CH. 3

3.0 Introduction

Soil: loose materials (organic / Inorganic) in ground

Rock

Index properties: To describe soil

- water content (w)
- unit weight (γ)
- particle size & shape
- aggregate
  - texture
  - structure
- consistency & sensitivity
- organic content

Soil classification & description system

3.1 Water in soils

3.1.1 Free water & hydration water

Soil = solid + void

void → water, air

$$\text{water content } (w) = \frac{M_w}{M_s}$$

- M_w: wet mass-dry mass
- M_s: dry mass ≈ 110°C overnight

Moisture content

w =
- 0 - dry
- 300% organic & marine soils

- water
  - pore water
    - free (only for soil behavior)
    - oriented (3 to 4 molecules in thickness)
  - interlayer water between basic structural units of montmorillonite & halloysite (adsorbed)
  - water in the clay mineral crystal lattice (hydration water) upto 13% allophone

3.1.2 Capillarity

water rise due to <u>surface terrain</u> between soil particles & water

results from differences in the forces of attraction between water molecules & those on solid particle surfaces.

Capillary rise ∝ (“void” diameter -1)

Weight of water = surface tension forces

$$g\left(p\,\frac{d^4}{\Delta}\,h_c\right) = T\,\mathrm{Cor}\,\alpha * \pi d$$

$$h_c = \frac{4T}{\partial_w d}\,\mathrm{Cor}\,a$$

For soil $\alpha = 0$

$d = 20\%\ D_{10}$ (effective particle size)

$T = 75$ dyn/cm

$H_c = 1.5 / D_{10}$

(H_c: cm, D_{10}: cm)

3.1.3 Omit

3.2 Grain size & shape

boulders 12 in ------- clay (can't be seen by unaided eye)

Cohesionless (granular)

- gravel
  - o coarse
  - o medium
  - o fine
- sand
- silt

Cohesive --- clay + water $\rightarrow$ plastic

Tests
- sieve analysis > 0.075 mm
- hydrometer analysis < 0.075 mm

Unified Soil Classification System (USCS)

- G 4.75-85 mm
- S 0.075-4.75
- m hydro
- c

  <0.002

  2 μ m

Cohesionless
- particle size
- particle shape
- packing

Cohesive
- clay mineral
- water
- particle arrangement (structure)
  - disperses (freshwater – dense)
  - flocculated (seawater - highly compressible)

Soil Aggregate

- Three phase system
  - solid
  - liquid (water)
  - gas (air)
- Phase diagram
- Phase relationships

  Vols:- V, V_a , V_w , V_s inter-relationships

  Weights:- W, W_a , W_w , W_s

5 unknowns → 5 equations - for dry or sat. 4 equations

* <u>dimensional parameters:</u>

$$g_w = \frac{W_w}{V_w}$$

$$g_s = \frac{W_s}{V_s}$$

$$g = \frac{W}{V}$$ γ_{sat} if $V_a = 0$

$$g_d = \frac{W_s}{V}$$

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

Density $\rho = \gamma/g$ gravitational acceleration $= 9.81\ m/sec^2$
$= 32.2\ ft/sec^2$

weights = mass * g

Dimensionless parameters”

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

$$n = \left(\frac{V_v}{V}\right) * 100\%$$

$$S_r = \left(\frac{V_w}{V_v}\right) * 100\%$$

$$w = \left(\frac{W_w}{W_s}\right) * 100\%$$

$$G_s = \frac{\gamma_s}{\gamma_w}$$

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5 equations:

$$V = V_s + V_w + V_a$$

$W = W_s + W_w$ $\qquad\qquad$ $W_a = 0$

$$w = W_w/W_s$$

$$G_s = \frac{W_s / V_s}{W_w / V_w}$$

$$\gamma_w = 9.81 \text{ kN/m}^3 = 62.4 \text{ lb/ft}^3$$

$$W_s = \frac{W}{1+w}$$

$$W_w = w\, W_s$$

$$V_s = \frac{W_s}{G_s \gamma_w}$$

$$= W_w/\gamma_w$$

$$V_a = V - V_w$$

Table 3.4

3.4 Consistency & Sensitivity of Clays

- composition
- size
- specific surface area

Atterberg 1911 Swedish limits

	1.	upper limit of viscous flow
→	2.	LL
	3.	sticky limit
	4.	cohesion limit
→	5.	plastic limit (PL)
→	6.	shrinkage limit (SL)

LL: water content @ lower limit of viscous flow
PL: water content @ lower limit of plastic state
SL: water content @ lower limit of volume change

* Plastic Index $PI = LL - PL$

* Liquidity Index $LI = \frac{w_n - PL}{PI}$

* Activity Index $A = PI/PC$ % of clay (< .002 mm)

	A
inactive	< .75
Normal	.75 – 1.25
Active	> 1.25

* Plasticity chart PI vs. LL p.89

3.5 Organic Soils Omit

3.6 Soil Classification

- Soil classification system: common language for geo tech. engrs.

  - eliminate soil behavior & expected problems

- Soil types
- Soil categories
- Soil designations

  - highway (AASHTO) Am. Assoc. of State Highway
  - agricultural (USDA)
  - civil eng. (USCS) Unified Soil Classification system

Based on
- particle size
- Atterberg limits

Coarse grained	- cobbles	
	- gravel	G
	- sand	S
Fine grained	- silt	m
	- clay	c
Peat	- organic	O

3.6.1 USCS

- 1948 Capegrande

Coarse - grain size distribution + plasticity of times
well-grade (w)
poorly grade (p)

Fine - plasticity (LL, PL)

- Sieve analysis
- Att. Limits

Low (L)
$PI = LL - PL$ so grain size 10, 30, 60% finer
High (H)

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

$C_z = (D_{30})^2/(D_{10} \cdot D_{60})$ coeff. of curvature

Single classification group symbol

Dual symbol CL – ML
GW – GM

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1. Coarse-grained
   50% retained on # 200
   Fine-grained

2. Coarse-grained
   Gravel (G)
   --------------------- 50% retained on # 4
   Sand (S)

3. Passing # 200
   LL & PL
   12%
   C_u & C_z
   5%
   well-grade (W)
   poorly graded (P)

   with 'sand' of ≥ 15%

4. Fine-grained ------- LL & PL → plasticity chart

3.6.2 AASHTO Soil Classification System

1920's

PSD, LL, PL
#10, #40, #200

A-1	
A-2	granular
A-3	
A-4	
A-5	fine-grained
A-6	
A-7	
A-8	organic

* Group Index: $GI = 0.2A + 0.005AC + 0.01\ BD$

$A = F - 35$
$B = LL - 40$
$C = F - 15$
$D = PI - 10$
$F = \%$ passing # 200

For A-2-6 & A-2-7 $\rightarrow$ $GI = 0.01\ BD$

GI:: (integral)

Classification Procedure

- Sieve analysis # 10
  40
  200

- LL & PL

- Fig. 3.18 from left to right

  (process of elimination)

3.7 Typical values

- Relative density (D_r) for granular soils

$$D_r = \frac{(e_{\max} - e)}{(e_{\max} - e_{\min})} * 100\% = \frac{\left[1 - \left(\frac{g_{d,\,\min}}{g_d}\right)\right]}{\left[1 - \left(\frac{g_{d,\,\min}}{g_{d,\,\max}}\right)\right]} * 100\%$$

$$\left(\frac{g_d - g_{d,\,\min}}{g_{d,\,\max} - g_{d,\,\min}}\right) * \frac{g_{d,\,\max}}{g_d}$$

H.W.