«ENGINEERING GEOLOGY»

Department of Geology
Laboratory of Engineering Geology

LABORATORY EXERCISES: Physical Properties of Soils

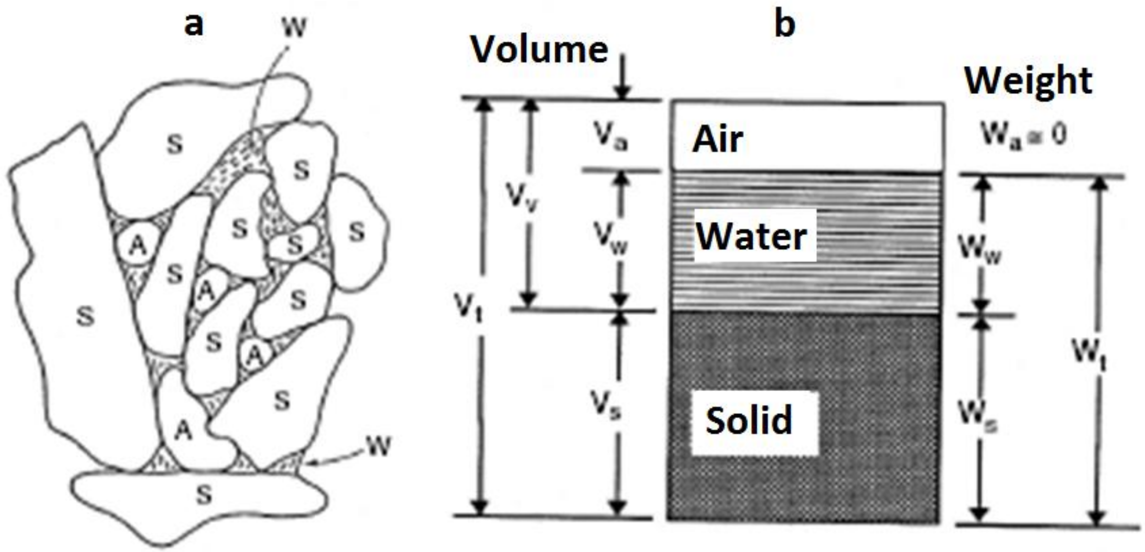
Exercise 1 : Moisture Content

Exercise 2 : Unit Weight (Density)

Exercise 3 : Specific Gravity-Calculation of Void Ratio and Porosity

Engineering Geology Laboratory Notes

Physical properties of Soil



Identification properties
"Index properties"

1. Void ratio (e),
2. Porosity (n),
3. Degree of saturation (S),
4. Moisture content (w),
5. Unit weight (γ)
6. Specific weight (G_s)
7. Relative density(D_r).

Classification properties

1. Particle size distribution
2. Plasticity

Soil index properties

Physical Properties

Moisture content $w = \frac{W_w}{W_s} \times 100\%$

Void ratio: $e = \frac{V_v}{V_s}$

Porosity: $n = \frac{V_v}{V}$

Degree of saturation: $S = \frac{V_w}{V_v} \times 100\%$

Dry soil: S=0%, Totally saturated soil: S=100%

Specific gravity of solids: $G_s = \frac{W_s}{V_s \gamma_w}$

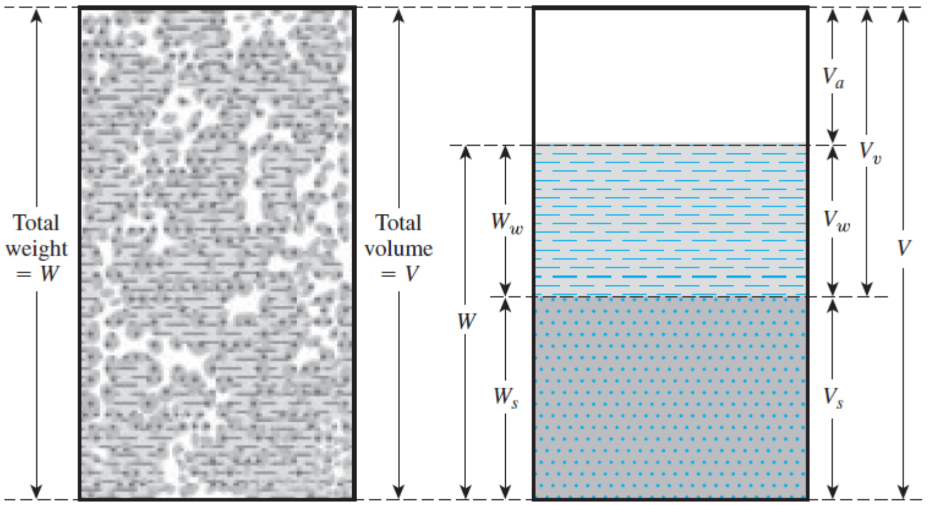
Density : $\rho = \frac{M}{V}$ «Mass»/ Volume»

