Soil Consistency

Consistency is a term which is frequently used to describe the condition of a soil. There are four states of consistency for fine-grained soils (Table 1.1).

The Liquid Limit is the water content at which the soil passes through to the liquid state from the the plastic state.

The Plastic Limit is the lowest water content at which the soil begins to crumble when rolled out into thin threads.

The Plasticity Index is measure of the range of water content over which the soil remains in the plastic state.

The Shrinkage Limit is unique in that it denotes a particular consistency and also a relatively abrupt change in the soil - water volume relation ship.

Table 1.1. Consistency limits for fine-grained soils.

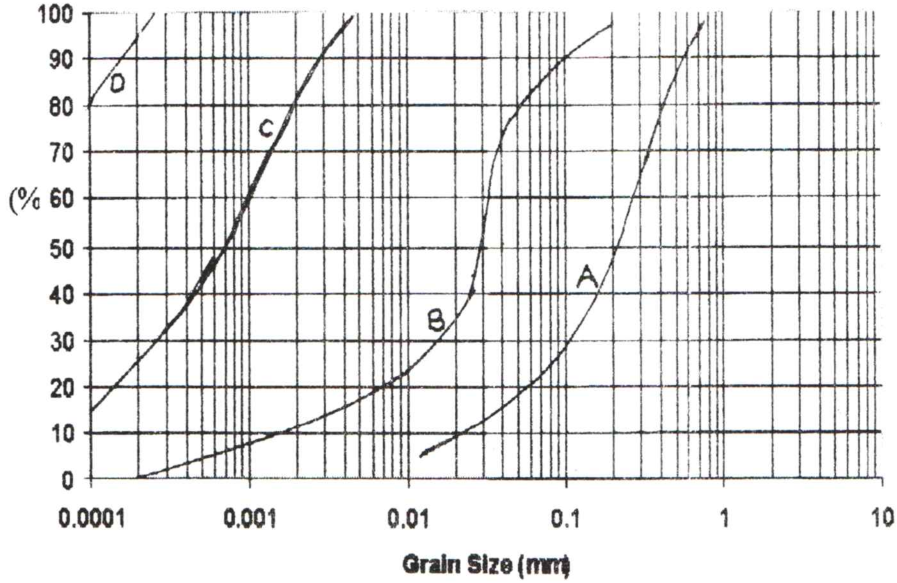
States	**Limits**	**Indexes**
Liquid		
	Liquid Limit, LL	
Plastic		Plasticity Index PI = LL - PL
	Plastic Limit, PL	
Semisolid		Shrinkage Index SI = PL- SL
	Shrinkage Limit, SL	
Solid		

PROBLEMS AND SOLUTIONS

Problem 1.1. The results of particle size analyses and, where appropriate, limit tests on samples of four soils are given in following table. Classify each soil according to the Unified Classification System.

	Percentage Smaller			
Particle size	Soil A	Soil B	Soil C	Soil D
63 mm				
20 mm	100			
6.3 mm	94	100		
2 mm	69	98		
600 mm	32	88	100	
212 mm	13	67	95	100
63 mm	2	37	73	99
0.020 mm		22	46	88
0.006 mm		11	25	71
0.002 mm		4	13	58
Liquid Limit		Non-Plastic	32	78
Plastic Limit			24	31

Solution 1.1:



Soil A and B :

These soils consist of more than 50% coarse material and these coarse materials have sand size more than 50%. So the primary letter of these soils is S. For determination of the secondary letters, C_u and C_c must be calculated.

The coefficient of curvature:

$$C_c = \frac{D_{30}^2}{D_{60} * D_{10}} \quad \text{and}$$

The coefficient of uniformity,

$$C_u = \frac{D_{60}}{D_{10}}$$

The C_c and C_u are obtained as 1.2 and 8.3 respectively by using these expressions for soil A. The unified soil classification group of soil A is **SW**.

There is no need to calculate the C_u and C_c for Soil B. Because, Soil B consists of more than 12% fine material and it is a non-plastic material. So the unified soil classification group of Soil B is **SM**.

