Introduction to Geotechnical Engineering 3rd edition Holtz Solutions Manual

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INSTRUCTOR'S SOLUTIONS MANUAL

AN INTRODUCTION TO GEOTECHNICAL ENGINEERING

THIRD EDITION

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CHAPTER 2: INDEX AND CLASSIFICATION PROPERTIES OF SOILS

2.1. Prepare a spreadsheet plot of dry density in kg/m^3 as the ordinate versus water content in percent as the abscissa. Assume $\rho_s = 2750$ kg/m^3 and vary the degree of saturation, S, from 100% to 40% in 10% increments. A maximum of 50% water content should be adequate (except for very soft clays, to be defined shortly). [Note: Such a graph is very useful to check problems that you do in this chapter, as there is a unique relationship between dry density, water content, and the degree of saturation for any given density of solids. Void ratio, wet density, and so on are then readily computed. Similar graphs for density of other solids may be easily computed and plotted.] Show all your equations as comments on your sheet for future reference.

Solution: Solve Eq. 2.12 and Eq. 2.15 for $\rho_d = f(\rho_s, \omega, S, G_s)$, or use Eq. 5.1.

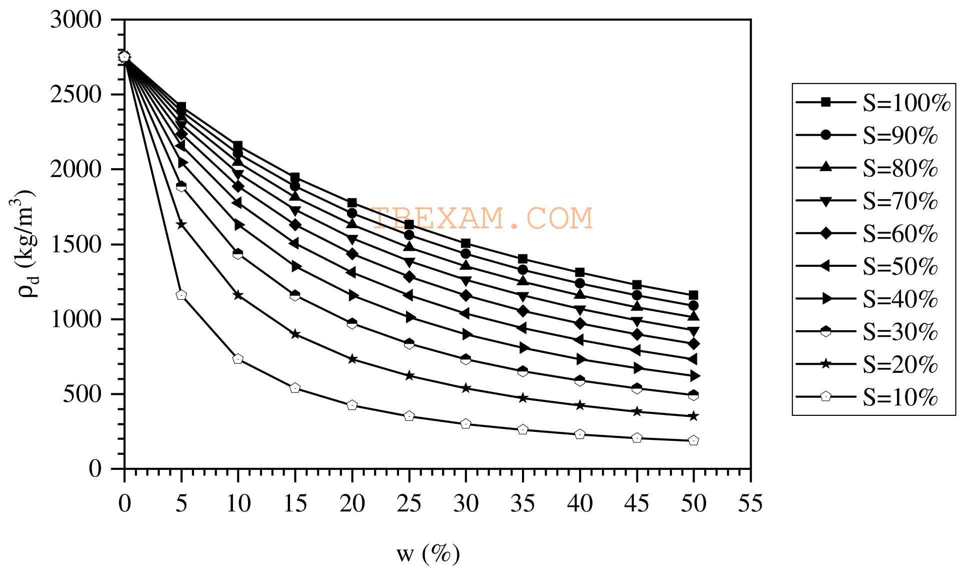
$$\rho_d = \frac{\rho_s}{1+e} \tag{2.12}$$

$$\rho_w S e = \omega \rho_s \tag{2.15}$$

Finally,

$$\rho_d = \frac{\rho_w S}{w + \dfrac{\rho_w}{\rho_s} S} = \frac{\rho_w S}{w + \dfrac{S}{G_s}}$$

ρ_w (kg/m^3)	1000									
ρ_s (kg/m^3)	2750									
G_s	2.75									
S(%)	100	90	80	70	60	50	40	30	20	10
w(%)					ρ_d (kg/m^3)					
0	2750	2750	2750	2750	2750	2750	2750	2750	2750	2750
5	2418	2386	2347	2299	2237	2157	2047	1886	1630	1158
10	2157	2106	2047	1974	1886	1774	1630	1435	1158	733
15	1947	1886	1814	1730	1630	1507	1354	1158	898	537
20	1774	1707	1630	1540	1435	1310	1158	971	733	423
25	1630	1559	1479	1387	1282	1158	1011	835	620	349
30	1507	1435	1354	1262	1158	1038	898	733	537	297
35	1401	1329	1248	1158	1056	940	807	653	473	259
40	1310	1238	1158	1069	971	859	733	589	423	229
45	1229	1158	1080	994	898	791	672	537	383	206
50	1158	1088	1011	928	835	733	620	493	349	186



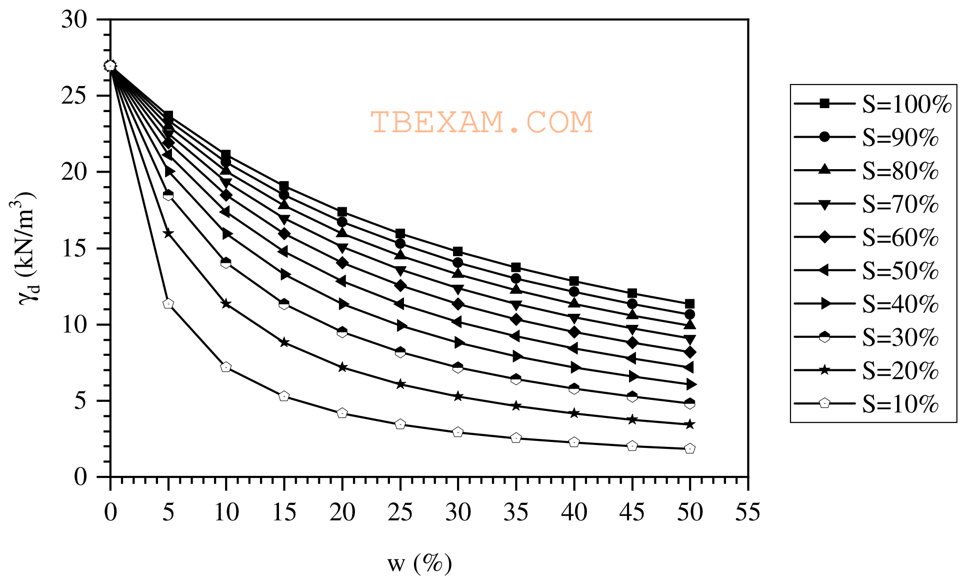
P. 2.1

2.2. Prepare a graph like that in Problem 2.1, only use dry density units of kN/m^3 and pounds per cubic feet.
Solution: From Eq. 2.12 and Eq. 2.15

$$\rho_d = \frac{\gamma_d}{g}; \qquad \gamma_d = \frac{\gamma_w S}{w + \dfrac{S}{G_s}}$$

2.2.a. In the SI unit system:

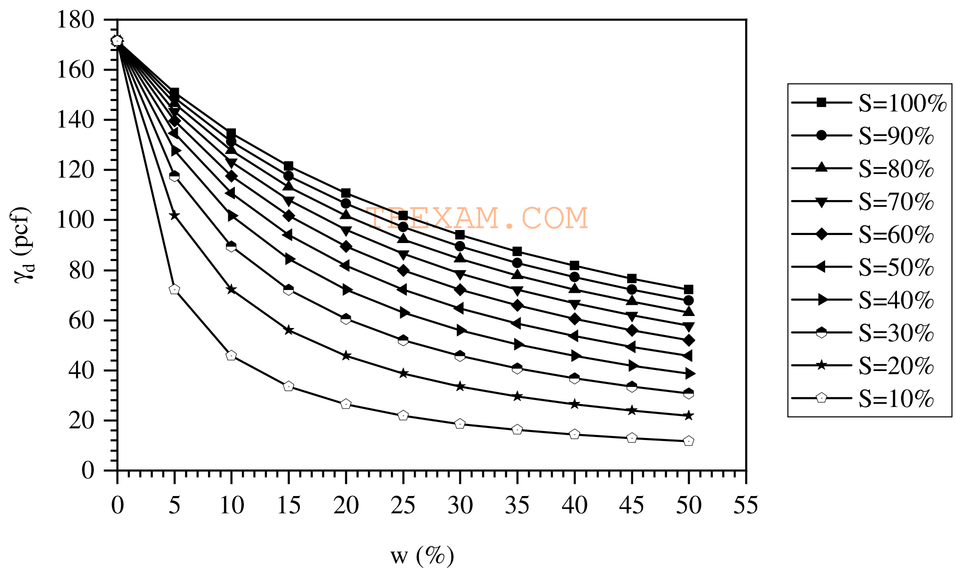
γ_w (kN/m^3)	9.8									
γ_s (kN/m^3)	26.95									
G_s	2.75									
S(%)	100	90	80	70	60	50	40	30	20	10
w(%)	γ_d (kN/m^3)									
0	26.95	26.95	26.95	26.95	26.95	26.95	26.95	26.95	26.95	26.95
5	23.69	23.38	23.00	22.53	21.93	21.14	20.06	18.48	15.97	11.35
10	21.14	20.64	20.06	19.35	18.48	17.39	15.97	14.06	11.35	7.19
15	19.08	18.48	17.78	16.96	15.97	14.77	13.27	11.35	8.80	5.26
20	17.39	16.73	15.97	15.09	14.06	12.83	11.35	9.51	7.19	4.15
25	15.97	15.28	14.49	13.60	12.56	11.35	9.91	8.19	6.07	3.42
30	14.77	14.06	13.27	12.37	11.35	10.17	8.80	7.19	5.26	2.91
35	13.73	13.02	12.23	11.35	10.35	9.21	7.91	6.40	4.64	2.54
40	12.83	12.13	11.35	10.48	9.51	8.42	7.19	5.78	4.15	2.25
45	12.04	11.35	10.58	9.74	8.80	7.76	6.58	5.26	3.75	2.01
50	11.35	10.66	9.91	9.09	8.19	7.19	6.07	4.83	3.42	1.83



P. 2.2.a

In the English unit system:

ρ_w (pcf)	62.4									
ρ_s (pcf)	171.6									
G_s	2.75									
$S(\%)$	100	90	80	70	60	50	40	30	20	10
$w(\%)$	ρ_d (pcf)									
0	171.56	171.56	171.56	171.56	171.56	171.56	171.56	171.56	171.56	171.56
5	150.82	148.82	146.40	143.39	139.57	134.56	127.67	117.64	101.67	72.24
10	134.56	131.41	127.67	123.17	117.64	110.68	101.67	89.51	72.24	45.75
15	121.46	117.64	113.19	107.95	101.67	94.01	84.46	72.24	56.02	33.48
20	110.68	106.49	101.67	96.07	89.51	81.70	72.24	60.55	45.75	26.39
25	101.67	97.26	92.27	86.55	79.95	72.24	63.10	52.12	38.66	21.79
30	94.01	89.51	84.46	78.75	72.24	64.74	56.02	45.75	33.48	18.55
35	87.42	82.90	77.87	72.24	65.88	58.65	50.37	40.77	29.52	16.15
40	81.70	77.20	72.24	66.72	60.55	53.61	45.75	36.76	26.39	14.30
45	76.68	72.24	67.36	61.98	56.02	49.37	41.91	33.48	23.87	12.83
50	72.24	67.87	63.10	57.88	52.12	45.75	38.66	30.73	21.79	11.63



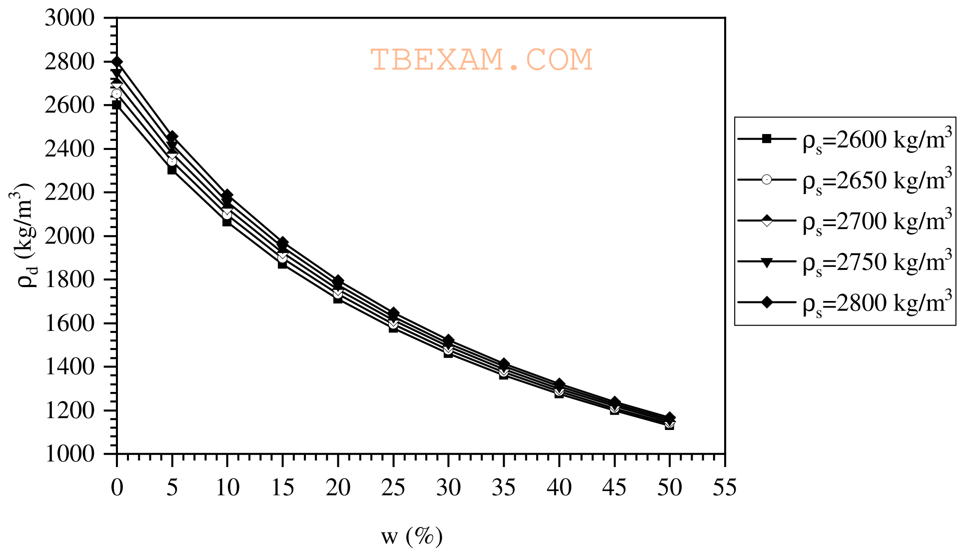
P. 2.2.b

2.3. Prepare a graph like that in Problem 2.1, only for S = 100%, and vary the density of solids from 2600 to 2800 kg/m^3. You decide the size of the increments you need to "satisfactorily" evaluate the relationship as ρ_s varies. Prepare a concluding statement of your observations.

Solution: The relationship between ρ_d and w is not overly sensitive to ρ_s.

$$\rho_d = \frac{\rho_w S}{w + \frac{\rho_w}{\rho_s} S}$$

ρ_w (kg/m^3)	1000				
S(%)	100				
ρ_s (kg/m^3)	2600	2650	2700	2750	2800
w(%)		ρ_d (kg/m^3)			
0	2600	2650	2700	2750	2800
5	2301	2340	2379	2418	2456
10	2063	2095	2126	2157	2188
15	1871	1896	1922	1947	1972
20	1711	1732	1753	1774	1795
25	1576	1594	1612	1630	1647
30	1461	1476	1492	1507	1522
35	1361	1375	1388	1401	1414
40	1275	1286	1298	1310	1321
45	1198	1209	1219	1229	1239
50	1130	1140	1149	1158	1167



P. 2.3.

2.4. The dry density of a compacted sand is 19.5 kN/m^3 and the density of the solids is 27.1 kN/m^3. What is the water content of the material when S=50%? Phase diagram!

From Eq. 5.1:

$$\rho_d = \frac{\rho_w S}{w + \dfrac{\rho_w}{\rho_s} S} = \frac{\gamma_d}{g}; \quad \gamma_d = \frac{\gamma_w S}{w + \dfrac{\gamma_w}{\gamma_s} S} \tag{5.1}$$

Solving for w:

$$w = S\gamma_w\left(\frac{1}{\gamma_d} - \frac{1}{\gamma_s}\right) = (0.5)(9.8)\left(\frac{1}{19.5} - \frac{1}{27.1}\right) = 0.07 = \underline{\underline{7\%}}$$

For phase diagram, assume $V_t = 1$ m^3.

$$\gamma_d = \frac{W_s}{V_t} \Rightarrow W_s = \gamma_s V_t = 19.5\,\text{kN}$$

$$w = \frac{W_w}{W_s} \times 100 \Rightarrow W_w = \frac{wW_s}{100} = \frac{(7)(19.5)}{100} = 1.37\,\text{kN}$$

$$W_t = W_w + W_s = 1.37 + 19.5 = 20.87\,\text{kN}$$

$$\rho_w = 9.8\,\text{kN/m}^3 = \frac{W_w}{V_w} \Rightarrow V_w = \frac{1.37}{9.8} = 0.14\,\text{m}^3$$

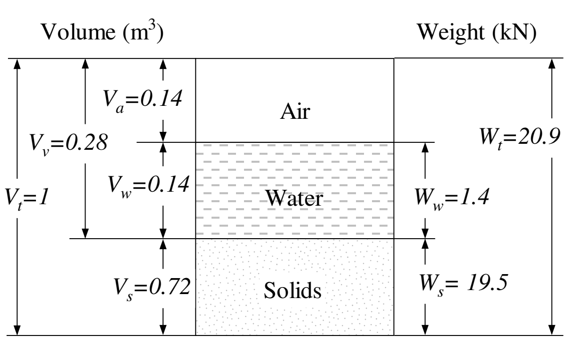
$$\rho_s = \frac{W_s}{V_s} \Rightarrow V_s = \frac{W_s}{\rho_s} = \frac{19.5}{27.1} = 0.72\,\text{m}^3$$

$$V_a = V_t - V_w - V_s = 0.14\,\text{m}^3$$

$$V_v = V_a + V_w = 0.28\,\text{m}^3$$

Checking that $S = 50$

$$S = \frac{V_w}{V_w} = \frac{0.14}{0.28} = 0.5 = 50\,\% \quad \text{(OK)}$$



P. 2.4. Phase diagram

2.5 A soil that is completely saturated has a total density of 2050 kg/m^3 and a water content of 20%. What is the density of the solids? What is the dry density of the soil? Phase diagram!