(Total or "bulk" Unit weight : $\gamma_b = \frac{W}{V}$

Dry unit weight: $\gamma_d = \frac{W_s}{V}$

Unit weight of saturated soil: $\gamma_{sat} = \frac{W_s + W_w}{V}$ (when S=100%)

Uni weight of submerged soil or "buoyant" unit weight : $\gamma_{sub} = \gamma_{sat} - \gamma_w$



Mass : kg

Weight: Newton (force)

Unit weight: The gravitational force of a 1kg mass on the ground surface≈9,81Nt

γ = ρ x g => kg/m³ x 9,81 m/sec² = Nt/m³

Typical values of identification properties of soils

	Soil	n (%)	e	w (%)	γ_b (gr/cm^3)
1	**Uniform sand, loose**	46	0.85	32	1.89
2	**Uniform sand, dense**	34	0.51	19	2.09
3	**Mixed-grained sand, loose**	40	0.67	25	1.99
4	**Mixed-grained sand, dense**	30	0.43	16	2.16
5	**Glacial till, very mixed-grained**	20	0.25	9	2.32
6	**Soft glacial clay**	55	1.2	45	1.77
7	**Stiff glacial clay**	37	0.6	22	2.07
8	**Soft slightly organic clay**	66	1.9	70	1.58
9	**Soft very organic clay**	75	3.0	110	1.43
10	**Soft bentonite**	84	5.2	194	1.27

Identification properties

Moisture content & degree of saturation

$$w\,(\%) = \frac{W_w}{W_s} \times 100$$

W_w: mass of water (losses of water after drying)
W_s: mass of solid

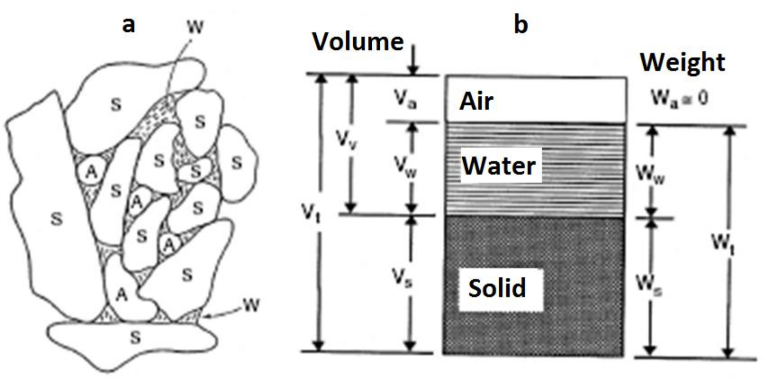
Usually in soil samples, **w <50%**
For **granular soils** is , **w : 0 – 40%**
For **sensitive clays & organic soils** it could be **w ≥ 500%**

The degree of saturation is the ratio of the volume of water (V_w) to the volume of voids (V_v)

$$S = V_w / V_v$$

It is equal to 0% when the soil is absolutely dry and 100% when the soil is fully saturated.