Soil C and D:

$LL_C = 32\ \%$ $\quad PL_C = 24\ \%$ $\quad PI_C = LL_C - PL_C = 8\ \%$

$LL_D = 78\ \%$ $\quad PL_D = 31\ \%$ $\quad PI_D = LL_D - PL_D = 47\ \%$

Soil D and Soil C consist of more than 50% fine grained material. LL values and PI calculated values are used and the classes of these soils are determined from the plasticity chart. So, the unified soil class group of Soil D is **CH** and that of Soil C is **ML**.

Problem 1.2. A soil has a bulk density of $1.91 g/cm^3$ and a water content of 9.5 %. The value of G_s is 2.70. Calculate the void ratio and degree of saturation of the soil. What would be the values of density and the water content, if the soil were fully saturated, at the same void ratio.

Solution 1.2:

$\rho = 1.91 g/cm^3$ $\quad w = 9.5\%$ $\quad G_s = 2.70$

$e = ?$ $\quad S_r = ?$

$$w = \frac{mass \text{ of water}}{mass \text{ of solid}} = \frac{m_w}{m_s} \qquad e = \frac{\text{volume of void}}{\text{volume of solid}} = \frac{V_v}{V_s}$$

assume $V_{total} = 1 cm^3 = V_w + V_s + V_{air}$

$$\rho = \frac{m_{total}}{V_{total}} \Rightarrow m_{total} = 1.91 g \qquad m_{total} = m_w + m_s$$

$$w = \frac{m_w}{m_s} \Rightarrow 0.095 * m_s = m_w$$

$$1.91 = m_s + 0.095 * m_s \Rightarrow m_s = 1.744\ g \qquad m_w = 0.166$$

$$\rho_w = \frac{m_w}{V_w} \quad \Rightarrow \quad V_w = 0.166 \text{ cm}^3$$

$$G_s = \frac{m_s}{V_s * \rho_w} \qquad 2.70 = \frac{1.744}{V_s * 1} \qquad V_s = 0.646 \text{ cm}^3 \quad V_v = V_T - V_s = 0.354 \text{ cm}^3$$

$$e = \frac{V_v}{V_s} = \frac{0.354}{0.646} \qquad \mathbf{e = 0.55 = 55\ \%}$$

$$Sr = \frac{w * Gs}{e} = \frac{0.095 * 2.70}{0.55} \qquad \mathbf{S_r = 0.466 = 46.6\ \%}$$

If $S_r = 1$ then $\rho = ?$ $\quad w = ?$

$$Sr = \frac{w * Gs}{e} \quad \Rightarrow \quad 1 = \frac{w * 2.70}{0.55} \quad \Rightarrow \quad \mathbf{w = 0.204 = 20.4\ \%}$$

$V_v = 0.354 \text{ cm}^3$ and $S_r = 1$ so, $\quad m_w = 0.354$ g

$$\rho = \frac{m_T (= m_s + m_w)}{V_T} \qquad \rho = \frac{1.744 + 0.354}{1} \quad \Rightarrow \quad \rho = \mathbf{2.098\ g/cm^3}$$

Problem 1.3. Calculate the dry unit weight, the saturated unit weight and the buoyant unit weight of a soil having a void ratio of 0.70 and a value of G_s of 2.72. Calculate also the unit weight and water content at a degree of saturation of 75%.

Solution 1.3:

$e = V_v/V_s$ $\qquad$ assuming $V_T = 1 \text{ cm}^3$

$0.7 * V_s = V_v \qquad 1 = V_s + 0.7 * V_s \quad \Rightarrow \quad V_s = 0.588 \text{ cm}^3 \qquad V_v = 0.412 \text{ cm}^3$

$\gamma_{dry} = \dfrac{m_s}{V_T} * 9.8$ $\qquad G = \dfrac{m_s}{V_s * \rho_w}$ $\Rightarrow$ $m_s = 1.599$ g.

$\rho_{dry} = \dfrac{1.599}{1} = 1.599$ g/cm³ $\Rightarrow$ γ_{dry} **= 15.67 kN/m³**

$\gamma_{sat} = \dfrac{m_s + m_w}{V_T} * 9.8$

if $S_r = 1$ $\quad V_v = V_w$ $\quad (\rho_w = 1$ g/cm³)

$\rho_w = m_w / V_w$ $\quad m_w = 0.412$ g.

