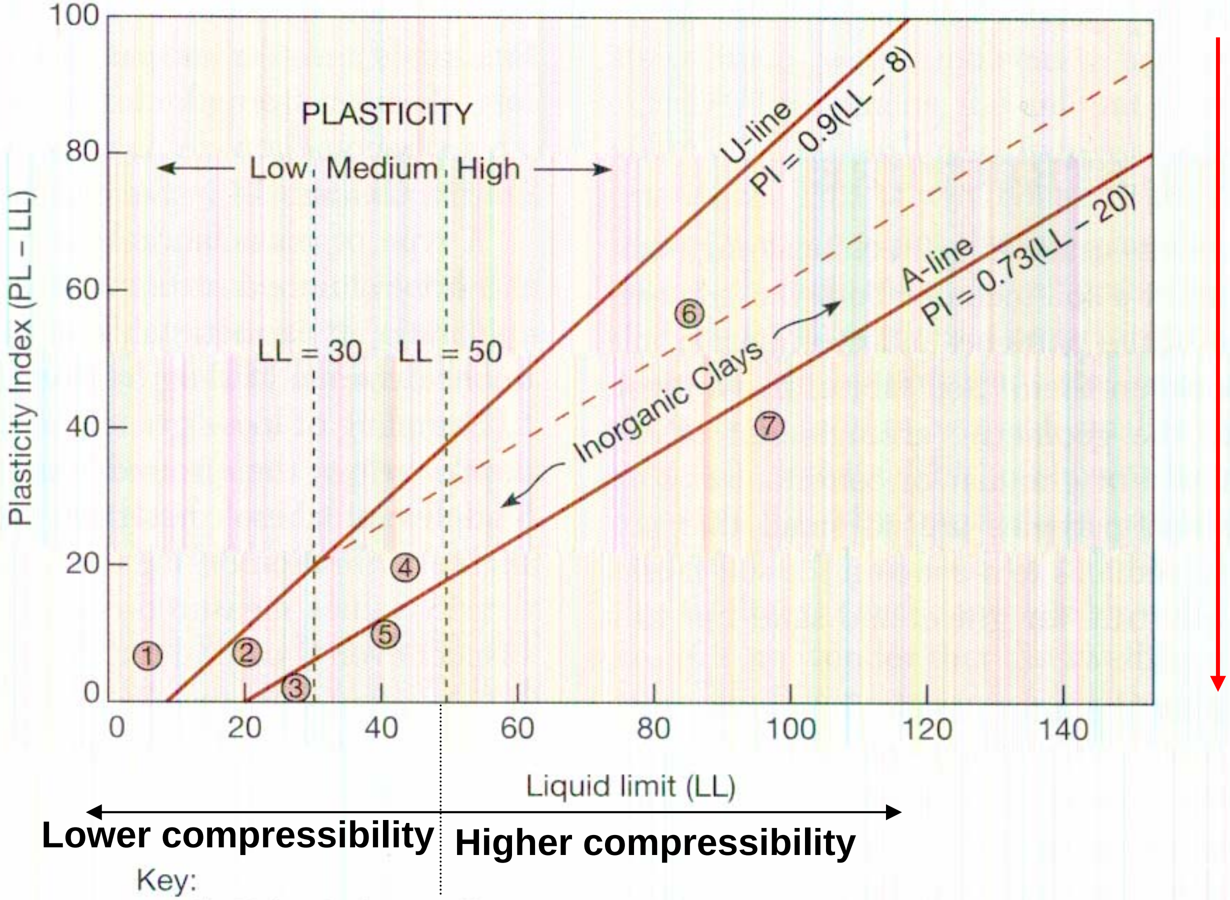
PL: The lowest water content at which soil behaves like a plastic material, normally below 40.

PI: The range between LL and PL.

Shrinkage limit: the water content below which soils do not decrease their volume anymore as they continue dry out. – needed in producing bricks and ceramics .

Consistency of Soils





Increase permeability and decrease compressibility

Key:

1) Cohesionless soils
2) Inorganic clays, low plasticity
3) Inorganic silts, low compressibility
4) Inorganic clays, medium plasticity
5) Inorganic silts and organic clays, medium compressibility
6) Inorganic clays, high plasticity
7) Inorganic silts and organic clays, high compressibility

West, Figure 7.11 Plasticity Chart

Reading Assignment:

West, Ch. 7

Homework:

7.1, 7.2, 7.3, 7.4