Condition of sand	Degree of saturation(%)
Dry	0
Humid	1 - 25
Damp	26 - 50
Moist	51 - 75
Wet	76 - 99
Saturated	100



Calculation of soil moisture content

- Objective : Determination of the percent of water (per weight) in a representative soil sample* https://www.youtube.com/watch?v=ZZ9qgQ9SbSM

** "Representative" soil sample (sample obtained from subsoil in an undisturbed state)*

- Testing according to specific Technical Standards

- American "ASTM"

- European "EN"

- British Standards "BS"

- German "DIN"

- Other National Standards (eg. Hellenic, Italian, French etc)

Calculation of soil moisture content

Required laboratory equipment.

Lab Oven

Lab balance

Lab dish

EXERCISE 1: Laboratory Determination of Moisture Content of soil

Laboratory Test Procedure

Basic Data and weights:

1. Weigh the dish without soil **(E)**
2. Place the (wet) sample in the dish and weigh the total **(A)**
3. Place the dish with wet soil in the oven and dry for 12 - 24 hours between 105 - 110 ºC
4. Weigh the dish with the dried soil **(B)** (after cooling in room temperature)

Calculations:

1. Weight of water (C=A-B)
2. Weight of dried sample (D=B-E)

3. Soil Moisture Content (C/D)*100 (in percent)

$$w\ (\%) = \frac{W_w}{W_s}\ x\ 100$$

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FORM OF LABORATORY DETERMINATION OF MOISTURE CONTENT OF SOIL

NAME: Register Number:

Sample's info: ....

No dish: 23

A:	Weight of wet sample and dish (gr)	365,64
B:	Weight of dry sample and dish (gr)	292,65
C:	Weight of water (C=A-B) (gr)	73,19
D:	Weight of dry sample (D=B-E) (gr)	187,84
E:	Weight of dish (gr)	104,81
F:	Moisture (%) (C/D) X 100	38,96

NOTICES:

Calculation of soil unit weight

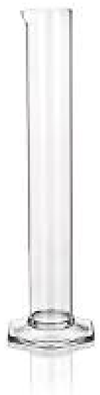
- Objective: The calculation or the unit weight of a cohesive soil.

Calculation according to the "Volume displacement" method".

https://www.youtube.com/watch?v=taNPfrqCTW8

Calculation of soil unit weight

Required laboratory equipment.



Water container (tube)

Lab balance

Paraffin

Twine

Unit weight-Density

The unit weight (γ_b) is the ratio of the amount of mass/weight to the total volume of the sample.

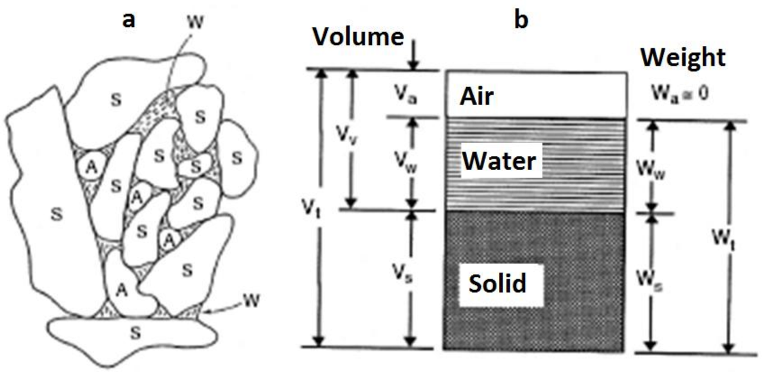
$$\gamma_b = \frac{W_t}{V_t}$$

W_t = total mass/weight

V_t = total volume

gr/cm³, KN/m³ ή Mg/m³

Moist (or "bulk") density-unit weight



$$\gamma_d = \frac{W_s}{V_t}$$

W_s = solid weight

V_t = total volume

Dry density - unit weight

$$\gamma_d = \gamma_b/(1 + w)$$

Saturated unit weight, γ_{sat} (when S = 100%)

$$\gamma_{sat} = \frac{W_s + W_w}{V_t}$$

$$\gamma_d < \gamma_b < \gamma_{sat}$$

Buoyant (or "submerged") unit weight, γ_{sub}

$$\gamma_{sub} = \gamma_{sat} - \gamma_w$$

$\gamma_w \approx 10$ kN/m³ or 1,0Mg/m³ or 1,0 gr/cm³

When a soil is below the water table, part of its weight is balanced by the buoyant effect of the water.