$m_s + m_w = 2.011$

$\gamma_{sat} = 2.011 * 9.8 =$ **19.71 kN/m³**

$\gamma' = \gamma_{sat} - \gamma_w$ $\Rightarrow$ γ' **= 9.91 kN/m³**

if $S_r = 0.75$ then $\gamma = ?,\ w = ?$

$S_r = (w * G_s) / e$ $\qquad 0.75 = \dfrac{w * 2.72}{0.7}$ $\Rightarrow$ $w =$ **0.19 =19 %**

$w = m_w / m_s$ $\quad 0.19 = m_w / 1.599$ $\Rightarrow$ $m_w = 0.304$ g.

$\gamma = \dfrac{m_{tot}}{V_{tot}} * 9.8$ $\qquad \gamma = \dfrac{1.599 + 0.304}{1} * 9.8$

$\gamma =$ **18.65 kN/m³**

Problem 1.4. A soil specimen is 38 mm. in diameter and 76 mm.in length and in its natural condition weighs 168.0 g. When dried completely in an oven, the specimen weighs 130.5 g. The value of G_s is 2.73. What is the degree of saturation of specimen?

Solution 1.4:

m at natural condition = 168 g. $\qquad m_{dry} = 130.5$ g.

$G_s = 2.73$ $\qquad S_r = ?$

$w = m_w / m_s = (168 - 130.5) / 130.5 = 0.29$ and $m_w = 37.5$ g.

$V_{total} = \pi * r^2 * h$

$G_s = m_s / (V_s * \rho_w)$

$V_{total} = \pi * 1.9^2 * 7.6$

$2.73 = 130.5 / V_s * 1$

$V_{total} = 86.19$ cm³

$V_s = 47.8$ cm³
$V_v = 38.39$ cm³
$V_w = 37.5$ cm³

$S_r = V_w / V_v = 37.5 / 38.39 =$ **0.98 = 98 %**

Problem 1.5. A Soil has been compacted in an embankment at a bulk density of 2.15 tons/m³ and a water content of 12%. The value of G_s is 2.65. Calculate the dry density, void ratio, degree of saturation and air content.

Solution 1.5:

$\rho = 2.15$ tons/m³ $w = 0.12$ $G_s = 2.65$

$\rho_{dry} = ?$ $e = ?$ $S_r = ?$ $A = ?$

$$w = \frac{m_w}{m_s} \quad \Rightarrow \quad m_s * 0.12 = m_w \ (1) \quad \text{assuming } V_T = 1 \text{ cm}^3$$

$$\rho = \frac{m_T}{V_T} = \frac{m_s + m_w}{1} \quad \Rightarrow \quad 2.15 = m_s + m_w \ (2)$$

$m_s = 1.92$ g. $m_w = 0.23$ g. (from (1) and (2))

$\rho_w = m_w / V_w \quad \Rightarrow \quad V_w = 0.23$ cm³

$$G_s = \frac{m_s}{V_s * \rho_w} \quad \Rightarrow \quad V_s = 0.72 \text{ cm}^3 \qquad V_a = 1 - (V_w + V_s)$$

$V_a = 0.05$ cm³

$\rho_{dry} = m_s / V_T = 1.92 / 1 =$ **1.92 g/cm³**

$e = V_v / V_s =$ **0.389**

$S_r = V_w / V_v = 0.23 / 0.28 = \mathbf{0.82 = 82\ \%}$

$A = V_a / V_T = 0.05 / 1 = \mathbf{0.05 = 5\ \%}$

Problem 1.6. The following results were obtained from a standard compaction test on a soil:

Mass(g)	2010	2092	2114	2100	2055
Water Content (%)	12.8	14.5	15.6	16.8	19.2

The value of G_s is 2.67. Plot the dry density / water content curve and give the optimum water content and maximum dry density. Give the value of air content at maximum dry density. The volume of the mould is 1000 cm³.