Solution:
a.) Solve using equations or phase diagrams:

$$\rho_d = \frac{\rho_t}{1+w} = \frac{2050}{1+0.20} = \underline{\underline{1708.3\,\mathrm{kg/m^3}}} \tag{2.14}$$

From: $\rho_{sat} = \left(1 + \frac{\rho_w}{\rho_s}\right)\rho_d + \rho_w$

$$\rho_s = \frac{\rho_w \rho_d}{\rho_d + \rho_w - \rho_{sat}} = \frac{(1000)(1708.3)}{(1708.3 + 1000 - 2045)} = \underline{\underline{2594.9\,\mathrm{kg/m^3}}}$$

b) Solve using phase diagram relationships: Assume $V_t = 1.0$ m^3

$$M_t = 2050\,\mathrm{kg}$$

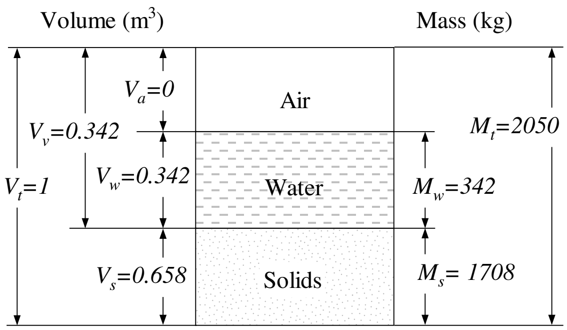
$$\frac{M_w}{M_s} = 0.20 \Rightarrow M_w = 0.20 M_s$$

$$M_t = M_w + M_s \Rightarrow 2050 = 0.2M_s + M_s \Rightarrow M_s = \frac{2050}{1+0.2} = 1708.3\,\mathrm{kg/m^3}$$

$$\rho_w = 1000 = \frac{M_w}{V_w} \Rightarrow V_w = \frac{0.20M_s}{1000} = 0.34\,\mathrm{m^3}$$

$$\rho_d = \frac{M_s}{V_t} = \frac{1708.3}{1} = \underline{\underline{1708.3\,\mathrm{kg/m^3}}}$$

$$\rho_s = \frac{M_s}{V_s} = \frac{1708.3}{1-0.34} = \underline{\underline{2594.9\,\mathrm{kg/m^3}}}$$



P. 2.5. Phase diagram

2.6 What is the water content of a fully saturated soil with a dry density of 1750 kg/m^3? Assume ρ_s = 2820 kg/m^3.

Solution:

From Eq. 2-12 and Eq. 2-15: $\rho_d = \dfrac{\rho_w S}{w + \dfrac{\rho_w}{\rho_s} S}$; Note that S = 100 %

Solving for w:

$$w = \rho_w S\left(\frac{1}{\rho_d} - \frac{1}{\rho_s}\right) = (1000\,\text{kg/m}^3)(100\,\%)\left(\frac{1}{1750\,\text{kg/m}^3} - \frac{1}{2820\,\text{kg/m}^3}\right) = 0.22 = \underline{\underline{22\,\%}}$$

2.7 A dry quartz sand has a density of 1675 kg/m^3. Determine its density when the degree of saturation is 65 %. The density of solids for quartz is 2680 kg/m^3.

Solution:

Recognize that ρ_d(initial) = ρ_d (final); S = 75 %

From Eq. 2-12 and Eq. 2-15: $\rho_d = \dfrac{\rho_w S}{w + \dfrac{\rho_w}{\rho_s} S}$; Note that S = 100 %

Solving for w:

$$w = \rho_w S\left(\frac{1}{\rho_d} - \frac{1}{\rho_s}\right) = (1000\,\text{kg/m}^3)(65\,\%)\left(\frac{1}{1675\,\text{kg/m}^3} - \frac{1}{2680\,\text{kg/m}^3}\right) = 0.168 = 16.8\,\%$$

Then, using Eq. 2.14:

$$\rho_d = \frac{\rho_t}{1 + w} \tag{2.14}$$

$\rho_t = \rho_d(1+w) = 1675\,\text{kg/m}^3(1+0.168) = \underline{\underline{1956.3\,\text{kg/m}^3}}$

2.8 The dry unit weight of a soil is 15.7 kN/m^3 and the solids have a unit weight of 26 kN/m^3 . Assuming the soil is saturated, find (a) water content, (b) void ratio, and (c) total unit weight.
a.) Water content. From Eq. 5.1:

$$\rho_d = \frac{\rho_w S}{w + \dfrac{\rho_w}{\rho_s}S} = \frac{\gamma_d}{g}; \quad \gamma_d = \frac{\gamma_w S}{w + \dfrac{\gamma_w}{\gamma_s}S} \tag{5.1}$$

Solving for w:

$$w = S\gamma_w\left(\frac{1}{\gamma_d} - \frac{1}{\gamma_s}\right) = (100\,\%)(9.8\,\text{kN/m}^3)\left(\frac{1}{15.7\,\text{kN/m}^3} - \frac{1}{26\,\text{kN/m}^3}\right) = 0.247 = \underline{\underline{24.7\%}}$$

b.) Void ratio. From Eq. 2.15:

$$\gamma_w Se = w\gamma_s \Rightarrow e = \frac{w\gamma_s}{S\gamma_w} = \frac{(24.7\%)(15.7\,\text{kN/m}^3)}{(100\%)(9.8\,\text{kN/m}^3)} = \underline{\underline{0.40}} \tag{2.15}$$

c.) Total density when the soil is saturated. Using Eq. 2.14:

$$\rho_d = \frac{\rho_t}{1+w} \tag{2.14}$$

$\rho_t = \rho_d(1+w) = 15.7\,\text{kN/m}^3(1+0.247) = \underline{\underline{19.6\,\text{kN/m}^3}}$

2.9 A natural deposit of soil is found to have a water content of 20% and to be 90 % saturated. What is the void ratio of this soil?

Solution:

$w = 20$ %, $S = 90$ %; assume $G_s = 2.70$ From Eq. 2.15:

$$\gamma_w Se = w\gamma_s \Rightarrow e = \frac{w\gamma_s}{S\gamma_w} = \frac{wG_s}{S} = \frac{(20)(2.7)}{(90)} = \underline{\underline{0.60}} \tag{2.15}$$

2.10 A chunk of soil has a wet weight of 62 lb and a volume of 0.56 ft^3. When dried in an oven, the soil weighs 50 lb. If the specific gravity of solids Gs = 2.64, determine the water content, wet unit weight, dry unit weight, and void ratio of the soil.

Solution:
Solve using phase diagram relationships.

a.) Water content:

$W_w = W_t - W_s = 62 - 50 = 12\,\text{lb}$

$w = \frac{W_w}{W_s} \times 100 = \frac{12(100)}{50} = 24.0\,\%$

b.) Wet unit weight:

$\gamma_t = \frac{W_t}{V_t} = \frac{62}{0.56} = 110.7\,\text{pcf}$

c.) Dry unit weight:

$\gamma_d = \frac{W_s}{V_t} = \frac{50}{0.56} = 89.29\,\text{pcf}$

d.) Void ratio:

$V_w = \frac{W_w}{\gamma_w} = \frac{12}{62.4} = 0.1923\,\text{ft}^3$

$V_s = \frac{W_s}{G_s\gamma_w} = \frac{50}{(2.64)(62.4)} = 0.3035\,\text{ft}^3$

$V_v = V_t - V_v = 0.56 - 0303 = 0.256$

$e = \frac{V_v}{V_s} = \frac{0.256}{0.303} = 0.84$

2.11 In the lab, a container of saturated soil had a mass of 115.5 g before it was placed in the oven and 102.4 g after the soil had dried. The container alone had a mass of 49.31 g. The specific gravity of solids is 2.70. Determine the void ratio and water content of the original soil sample.