EXERCISE 2: Laboratory determination of density of cohesive materials

Laboratory Test Procedure

Basic Data and weights:

1. Weigh the sample of the cohesive soil **(B)**
2. Sink the sample into paraffin and calculate total weight **(A)**
3. Place a container full of water on the balance.
4. Suspend the sample with the paraffin coating in water and record the weight again **(F)**

*The specific weight of the paraffin **(D)** is given by default.*

Calculations:

1. Weight of paraffin **(C=A-B)**
2. Volume of paraffin **(E=C/D)**
3. Volume of soil **(G=F-E)**
4. Soil Unit weight ("density") **(H=B/G)**

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LABORATORY DETERMINATION OF DENSITY OF COHESIVE MATERIALS

(with the method of sample's suspension)

NAME ....
REGISTER NUMBER ....

A	Weight of soil + paraffin (gr)	201,16
B	Weight of soil (gr)	193,15
C	Weight of paraffin (C=A-B) (gr)	8,01
D	Spesific weight of paraffin (gr/cm^3)	0,89
E	Volume of paraffin (E=C/D) (cm^3)	9,0
F	Volume of soil + paraffin = reading of scale*	109,20
G	Volume of soil (G=F-E) (cm^3)	100,2
H	Density (H=B/G) (gr/cm^3)	1,927

* The reading of scale shows the volume of sample in weight of the water that is displaced. That happens because the specific weight of water (density) is $1gr/cm^3$ and so the reading of scale shows the volume of water that is displaced and so the volume of the sample.

Typical unit weight values of soils

"Range" of unit weight

Soil Type	Unit weight (kN/m³)		
	γ_{sat}	γ_d	γ_{sub}
Sand - Gravels	19-24	15-23	10-13
Silt - Clay	14-23	6-20	4-12
Glacial till	21-24	17-23	11-14
Weathered rock	19-22	15-20	9-12
Peat	10-11	1-3	0-1
Organic silt - clay	13-18	5-15	3-8

Holtz and Kovacs (1981)

$1{,}0 gr/cm^3 \approx 10 kN/m^3$

Specific Gravity (specific density) of solids

Gs: The ratio of the mass of a unit volume of a soil solids to the mass of the same volume of gas-free distilled water at 20°C.

$$G_s = \frac{m_s}{V_s \rho_w}$$

Unitless

Ws : mass of soil solids
Vs : volume of soil solids
ρ_w : density of water at 4°C = 1 Mg/m^3 ≈ 10 kN/m^3

Scope : Determination of the specific gravity of soil solids that pass the 4.75mm (No. 4) sieve or soils solids that pass the 2.00mm (No10) sieve , by means of a water pycnometer

(Sand and fines)

Significance and Use:

- Used in calculating the phase relationships of soils, such as void ratio and degree of saturation.
- Used to identify naturally occurring mineral particles or soil like particles that are not readily soluble in water.
- The specific gravity of soil solids containing extraneous (foreign) matter, such as cement, lime, and the like, water-soluble matter, such as sodium chloride, and soils containing matter with a specific gravity less than one, typically require special treatment.

Specific Gravity (specific density) of solids

$$n = 1 - \frac{\gamma_b}{(1+w)G_s} \qquad e = \frac{G_s(1+w)}{\gamma_b} - 1$$

$w \times G_s = S \times \mathrm{e}$ **(When S ≠ 100%)** $\mathrm{e} = w \times G_s$ **(When S = 100%)**

$$\gamma_b = \frac{1}{n} \times (1+w) \times G_s \qquad \gamma_b = \gamma_w \frac{(G_s + eS)}{1+e}$$

$$\gamma_d = \gamma_w \frac{G_s}{1+e} \qquad \gamma_{sat} = \gamma_w \frac{G_s + e}{1+e} \qquad \gamma_{sub} = \gamma_w \frac{G_s - 1}{1+e}$$

Specific Gravity (relative density) of solids

Range of Specific Gravity of some common Minerals

Mineral	G_s
Quartz	2.65
Kaolinite	2.6
Illite	2.8
Montmorillonite	2.65 - 2.80
Halloysite	2.0 - 2.55
K+ Felspar	2.57
Na+ and Ca+ feldspar	2.62 - 2.76
Chlorite	2.6 - 2.9
Biotite	2.8 - 3.2
Muscovite	2.76 - 3.1
Horlblende	3.0 - 3.47
Leimonite	3.6 - 4.0
Olivine	3.27 - 3.7

Iron has Gs=7,0 , meaning that 1 cm^3 has a mass of 7,0 gr.
Quartz has Gs=2.65, meaning that 1 cm^3 has a mass of 2.65gr.