Solution 1.6:

no	1	2	3	4	5
mass (g.)	2010	2092	2114	2100	2055
w (%)	12.8	14.5	15.6	16.8	19.2

$G_s = 2.67 \quad V_T = 1000\ cm^3 \quad w = m_w / m_s \quad mass = m_w + m_s$

1) $0.128 * m_s = m_w \quad 2010 = m_w + m_s \quad \Rightarrow \quad m_w = 228.1g \quad m_s = 1781.9\ g.$

$\rho_{dry} = m_s / V_T = 1781.9 / 1000 = 1.7819\ g/cm^3$

2) $0.145\ m_s = m_w \quad 2092 = m_w + m_s \quad \Rightarrow \quad m_w = 264.9\ g \quad m_s = 1827.1\ g.$

$\rho_{dry} = m_s / V_T = 1827.1 / 1000 = 1.8271\ g/cm^3$

3) $0.156\ m_s = m_w \quad 2114 = m_w + m_s \quad \Rightarrow \quad m_w = 285.3\ g. \quad m_s = 1828.7\ g.$

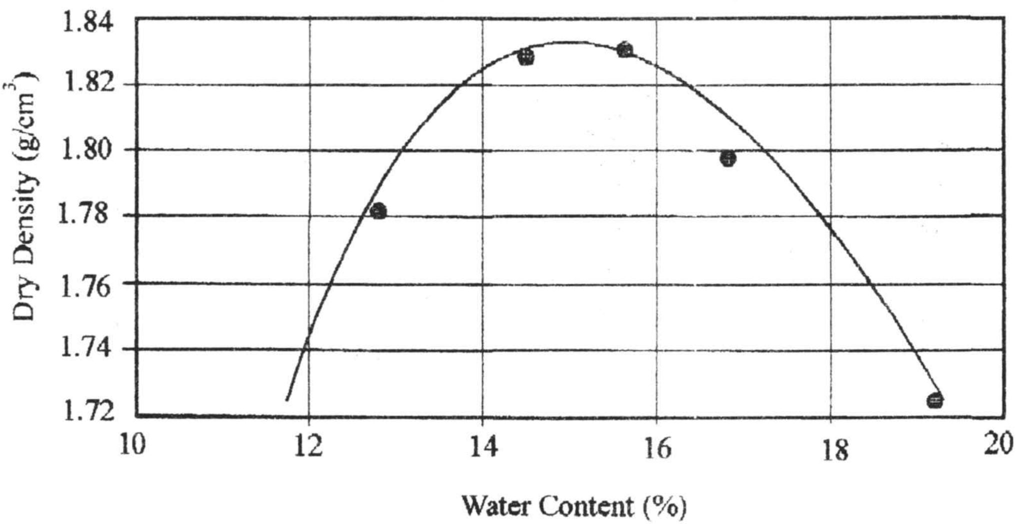
$\rho_{dry} = m_s / V_T = 1828.7 / 1000 = 1.8287\ g/cm^3$

4) $0.168\ m_s = m_w \quad 2100 = m_w + m_s \quad \Rightarrow \quad m_w = 302.1\ g. \quad m_s = 1797.9\ g.$

$\rho_{dry} = m_s / V_T = 1797.9 / 1000 = 1.7979\ g/cm^3$

5) $0.192\ m_s = m_w \quad 2055 = m_w + m_s \quad \Rightarrow \quad m_w = 331\ g. \quad m_s = 1724\ g.$

$\rho_{dry} = m_s / V_T = 1724 / 1000 = 1.724\ g/cm^3$



max ρ_{dry} = **1.83 g/cm³** optimum w (%) = **15 %**

$\rho_{dry\ max} = 1.83\ g/cm^3 = m_S/V_T \Rightarrow m_S = 1830\ g$

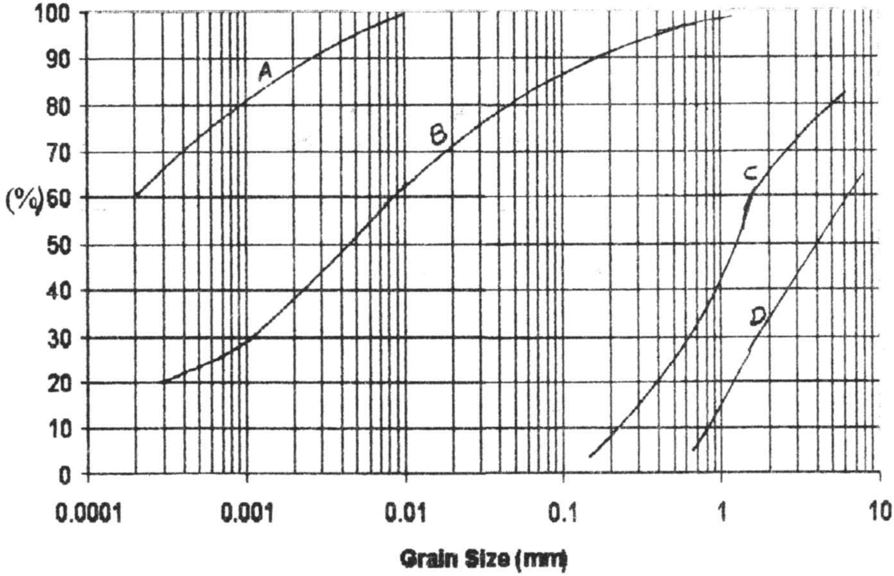
$0.15\ m_S = m_W \qquad m_W = 274.5\ g \Rightarrow V_W = 274.5\ cm^3$