Solution:

Solve using phase diagram relationships.

$M_s = 102.4 - 49.31 = 53.09\,\text{g}$

$M_w = 115.5 - 102.4 = 13.10\,\text{g}$

$w = \frac{M_w}{M_s} \times 100\% = 24.67\,\%$

From Eq. 2.15: $e = \frac{G_s w}{S} = \frac{(2.70)(24.67)}{100} = \underline{\underline{0.66}}$

2.12 The natural water content of a sample taken from a soil deposit was found to be 20.0 %. It has been calculated that the maximum density for the soil will be obtained when the water content reaches 25.0 %. Compute how many grams of water must be removed to each 1000 g of soil (in its natural state) in order to decrease the water content to 25.0 %.

Solution:

Natural state:

$w = 0.20 = \dfrac{M_w}{M_s} \Rightarrow M_w = 0.20M_s$

$M_t = M_s + M_w = M_s + 0.20M_s = 1.20M_s = 1000\,\mathrm{g}$

$M_s = 1000/1.20 = 833.33\,\mathrm{g}$

$M_w = (0.20)(833.3) = 166.67\,\mathrm{g}$

Target state:

(Note: M_s does not change between the natural state and the target state)

$M_w = wM_s = 0.25(833.33) = 208.33\,\mathrm{g}$

additional water necessary = 208.33-166.67 = $\underline{\underline{41.67\ \mathrm{g}}}$

2.13 A cubic meter of dry quartz sand ($G_s = 2.65$) porosity of 60 % is immersed in an oil bath having a density of 0.92 g/cm^3 . If the sand contains 0.27 m^3 of entrapped air, how much force is required to prevent it from sinking? Assume that a weightless, permeable membrane surrounds the specimen. (Prof. C. C. Ladd.)

Solution:

$V_t = 1\,\mathrm{m}^3 = 1,000,000\,\mathrm{cm}^3$

$n = \dfrac{V_v}{V_t} \Rightarrow V_v = nV_t = 0.6(1.0) = 0.60\,\mathrm{m}^3$

$V_s = V_t - V_v = 1.0 - 0.6 = 0.40\,\mathrm{m}^3$

$M_s = G_s\rho_w V_s = 2.65(1000\,\mathrm{kg/m}^3)(0.40\,\mathrm{m}^3) = 1060\,\mathrm{kg} = M_t$ (dry quartz sand)

$\rho_t = \dfrac{M_t}{V_t} = \dfrac{1060}{1.0} = 1060\,\mathrm{kg/m}^3$

$\rho_{bouy} = \rho_t - \rho_{oil} = 1060 - 920 = 140\,\mathrm{kg/m}^3$

$\gamma_{bouy} = \rho_{bouy} \times g = 140(9.81) = 1373.4\,\mathrm{N/m}^3$

Finally the force (F) is calculated as:

$F = \gamma_{bouy} \times (\text{entrapped air}) = 1373.4\,\mathrm{N/m}^3 \times 0.27\mathrm{m}^3 = \underline{\underline{370.8\,\mathrm{N}}}$

2.14 A soil sample taken from a borrow pit has a natural void ratio of 0.89. The soil will be used for a highway project where a total of 100,000 m^3 of soil is needed in its compacted state; its compacted void ratio is 0.69. How much volume has to be excavated from the borrow pit to meet the job requirements?

Solution:

$$V_s = \frac{V_v}{e} = \frac{V_t - V_s}{e} \Rightarrow V_s = \frac{V_t}{e+1}$$

Embankment:

$V_t = 100,000\,\mathrm{m}^3$

$$V_{s(emb)} = \frac{100,000}{0.69+1} = 59171.6\,\mathrm{m}^3$$

Borrow pit:

$V_{s(borr)} = V_{s(emb)} = 59171.6\,\mathrm{m}^3$

$$V_{s(emb)} = \frac{100,000}{0.89+1} = \frac{V_t}{e+1}$$

$V_{t(emb)} = V_s(e_{borr}+1) = (59171.6)(0.89+1) = \underline{\underline{111,834.3\,\mathrm{m}^3}}$

2.15 A sample of moist soil was found to have the following characteristics:

Total volume: $0.0138\ \mathrm{m}^3$
Total mass: 28.31 kg
Mass after oven drying: 23.40 kg
Specific gravity of solids: 2.71

Find the density, unit weight, void ratio, porosity, and degree of saturation for the moist soil.?

Solution:

a.) Density:

$$\rho_t = \frac{M_t}{V_t} = \frac{28.31}{0.0138} = \underline{\underline{2051.45\,\mathrm{kg/m}^3}}$$

b.) unit weight:

$\gamma_t = \rho_t \times g = (2051.45)(9.81) = 20124.72\,\mathrm{N/m}^3 = \underline{\underline{20.12\mathrm{kN/m}^3}}$

c.) void ratio:

$$V_s = \frac{M_s}{G_s\rho_w} = \frac{23.40}{2.71(1000)} = 0.00863\,\mathrm{m}^3$$

$V_v = V_v - V_s = 0.0138 - 0.00863 = 0.00516\,\mathrm{m}^3$

$$e = \frac{V_v}{V_s} = \frac{0.00516}{0.00863} = \underline{\underline{0.60}}$$

d.) porosity:

$$n = \frac{e}{1+e} \times 100 = \frac{0.60}{1+0.60} \times 100 = \underline{\underline{37.5\,\%}}$$

e.) degree of saturation:

$$M_w = 28.31 - 23.40 = 4.91\,\mathrm{g}$$

$$V_w = \frac{M_w}{\rho_w} = \frac{4.91}{1000} = 0.00491$$

$$S = \frac{V_w}{V_v} \times 100 = \frac{0.00491}{0.00516} = \underline{\underline{95.1\,\%}}$$

2.16 A gray silty clay (CL) is sampled from a depth of 12.5 feet. The "moist" soil was extruded from a 6-inch-high brass liner with an inside diameter of 7.18 cm and weighed 823 grams.

(a) Calculate the wet unit weight in pounds per cubic feet.
(b) A small chunk of the original sample had a wet weight of 154.3 grams and weighed 74.3 grams after drying. Compute the water content, using the correct number of significant figures.
(c) Compute the dry density in kg/m^3.

Solution:

a.) Wet unit weight in pcf:

$$V_t = \frac{\pi d^2}{4} \times L = \frac{\pi\left(7.18\,\mathrm{cm}\,(1\,\mathrm{in}/2.54\,\mathrm{cm})\right)^2}{4} \times 6\,\mathrm{in} = 37.65\mathrm{in}^3 = 37.65\mathrm{in}^3\left(1\,\mathrm{ft}^3/(12^3\,\mathrm{in}^3)\right) = 0.0218\,\mathrm{ft}^3$$

$$\gamma_t = \frac{M_t}{V_t} = \frac{823\,\mathrm{g}(1\,\mathrm{lb}/453.6\,\mathrm{g})}{0.0218\,\mathrm{ft}^3} = \underline{\underline{83.26\,\mathrm{lb/ft}^3}}$$

b.) water content

$$M_w = M_t - M_s = 140.9 - 85.2 = 55.7\,g$$

$$w = \frac{M_w}{M_s} \times 100 = \frac{55.7\,\mathrm{g}}{85.2\,\mathrm{g}} \times 100 = \underline{\underline{65\,4\%}}$$

c.) dry density

$$\gamma_d = \frac{\gamma_t}{1+w} = \frac{83.25\,\mathrm{pcf}}{1+0.654} = 50.35\,\mathrm{pcf}$$

$$\gamma_d = 50.35\,\mathrm{pcf}\left(\frac{1\,\mathrm{ft}}{0.3048\,\mathrm{m}}\right)^3\left(\frac{0.4536\,\mathrm{kg}}{1\,\mathrm{lb}}\right) = \underline{\underline{806.50\,\mathrm{kg/m}^3}}$$

2.17 A cylindrical soil specimen is tested in the laboratory. The following properties were obtained:

Sample diameter : 3 inches
Sample length: 6 inches
Wt. before drying in oven: 2.95 lb
Et. after drying in oven: 2.54 lb
Oven temperature: 110^oC
Drying time: 24 hours
Specific gravity of solids: 2.65

What is the degree of saturation of this sample?