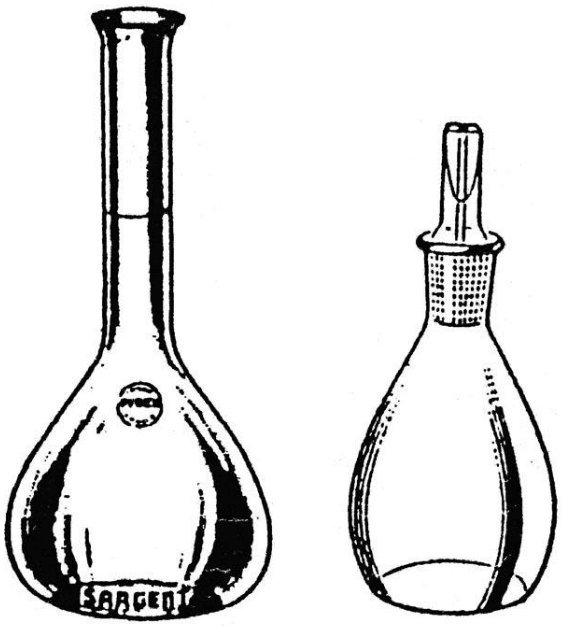
Laboratory Test Procedure

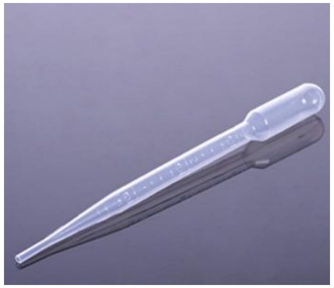
(Testing Standard ASTM D854)

Laboratory Equipment

- Pycnometer
- Distilled water
- Water dropper or burette
- Water bath
- Lab balance
- Lab oven

https://www.youtube.com/watch?v=_PqKWiUlbYg





Laboratory Test Procedure

Testing Procedure

a) Weight of a clean and dried pycnometer **(B1)**.

b) Filling the pycnometer with distilled water up to the line in room temperature and remove the air bubbles with a vacuum pump for 10 minutes (or slight boiling).

c) Placing the pycnometer in a water bath of 20°C, fill again with water until the line and weight **(B4)**.

d) Prepare the soil sample and drying it in the oven at 60 °C. Then the dried sample is left to the moistener to cool down

Soil Type	Specimen Dry Mass (g) When Using 250 mL Pycnometer	Specimen Dry Mass (g) When Using 500 mL Pycnometer
SP, SP-SM	60 ± 10	100± 10
SP-SC, SM, SC	45 ± 10	75± 10
Silt or Clay	35 ± 5	50± 10

Recommended Mass for Test Specimen ASTM D-854

e) Place the dried soil sample in the pycnometer and weigh again **(B2)**

f) Fill again the pycnometer+sample with water in room temperature (fill at approximately ¾ of full capacity) and remove the air with vacuum pump for 10min.

g) Placing the pycnometer + sample in water bath of 20°C, refilling with water (up to te line) and weight **(B3)**.

h) Calculating the Gs at 20°C

Laboratory Test Procedure

Testing Procedure

$$G_s = \frac{\rho_s}{\rho_{w,t}} = \frac{M_s}{(M_{\rho_{w,t}} - (M_{\rho ws,t} - M_s))}$$

ρ_s = the density of the soil solids Mg/m^3 or g/cm^3,
$\rho_{w,t}$ = the density of water at the test temperature (T_t), from Table 2, g/mL or g/cm^3.
M_s = the mass of the oven dry soil solids (g), and
$M_{\rho ws,t}$ = the mass of pycnometer, water, and soil solids at the test temperature, (T_t), g.