$G_s = \dfrac{m_s}{V_s * \rho_w} \Rightarrow V_S = 685.4\ cm^3 \qquad V_a = 40.1\ cm^3$

$A = \dfrac{V_a}{V_T}$ = **0.04 = 4 %**

Problem 1.7. Classify the following soils according to the Unified Soil Classification system by using the given particle size distrubutions and Atterberg limits.

	LL	PL
Soil A	60	25
Soil B	28	12
Soil C	-	-
Soil D	-	-



Solution 1.7:

Soil A: LL = 60 PL = 25 PI = LL - PL PI = 35

soil A is **CH** (by using plasticity chart)

Soil B: LL = 28 Pl = 12 PI = LL - PL PI =16

soil B is **CL** (by using plasticity chart)

Soil C: $C_u = D_{60}/D_{10}$ $C_u = 1.5/0.2 = 7.5$

$C_c = D_{30}^2/(D_{60}*D_{10})$ $C_c = 0.36/(1.5*0.2) = 1.2$

soil C is **SW** (by using the unified soil classification system)

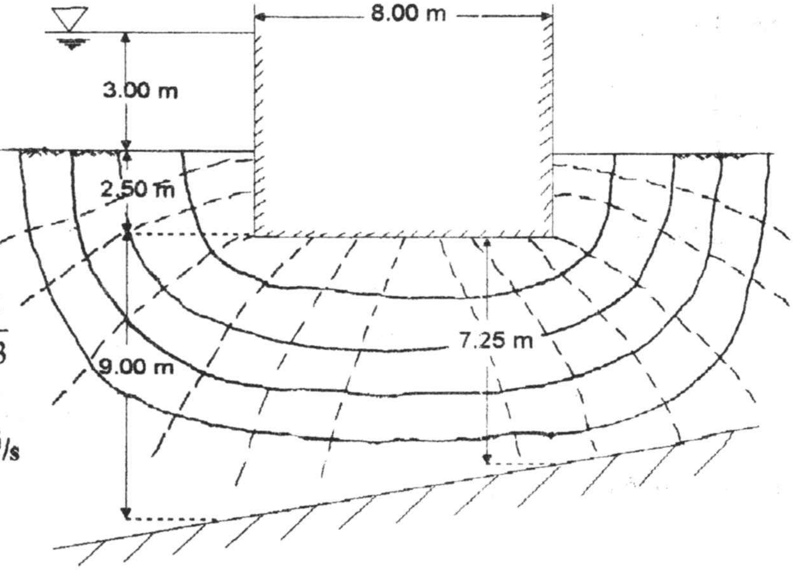
Soil D: $C_u = D_{60}/D_{10}$ $C_u = 6/0.8 = 7.5$

$C_c = D_{30}^2/(D_{60}*D_{10})$ $C_c = 2.7/(6*0.8) = 1.5$

soil D is **GW** (by using the unified soil classification system)

Problem 2.3. Draw the flow net for seepage under the structure detailed in following figure and determine the quantity of seepage. The coefficient of permeability of the soil is $5.0*10^{-5}$ m/s.