Solution:

$$V_t = \frac{\pi(3)^2}{4} \times 6 = 42.4115\,\text{in}^3$$

$$V_s = \frac{W_s}{G_s\gamma_w} = \frac{2.54\,\text{lb}}{2.65(62.4\,\text{pcf})} = 0.01536\,\text{ft}^3 = 26.542\,\text{in}^3$$

$$V_v = V_t - V_s = 42.4115 - 26.542 = 15.869\,\text{in}^3$$

$$W_w = W_t - W_s = 2.95 - 2.54 = 0.41\,\text{lb}$$

$$V_w = \frac{W_w}{\gamma_w} = \frac{0.41\,\text{lb}}{62.4\,\text{pcf}} = 0.00657\,\text{ft}^3 = 11.354\,\text{in}^3$$

$$S = \frac{V_w}{V_v} \times 100\,\% = \frac{11.354}{15.869} \times 100 = \underline{\underline{71.5\,\%}}$$

2.18 A sample of saturated silt is 10 cm in diameter and 2.5 cm thick. Its void ratio in this state is 1.42, and the specific gravity of solids is 2.68. The sample is compressed to a 2-cm thickness without a change in diameter.
(a) Find the density of the silt sample, in g/cm^3, prior to being compressed.
(b) Find the void ratio after compression and the change in water content that occurred from initial to final state.

Solution:

a.) density

$$V_t = \frac{\pi(10)^2}{4} \times 2.5 = 196.35\,\text{cm}^3$$

$S = 100\,\% = \dfrac{V_w}{V_v} \Rightarrow V_w = V_v$

$e = \dfrac{V_v}{V_s} \Rightarrow V_v = eV_s = 1.42V_s$

$V_t = V_v + V_s = 1.42V_s + V_s = 2.42V_s = 196.35\,\mathrm{cm}^3 \Rightarrow V_s = 81.14\,\mathrm{cm}^3$

$V_v = 1.42V_s = 1.42(81.14) = 115.21\,\mathrm{cm}^3$

$M_w = \rho_w V_w = (1\,\mathrm{g/cm}^3)(115.21) = 115.21\,\mathrm{g}$

$M_s = G_s\rho_w V_s = 2.68(1\,\mathrm{g/cm}^3)(81.14\,\mathrm{cm}^3) = 217.44\,\mathrm{g}$

$M_t = M_w + M_s = 115.21 + 217.44 = 332.66\,\mathrm{g}$

$\rho_t = \dfrac{M_t}{V_t} = \dfrac{332.66}{196.35} = 1.694\,\mathrm{g/cm}^3 = \underline{\underline{1694\,\mathrm{kg/m}^3}}$

$w_{initial} = \dfrac{M_w}{M_s} \times 100 = \dfrac{115.21}{217.44} \times 100 = 53.0\,\%$

b.) void ratio and change in water content

<u>final conditions:</u>

$V_{t,2} = \dfrac{\pi(10)^2}{4} \times 2.0 = 157.08\,\mathrm{cm}^3$

$V_s = 81.14\,\mathrm{cm}^3 \quad \text{(no change)}$

$V_v = V_{t,2} - V_s = 157.08 - 81.14 = 75.94\,\mathrm{cm}^3$

$e_{final} = \dfrac{V_v}{V_s} = \dfrac{75.94}{81.14} = \underline{\underline{0.94}}$

$V_w = V_v = 75.94\,\mathrm{cm}^3 \quad \text{(Saturated)}$

$M_w = \rho_w V_w = (1\,\mathrm{g/cm}^3)(75.94\,\mathrm{cm}^3) = 75.94\,\mathrm{g}$

$w_{final} = \dfrac{75.94}{217.44} \times 100 = 34.9\,\%$

$\Delta w = w_{initial} - w_{final} = 53.0 - 34.9 = \underline{\underline{18.1\,\%}}$

2.19 A sample of sand has the following properties: total mass $M_t = 182$ g; total volume $V_t = 90$ cm^3; water content $w = 14$ %; specific gravity of solids $G_s = 2.71$. How much would the sample volume have to change to get 90 % saturation, assuming the sample mass M_t stayed the same?

Solution:

initial conditions:

$M_w = wM_s = 0.14M_s$

$M_t = M_s + 0.14M_s = 182\,\text{g} \Rightarrow M_s = \dfrac{182}{1.14} = 159.65\,\text{g}$

$M_w = 0.14(159.65) = 22.35\,\text{g}$

$V_w = \gamma_w M_w = (1\,\text{g/cm}^3)(22.35) = 22.35\,\text{cm}^3$

$V_s = \dfrac{M_s}{G_s\rho_w} = \dfrac{159.65}{2.71(1)} = 58.91\,\text{cm}^3$

$V_v = V_t - V_s = 90 - 58.91 = 31.09\,\text{cm}^3$

$S = \dfrac{V_w}{V_v} \times 100 = \dfrac{22.35}{31.09} \times 100 = 71.9\,\%$

desired condition: S= 90 %:

V_t changes, but V_s, V_w, M_s and M_w remain the same

$S = \dfrac{V_w}{V_v} \Rightarrow V_v = \dfrac{V_w}{S} = \dfrac{22.35}{0.90} = 24.834\,\text{cm}^3$

$V_t = V_s + V_v = 58.91 + 24.834 = 83.74\text{cm}^3$

$\Delta V = 90 - 83.74 = \underline{\underline{6.26\,\text{cm}^3}}$

2.20 A sample of soil plus container weighs 413.7 g when the initial water content is 9.5 %. The container weighs 258.7 g. How much water needs to be removed the original specimen if the water content is to be decreased by 4.2 %? (After U.S. Dept. of Interior, 1990.)

Solution:

initial conditions:

$M_{s+c} = 413.7\,\text{g}$

$M_c = 258.7\,\text{g}$

$M_s = M_{s+c} - M_c = 155\,\text{g}$

$w = \dfrac{M_w}{M_s} \Rightarrow M_w = M_s w = 155(0.095) = 14.72\,\text{g}$

Desired conditions:

$w_f = w_i - 4.2 = 9.5 - 4.2 = 5.3\,\%$

$M_{w,f} = M_s(w) = 155(0.053) = 8.22\,\%$

$\Delta w = M_w - M_{w,f} = 14.725 - 8.22 = \underline{\underline{6.51\,\text{g}}}$

2.21 A soil sample is dried in a microwave oven to determine its water content. From the data below, evaluate the water content and draw conclusions. The oven-dried water content is 19.4 %. The mass of the dish is 131.2 grams. (After U.S. Dept. of Interior, 1990.)

Time in Oven, min	Total Oven Time, min	Mass of Soil + Dish (g)
0	0	231.62
3	3	217.75
1	4[a]	216.22
1	5	215.72
1	6	215.48
1	7	215.32
1	8	215.22
1	9	215.19
1	10	215.19

[a] This total time of 4 minutes is from 3 minutes before and one more minute, giving a mass of soil + dish = 216.22 grams, and so on.

Solution:

$M_t = 231.62 - 131.2 = 100.42\,\text{g}$

$M_w = (0.194)M_s$

$M_t = 0.194M_s + M_s$

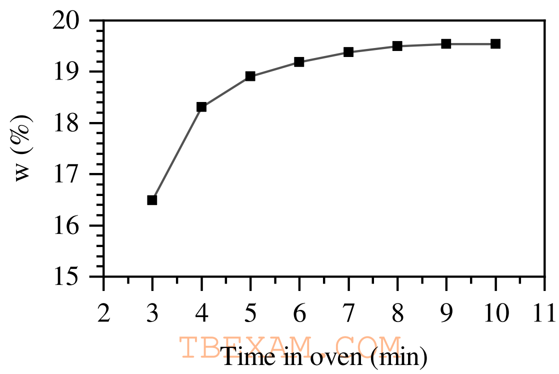
$M_s = \dfrac{M_t}{1.194} = 84.10\,\text{g} \quad \text{(this value is constant throughout drying period)}$

$w = \text{column 5} = \dfrac{M_w}{M_s} \times 100 = \dfrac{231.62 - \text{column 3}}{84.10} \times 100$

Conclusion: The loss of additional water in the soil sample becomes negligible after 8 to 10 minutes in the microwave oven used in the experiment.