- ✓ If the test is done in temperature other than 20oC we correct using Correction Coefficient (K) (given in Tables).

Test Temperature	Water density (gr/cm^3)	Correction coefficient
18	0,9986244	1,0004
19	0,9984347	1,0002
20	0,9982343	1,0000
21	0,9980233	0,9998
22	0,9978019	0,9996
23	0,9975702	0,9993
24	0,9973286	0,9991
25	0,9970770	0,9989
26	0,9968156	0,9986
27	0,9965451	0,9983
28	0,9962652	0,9980
29	0,9959761	0,9977
30	0,9956780	0,9974

$$G_s(20^oC) = K \; x \; G_s$$

- ✓ Test is done in two specimens of the same sample and result is given in two decimals.
- ✓ The final result is the average of both tests.
- ✓ If results differ >0,03 the test must be repeated (due to possible "human" or "systematic error"

EXERCISE 3: Specific Gravity Determination Form

Basic Weights

- Weight of empty pycnometer **(B1)**
- Weight of pycnometer with sample **(B2)**
- Weight of pycnometer and sample with water at 20oC **(B3)**
- Weight of pycnometer with water **(B4)**

Calculations

- Weight of soil (B2-B1)
- Weight of water at 20oC (B4-B1)
- Weight of water (B3-B2)
- Volume of soil (B4-B1) – (B3-B2)
- Specific gravity: (B2-B1)/ [(B4-B1) – (B3-B2)

Note:

correction due to hygroscopic moisture

$$\textbf{Hygr moisture (\%)} = \frac{W_a - W_s}{W_s}$$

$$\textbf{Corrected Ws} = W_a \; x \; \frac{100 - hygr.moisture}{100}$$

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SHEET OF DETERMINATION OF SPECIFIC GRAVITY

OF MATERIAL FINER THAN 2.OO mm

Name: ....

Resgister Number: ....

Test	1	2
Weight of void pycnometer (B_1) (gr)	99,3	
Number of pycnometer	5	4

		Number of Test		
		1	2	
Weight of pycnometer and sample	(B_2) (gr)	149,3		
Weight of pycnometer and sample and water in 20oC	(B_3) (gr)	330,0		
Weight of pycnometer with water in 20oC	(B_4) (gr)	298,7		
Weight of soil	(B_2 - B_1)(gr)	50,0		
Weight of water in 20^{o}C	(B_4 - B_1) (gr)	199,4		
Weight of water	(B_3 - B_2)(gr)	180,7		
Volume of soil (B_4 - B_1) - (B_3 - B_2)	(gr)	18,91		
Specific gravity of soil G_s = (B_2 - B_1) / (B_4 - B_1) - (B_3 - B_2)		2,67		
AVERAGE				

NOTICE : Correction coefficient for hygroscopic moisture : 0,9986

*: The best case is to be done 3 tests (in order to be taken all the granule's sizes) and for the average to be calculated.

Void ratio - Porosity

Void ratio $e = V_v / V_s$

Void ratio is the volume of voids (V_v) to the volume of soil solids (V_s).

***Porosity*:** $n (\%) = (V_v / V_t) x 100$

It is defined as the ratio of volume of voids (V_v) to the total volume (V_t).

$e = n / (1-n)$ *or* $n = e / (1+e)$

n

Sand: 30 to 50%
Clay: 20 to 60% (and higher)

e

Sand: 0.3 - 0.80
Clay: 0.6 - 1.5 (and higher)
(e.g. clay of Mexico city e : 3 to 6).

Relative Density

e: Soil Void ratio on site

e_{max} : Soil maximum void ratio (i.e. void ratio at the loose state of the soil, e.g. during deposition)

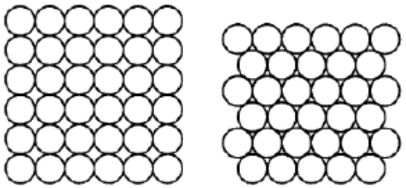
e_{min} : Soil minimum void ratio (i.e. void ratio at the most dense state, e.g. after maximum compaction)

$$D_r = \frac{e_{max} - e}{e_{max} - e_{min}}$$

$e = e_{max} \Rightarrow D_r = 0$

$e = e_{min} \Rightarrow D_r = 1$ (ή 100%)

Usual range in granular soil Dr≈0.40 – 0.80.