Solution 2.3:



$k = 5 * 10^{-5}$ m/s
$N_f = 5$
$N_d = 13$

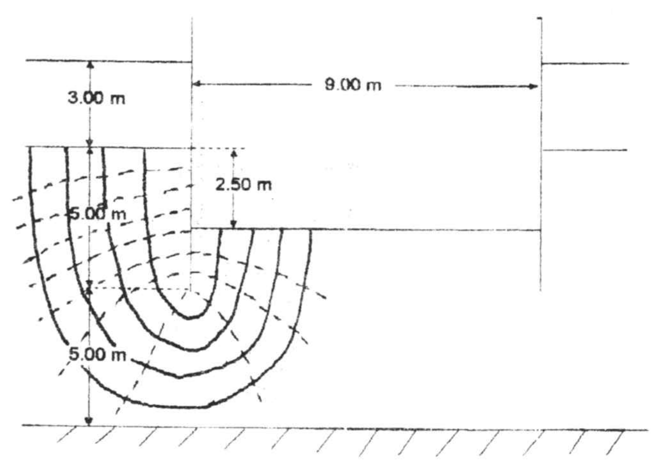
$$Q = k * h \frac{N_f}{N_d}$$

$$Q = 5 * 10^{-5} * 3 \frac{5}{13}$$

$$Q = \mathbf{5.77 * 10^{-5}\ m^3/s}$$

Problem 2.4. The section through a long cofferdam is shown in the following figure, the coefficient of permeability of the soil being $4.0*10^{-7}$ m/s. Draw the flow net and determine the quantity of seepage entering the cofferdam.

Solution 2.4:



$k = 4 * 10^{-7}$ m/s
$N_f = 5$
$N_d = 11$

$$Q \text{ of the right side} = k * h \frac{N_f}{N_d}$$

$$Q = 4 * 10^{-7} * 5.5 \frac{5}{11}$$

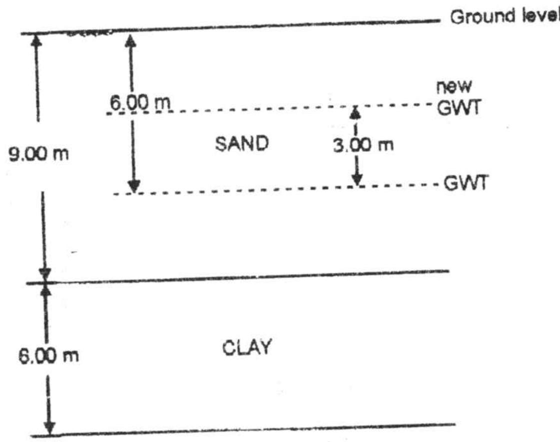
$Q = 10^{-6}$ m^3/s (per m)

Q of the right side=Q of the left side so;

Q of the coffer dam = **$2 * 10^{-6}$ m^3/s (per m)**

Problem 3.4. A layer of sand extends from ground level to a depth of 9 m. and overlies a layer of clay, of very low permeability, 6 m. thick. The water table is 6 m. below the surface of the sand. The saturated unit weight of the sand is 19 kN/m^3 and that of the clay 20 kN/m^3: the unit weight of the sand above the water table is 16 kN/m^3. Over a short period of time the water table rises by 3 m. and is expected to remain permanently at this new level. Determine the effective vertical stress at depths of 8 m. and 12 m. below ground level (a) before the rise of the water table, (b) several years after the rise of the water table.

Solution 3.4:



γ_{sat} for sand = 19 kN/m^3
γ_{sat} for clay = 20 kN/m^3
γ above the GWT = 16 kN/m^3

a) for the depth of 8 m;

$\sigma_v = (16 * 6) + (19 * 2) = 134$ kN/m^2
$u = 9.8 * 2 = 19.6$ kN/m^2
$\sigma'_v = \sigma_v - u = 134 - 19.6 =$ **114.4 kN/m^2**

for the depth of 12 m;

$\sigma_v = (16 * 6) + (19 * 3) + (20 * 3) = 213$ kN/m^2
$u = 9.8 * 6 = 58.8$ kN/m^2
$\sigma'_v = \sigma_v - u = 213 - 58.8 =$ **154.2 kN/m^2**

b) for the depth of 8 m;

$\sigma_v = (16 * 3) + (19 * 5) = 143$ kN/m^2
$u = 9.8 * 5 = 49$ kN/m^2
$\sigma'_v = \sigma_v - u = 143 - 49 =$ **94 kN/m^2**

for the depth of 12 m;

$\sigma_v = (16 * 3) + (19 * 6) + (20 * 3) = 222$ kN/m^2
$u = 9.8 * 9 = 88.2$ kN/m^2
$\sigma'_v = \sigma_v - u = 222 - 88.2 =$ **133.8 kN/m^2**