Time in Oven, min	Total Oven Time, min	Mass of Soil + Dish (g)	Mass of water (g)	w_n (%)
0	0	231.62		
3	3	217.75	13.87	16.5
1	4[a]	216.22	15.4	18.3
1	5	215.72	15.9	18.9
1	6	215.48	16.14	19.2
1	7	215.32	16.3	19.4
1	8	215.22	16.4	19.5
1	9	215.19	16.43	19.5
1	10	215.19	16.43	19.5

[a] This total time of 4 minutes is from 3 minutes before and one more minute, giving a mass of soil + dish = 216.22 grams, and so on.



P. 2.21

2.22 The volume of water in a sample of soil with $S = 85\%$ is 0.32 m^3. The volume of solids V_s is 0.34 m^3. Given that the density of soil solids ρ_s is 2690 kg/m^3, find (a) the water content, (b)the void ratio, (c) the porosity, (d) the total or wet density and (e) the dry density. Give your answers in kg/m^3, and lbf/ft^3.

Solution:

a.) water content

$M_s = \rho_s V_s = 2690(0.34) = 914.6\,\text{kg}$

$M_w = \rho_w V_w = 1000(0.32) = 320\,\text{kg}$

$$w = \frac{M_w}{M_s} \times 100 = \frac{320}{914.6} \times 100 = \underline{\underline{35.0\%}}$$

b.) void ratio

$$G_s = \frac{\rho_s}{\rho_w} = \frac{2690}{1000} = 2.69$$

$$e = \frac{G_s w}{S} = \frac{2.69(35)}{85} = \underline{\underline{1.11}}$$

c.) the porosity

$$n = \frac{e}{1+e} \times 100 = \frac{1.107}{1+1.107} \times 100 = \underline{\underline{52.5\,\%}}$$

d.) total or wet density

$$V_t = V_s + V_v = V_s + eV_s = V_s(1+e) = 0.34(1+1.107) = 0.716\,\mathrm{m}^3$$

$$\rho_t = \frac{M_t}{V_t} = \frac{1234.6}{0.716} = \underline{\underline{1723.17\,\mathrm{kg/m^3}}} = \underline{\underline{107.57\,\mathrm{pcf}}}$$

$$\rho_d = \frac{M_s}{V_t} = \frac{914.94}{0.716} = \underline{\underline{1276.54\,\mathrm{kg/m^3}}} = \underline{\underline{79.69\,\mathrm{pcf}}}$$

2.23 A 592-cm^3 volume of moist sand weighs 1090 g. Its dry weight is 920 g and the density of solids is 2680 kg/m^3. Compute the void ratio, porosity, water content, degree of saturation, and total density in kg/m^3.

Solution:

$$\rho_s = 2680\,\mathrm{kg/m^3} = 2.68\,\mathrm{g/cm^3}$$

$$V_s = \frac{V_s}{\rho_s} = \frac{920}{2.68} = 343.284\,\mathrm{cm}^3$$

$$V_v = V_t - V_s = 592 - 343.284 = 248.716\,\mathrm{cm}^3$$

a.) void ratio

$$e = \frac{V_v}{V_s} = \frac{248.716}{343.284} = 0.724 = \underline{\underline{0.72}}$$

c.) the porosity

$$n = \frac{e}{1+e} \times 100 = \frac{0.7245}{1+0.7245} \times 100 = \underline{\underline{42.0\,\%}}$$

d.) water content

$$M_w = 1090 - 920 = 170\,\mathrm{g}$$

$$w = \frac{M_w}{M_s} \times 100 = \frac{170}{920} \times 100 = \underline{\underline{18.5\%}}$$

d.) saturation

$$V_w = \frac{M_w}{\rho_w} = 170\,\text{cm}^3$$

$$S = \frac{V_w}{V_v} \times 100 = \frac{170}{248.716} \times 100 = \underline{\underline{68.4\%}}$$

e.) total or wet density

$$\rho_t = \frac{M_t}{V_t} = \frac{1090}{592} = \underline{\underline{1.841\,\text{g/cm}^3}} = \underline{\underline{1841\,\text{kg/m}^3}}$$

2.24 The saturated unit weight γ_{sat} of a soil is 128 lbf/ft^3. Find the buoyant unit weight of this soil in lbf/ft^3 and buoyant density in kg/m^3.

Solution:

$$\gamma' = \gamma_{sat} - \gamma_w = 128 - 62.4 = \underline{\underline{65.6\,\text{lbf/ft}^3}}$$

$$\rho' = (65.6\text{lbf/ft}^3)\left(\frac{16.018\,\text{kg/m}^3}{1\,\text{lbf/ft}^3}\right) = \underline{\underline{1050.8\,\text{kg/m}^3}}$$

2.25 A sand is composed of solid constituents having a unit weight of 168.5 lb/ft^3. The void ratio is 0.62. Compute the unit weight of the sand when dry and when saturated and compare it with the unit weight when submerged.

Solution:

Assume $V_s = 1$ ft^3

$$V_v = eV_s = 0.62\,\text{ft}^3$$

$$V_t = V_s + V_v = 0.62 + 1 = 1.62\,\text{ft}^3$$

$$W_s = \rho_s V_s = 168.5(1) = 168.5\,\text{lb}$$

$$\gamma_d = \frac{W_s}{V_t} = \frac{168.5}{1.62} = 168.5\,\text{lb/ft}^3$$

$$\gamma_d = \frac{W_s}{V_t} = \frac{168.5}{1.62} = \underline{\underline{168.5\,\text{lb/ft}^3}}$$

When soil is saturated S=100 %, then $V_w = V_v = 0.62$ lb/ft^3

$W_w = \gamma_w V_w = 62.4(0.62) = 38.69\,\mathrm{lb}$

$\gamma_{sat} = \dfrac{W_s + W_w}{V_t} = \dfrac{168.5 + 38.69}{1.62} = \underline{\underline{127.9\,\mathrm{lb/ft^3}}}$

$\gamma' = \rho_{sat} - \rho_w = 127.9 - 62.4 = \underline{\underline{65.49\,\mathrm{lb/ft^3}}}$

2.26 A sample of natural glacial till was taken from below the groundwater table. The water content was found to be 43%. Estimate the wet density, dry density, buoyant density, porosity, and void ratio. Clearly state any necessary assumption.

Solution:

Assume $V_s = 1\ \mathrm{m^3}$ and $G_s = 2.70$

a.) total or wet density

$M_s = G_s V_s \rho_s = 2.7(1)(1000) = 2700\,\mathrm{kg/m^3}$

$M_w = wM_s = 0.43(2700) = 1161\,\mathrm{kg/m^3}$

$M_t = M_s + M_w = 2700 + 1161 = 3861\,\mathrm{kg/m^3}$

$S = \dfrac{V_w}{V_v} = 1 \Rightarrow V_w = V_v = \dfrac{M_w}{\rho_w} = 1.161\,\mathrm{m^3}$

$V_t = V_v + V_s = 1.161 + 1 = 2.161\,\mathrm{m^3}$

$\rho_t = \dfrac{M_t}{V_t} = \dfrac{3861}{2.161} = \underline{\underline{1786.7\,\mathrm{kg/m^3}}}$

b.) dry density

$\rho_d = \dfrac{M_s}{V_t} = \dfrac{2700}{2.161} = \underline{\underline{1249.4\,\mathrm{kg/m^3}}}$

c.) buoyant density

$\rho' = \rho_{sat} - \rho_w = 1786.67 - 1000 = 786.7 = \underline{\underline{786.7\mathrm{kg/m^3}}}$

c.) porosity

$n = \dfrac{V_v}{V_t} = \dfrac{1.161}{2.161} = \underline{\underline{53.7\,\%}}$

d.) void ratio

$e = \dfrac{V_v}{V_s} = \dfrac{1.161}{1} = \underline{\underline{1.2}}$

2.27 The void ratio of clay soil is 0.58 and the degree of saturation is 80%. Assuming the specific gravity of solids is 2.69, compute (a) the water content and (b) dry and wet densities in both SI and British imperial units.