(a) Loosest state (b) Densest state

D_r (%)	Description
0 - 15	Very loose
15 - 35	Loose
35 - 65	Medium Dense
65 - 85	Dense
85 - 100	Very Dense

Or….

$$D_d = \frac{\gamma_{dmax}(\gamma_d - \gamma_{dmin})}{\gamma_d(\gamma_{dmax} - \gamma_{dmin})}$$

Relationships between soil physical and index properties

Μεγέθη	Συμβολισμοί	Ορισμοί	Διαστάσεις	n	e	γ_b	γ_d
Περιεχόμενη υγρασία (moisture content)	w	$\frac{W_w}{W_s}$	αδιάστατο (%)		$e = w\,G_s$ (όταν S=100%)	$w = \frac{\gamma_b - \gamma_d}{\gamma_d}$	
Πορώδες (porosity)	n	$\frac{V_v}{V_t}$	αδιάστατο (%)		$n = \frac{e}{1+e}$	$n = 1 - \frac{\gamma_b}{(1+w)G_s}$	$n = \frac{G_s - \gamma_d}{G_s}$
Λόγος κενών (void ratio)	e	$\frac{V_v}{V_s}$	αδιάστατο	$e = \frac{n}{1-n}$		$e = \frac{G_s(1+w)}{\gamma_b} - 1$	$e = \frac{G_s - \gamma_d}{\gamma_d}$
Βαθμός κορεσμού (degree of saturation)	S	$\frac{V_w}{V_v} = \frac{W_w}{\gamma_w V_v}$	αδιάστατο (%)		$w\,G_s = Se = \frac{V_w}{V_s}$ (όταν S≠100%)		
Ειδικό βάρος κόκκων (particle specific gravity)	G_s	$\frac{W_s}{V_s \gamma_w}$	αδιάστατο				
Σχετική πυκνότητα (relative density)	D_r	$\frac{e_{max} - e}{e_{max} - e_{min}}$	αδιάστατο (%)				
Φαινόμενο βάρος (bulk unit weight)	γ_b	$\frac{W_t}{V_t}$	kN/m^3	$\gamma_b = (1-n)(1+w)G_s$	$\gamma_b = \gamma_w \frac{(G_s + eS)}{1+e}$		
Ξηρό φαινόμενο βάρος (dry unit weight)	γ_d	$\frac{W_s}{V_t}$	kN/m^3	$\gamma_d = (1-n)G_s$	$\gamma_d = \gamma_w \frac{G_s}{1+e}$	$\gamma_d = \frac{\gamma_b}{1+w}$	
Φαινόμενο βάρος κορεσμένου εδάφους (saturated unit weight)	γ_{sat}	$\frac{W_s + W_w}{V_t}$	kN/m^3		$\gamma_{sat} = \gamma_w \frac{(G_s + e)}{1+e}$		$\gamma_d < \gamma_b < \gamma_{sat}$
Φαινόμενο βάρος βυθισμένου εδάφους (buoyant unit weight)	γ_{sub}	$\gamma_{sat} - \gamma_w$	kN/m^3		$\gamma_{sub} = \gamma_w \frac{(G_s - 1)}{1+e}$		
Πυκνότητα (bulk density)	ϱ	$\frac{M}{V_t}$	Mg/m^3		$\varrho = \varrho_w \frac{(G_s + eS)}{1+e}$	$\varrho = \frac{M}{V_t} = \frac{Mg}{V_t g} = \frac{W_t}{V_t g} = \frac{\gamma_b}{g}$ ή $\gamma_b = \varrho g$	
						όπου g: η επιτάχυνση της βαρύτητας	
όπου γ_w = φαινόμενο βάρος νερού = 10 kN/m^3 και ϱ_w = πυκνότητα νερού = 1 Mg/m^3 = 1 ton/m^3							