Solution:

Assume $V_s = 1.0\ \text{m}^3$

$V_v = eV_s = 0.58(1.0) = 0.58\,\text{m}^3$

$V_w = SV_v = 0.80(0.58) = 0.464\,\text{m}^3$

$V_t = 0.58 + 1 = 1.58\,\text{m}^3$

$M_w = \rho_w V_w = (1000)(0.464) = 464\,\text{kg}$

$M_s = \rho_s V_s = (2690)(1) = 2690\,\text{kg}$

$M_t = M_s + M_w = 2690 + 464 = 3154\,\text{kg}$

a.) water content:

$$w = \frac{M_w}{M_s} \times 100 = \frac{464}{2690} = \underline{\underline{17.2\,\%}}$$

b.) dry density

$$\rho_d = \frac{M_s}{V_t} = \frac{2690}{1.58} = \underline{\underline{1702\,\text{kg/m}^3}} = \underline{\underline{106.29\,\text{lb/ft}^3}}$$

c.) wet density

$$\rho_t = \frac{M_t}{V_t} = \frac{2690}{1.58} = \underline{\underline{1996\,\text{kg/m}^3}} = \underline{\underline{124.6\,\text{lb/ft}^3}}$$

2.28 The values of minimum n and maximum n for a pure silica sand ($G_s = 2.7$) were found to be 35 % and 42 %, respectively. What is the corresponding range in the saturated unit weight in lb/ft^3?

Solution:

$$e = \frac{n}{1-n} \Rightarrow e_{min} = \frac{0.35}{1-0.35} = 0.54; \quad e_{max} = \frac{0.42}{1-0.42} = 0.72$$

$$\text{From} : \rho_{sat} = \frac{\rho_s + \rho_w e}{1+e} \tag{2.17}$$

$$G_s = \frac{\rho_s}{\rho_w} \Rightarrow \rho_s = G_s \rho_w = 2.7(62.4) = 168.5\,\text{pcf}$$

maximum: $\rho_{sat} = \dfrac{168.5 + 62.4(0.538)}{1 + 0.538} = \underline{\underline{131.35\,\text{pcf}}}$

minimum: $\rho_{sat} = \dfrac{168.5 + 62.4(0.724)}{1 + 0.724} = \underline{\underline{123.926\,\text{pcf}}}$

2.29 Calculate the maximum possible porosity and void ratio for a collection of (a) basketballs (9 in. in diameter), (b) tennis balls (2.7 in. in diameter) and (c) tiny ball bearings 0.01 in. in diameter. Write a sentence about what causes the differences across these size "particles."

Solution:

Three-dimensional particle arrangement of equal spheres has been studied in depth by mathematicians, statisticians, and materials scientists since the 1600s. A quick internet search on packing of equal spheres will reveal numerous mathematical theories and approaches for estimating the densest and loosest possible packing. In general, the loosest arrangement of equal spheres yields a void fraction of about 0.48, regardless of sphere size. As an aside, the densest possible packing of equal-size spheres yields a solids volume of about: $V_s = \pi/\sqrt{18} = 0.7405$ (These values are approximate – there is not a unified consensus in the literature.)

Loosest packing

For $V_t = 1.0, \quad V_v = 0.48, \quad$ and $\quad V_s = 1 - 0.48 = 0.52;$ thus:

$$n_{max} = \frac{V_v}{V_t} \times 100 = \frac{0.48}{1.0} \times 100 = \underline{\underline{48\%}}$$

$$e_{max} = \frac{V_v}{V_s} = \frac{0.48}{0.52} = \underline{\underline{0.92}}$$

Densest packing (not required in problem statement)

$V_s = 0.7405, \quad V_v = 1 - 0.7405 = 0.2595,$ thus:

$$n_{max} = \frac{V_v}{V_t} \times 100 = \frac{0.2595}{1.0} \times 100 = \underline{\underline{26\%}}$$

$$e_{max} = \frac{V_v}{V_s} = \frac{0.595}{0.7405} = \underline{\underline{0.35}}$$

2.30 A plastic-limit test has the following results:

Wet weight + container = 24.75 g
Dry weight + container = 19.37 g
Container weight = 1.46 g

Compute the PL of the soil.

Solution:

$M_w = 24.75 - 19.37 = 5.38\,\text{g}$

$M_s = 19.37 - 1.46 = 17.91\,\text{g}$

$$PL = \frac{M_w}{M_s} \times 100 = \frac{5.38}{17.91} \times 100 = \underline{\underline{30\%}}$$

2.31 During a liquid-limit test, the following data was obtained for one of the samples::

$$\text{Wet weight + container} = 24.29\,\text{g}$$
$$\text{Dry weight + container} = 17.62\,\text{g}$$
$$\text{Container weight} = 1.50\,\text{g}$$

And the groove in the Casagrande cup close 1/2" at 22 blows. What is the LL of th soil.

Solution:

Use the one-point method.

$M_w = 24.29 - 17.62 = 6.67\,\text{g}$

$M_s = 17.62 - 1.5 = 16.12\,\text{g}$

$$w_n = \frac{M_w}{M_s} \times 100 = \frac{6.67}{16.12} \times 100 = \underline{\underline{41.4\%}}$$

Use Eq. (2.38)

$$LL = w_n\left(\frac{N}{25}\right)^a = 0.414\left(\frac{22}{25}\right)^{0.12} = \underline{\underline{40.7\%}} \tag{2.38}$$

2.32 The "chunk density" method is often used to determine the unit weight (and other necessary information) of a specimen of irregular shape, especially of friable samples. The specimen at its natural water content is (1) weighed, (2) painted with a thin coat o wax or paraffin (to prevent water from moving into or out of the pores), (3) weighed again ($W_t + W_{max}$), and (4) weighed in water (to get the volume of the sample + wax coating - remember Archimedes?). Finally, the natural water content of the specimen is determined. A specimen of cemented silty sand is treated in this way to obtain the "chunk density." From the information given below, determine the (a) wet density, (b) dry density, (c) void ratio, and (d) degree of saturation of the sample.

Given:

Weight of specimen at natural water content in air	$= 181.8\,\mathrm{g}$
Weight of specimen + wax coating in air	$= 215.9\,\mathrm{g}$
Weight of specimen + wax in water	$= 58.9\,\mathrm{g}$
Natural water content	$= 2.5\,\%$
Soil solid density, ρ_s	$= 2650\,\mathrm{kg/m^3}$
Wax solid density, ρ_{wax}	$= 940\,\mathrm{kg/m^3}$

Phase diagram!!

Solution:

$$w = \frac{M_t - M_s}{M_s} \Rightarrow M_s = \frac{M_t}{1+w} = \frac{181.8}{1+0.025} = 177.366\,\mathrm{g}$$

$$M_w = M_t - M_s = 181.8 - 177.4 = 4.43\,\mathrm{g}$$

$$V_s = \frac{M_s}{\rho_s} = \frac{177.366\,\mathrm{g}}{2.650\,\mathrm{g/cm^3}} = 66.93\,\mathrm{cm^3}$$

$$V_w = \frac{M_w}{\rho_w} = \frac{4.43\,\mathrm{g}}{1.0\,\mathrm{g/cm^3}} = 4.43\,\mathrm{cm^3}$$

$$M_{wax} = M_{t+wax} - M_{\text{water displaced}} \Rightarrow M_{\text{water displaced}} = 215.9 - 58.9 = 157.0\,\mathrm{g}$$

$$V_{t+wax} = \frac{M_{\text{water displaced}}}{\rho_w} = \frac{157}{1.0} = 157.0\,\mathrm{cm^3}$$

$$V_{air} = V_{t+wax} - V_{wax} - V_w - V_s = 157.0 - 36.28 - 4.43 - 66.93 = 49.36\,\mathrm{cm^3}$$

$$V_v = V_{air} + V_w = 49.36 + 4.43 = 53.79\,\mathrm{cm^3}$$

$$V_t = V_{t+wax} - V_{wax} = 157.0 - 36.28 = 120.72\,\mathrm{cm^3}$$

a.) total density

$$\rho_t = \frac{M_t}{V_t} = \frac{181.8}{120.72} = \underline{\underline{1.50\,\mathrm{g/cm^3}}} = \underline{\underline{1506\,\mathrm{kg/m^3}}}$$

b.) dry density

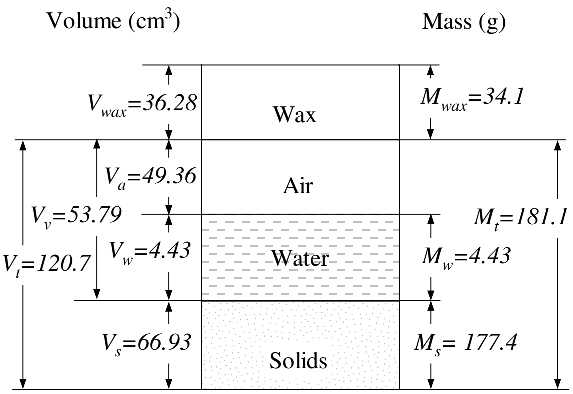
$$\rho_d = \frac{M_s}{V_t} = \frac{177.366}{120.72} = \underline{\underline{1.47\,\mathrm{g/cm^3}}} = \underline{\underline{1469\,\mathrm{kg/m^3}}}$$

c.) void ratio

$$e = \frac{V_v}{V_s} = \frac{53.79}{66.93} = \underline{\underline{0.80}}$$

c.) saturation

$$S = \frac{V_w}{V_v} \times 100 = \frac{4.43}{53.79} = \underline{\underline{8.2\%}}$$



P. 2.32. Phase diagram

2.33 A sensitive volcanic clay soil was tested in the laboratory and found to have the following properties:

(a) $\rho = 1280\ \text{kg/m}^3$
(b) e = 9.0
(c) S = 95 %
(d) $\rho_s = 2750\ \text{kg/m}^3$
(e) w = 311 %

In rechecking the above values, one was found to be inconsistent with the rest. Find the inconsistent value and report it correctly. Show all your computations and phase diagrams.

Solution:

Assume $V_s = 1\ \text{m}^3$

$$M_s = \rho_s V_s = 2750\,\text{kg}$$

$$M_w = wM_s = 3.11(2750) = 8552.5\,\text{kg}$$

$$M_t = M_s + M_w = 2750 + 8552.5 = 11302.5\,\text{kg}$$

$$V_t = \frac{M_t}{\rho_t} = \frac{11302.5}{1280} = 8.83\,\text{m}^3$$

$$V_v = eV_s = 9(1) = 9\,\text{m}^3$$

$$V_t = V_v + V_s = 9 + 1 = 10\,\text{m}^3 \neq 8.83\,\text{m}^3$$

Check: $G_s w = Se$

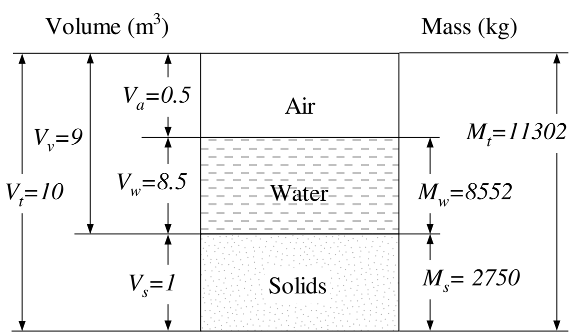
$$2.65(3.11) = (0.95)(9.0)$$

$8.55 = 8.55$ These values are in correct proportion

Consequently, the error must be in ρ_t value.

Re-calculate $\rho_t = \dfrac{M_t}{V_t} = \dfrac{11302.5}{10} = 1130.2\,\mathrm{kg/m^3}$

Solution $\rho_t = \underline{\underline{1130.2\,\mathrm{kg/m^3}}}$



P. 2.33. Phase diagram

2.34 A 15 cm high cylinder contains 847 cm^3 of loose dry sand which weighs 843 g. Under a static load of 200 kPa the volume is reduced 3%, and then by vibration it is reduced 12% from the original volume. Assume the solid density of the sand grains is 2710 kg/m^3. Compute the void ratio, porosity, dry density, and total density corresponding to each of the following cases:

(a) Loose sand
(b) Sand under static load
(c) Vibrated and loaded sand

Solution:

$V_s = \dfrac{M_s}{\rho_s} = \dfrac{843}{2.71} = 311.1\,\mathrm{cm^3}$; $\quad M_t = 843g$

dry sand: $M_w = V_w = 0$

a.) loose sand - Initial condition

$V_t = 847\,\mathrm{cm^3}$

$V_v = V_t - V_s = 847 - 311.1 = 535.93\,\mathrm{cm^3}$

$e = \dfrac{V_v}{V_s} = \dfrac{535.93}{311.1} = \underline{\underline{1.72}}$

$$n = \frac{V_v}{V_t} \times 100 = \frac{535.93}{847} \times 100 = \underline{\underline{63.3\,\%}}$$

$$\rho_d = \rho_t = \frac{M_s}{V_t} = \frac{843}{847} = 0.995\,\text{g/cm}^3 = \underline{\underline{995\,\text{kg/m}^3}}$$

b.) Sand under static load

$$V_t = 847 - 847(0.03) = 821.59\,\text{cm}^3$$

$$V_v = V_t - V_s = 821.59 - 311.1 = 510.52\,\text{cm}^3$$

$$e = \frac{V_v}{V_s} = \frac{510.52}{311.1} = \underline{\underline{1.64}}$$

$$n = \frac{V_v}{V_t} \times 100 = \frac{510.52}{821.59} \times 100 = \underline{\underline{62.14\,\%}}$$

$$\rho_d = \rho_t = \frac{M_s}{V_t} = \frac{843}{821.59} = 1.026\,\text{g/cm}^3 = \underline{\underline{1026\,\text{kg/m}^3}}$$

c.) Vibrated and loaded sand

$$V_t = 847 - 847(0.12) = 723\,\text{cm}^3$$

$$V_v = V_t - V_s = 723 - 311.1 = 411.93\,\text{cm}^3$$

$$e = \frac{V_v}{V_s} = \frac{411.93}{311.1} = \underline{\underline{1.32}}$$

$$n = \frac{V_v}{V_t} \times 100 = \frac{411.93}{723} \times 100 = \underline{\underline{57.0\,\%}}$$

$$\rho_d = \rho_t = \frac{M_s}{V_t} = \frac{843}{723} = 1.166\,\text{g/cm}^3 = \underline{\underline{1166\,\text{kg/m}^3}}$$

2.35 On five-cycle semilogarithmic paper, plot the grain-size distribution curves from the following mechanical analysis data on six soils, A through F. For each soil determine the effective size as well as the uniformity coefficient and the coefficient of curvature. Determine also the percentages of gravel, sand silt, and clay according to (a) ASTM, (b) AASHTO, (c) USCS, and (d) the British Standard.

U.S. Standard Sieve No. or Particle Size	Percent Passing by Weight Soil A	Soil B	Soil C	Soil D	Soil E	Soil F
75 mm (3 in.)	100.00		100			
38 (1-1/2)	70		—			
19 (3/4)	49	100	91			
9.5 (3/8)	36	—	87			
No. 4	27	88	81		100	
No. 10	20	82	70	100	89	
No. 20	—	80	—	99	—	
No. 40	8	78	49	91	63	
No. 60	—	74	—	37	—	
No. 100	5	—	—	9	—	
No. 140	—	65	35	4	60	
No. 200	4	55	32	—	57	100
40 μm	3	31	27		41	99
20 μm	2	19	22		35	92
10 μm	1	13	18		20	82
5 μm	<1	10	14		8	71
2 μm	—	—	11		—	52
1 μm	—	2	10		—	39

Note: Missing data is indicated by a dash in the column.

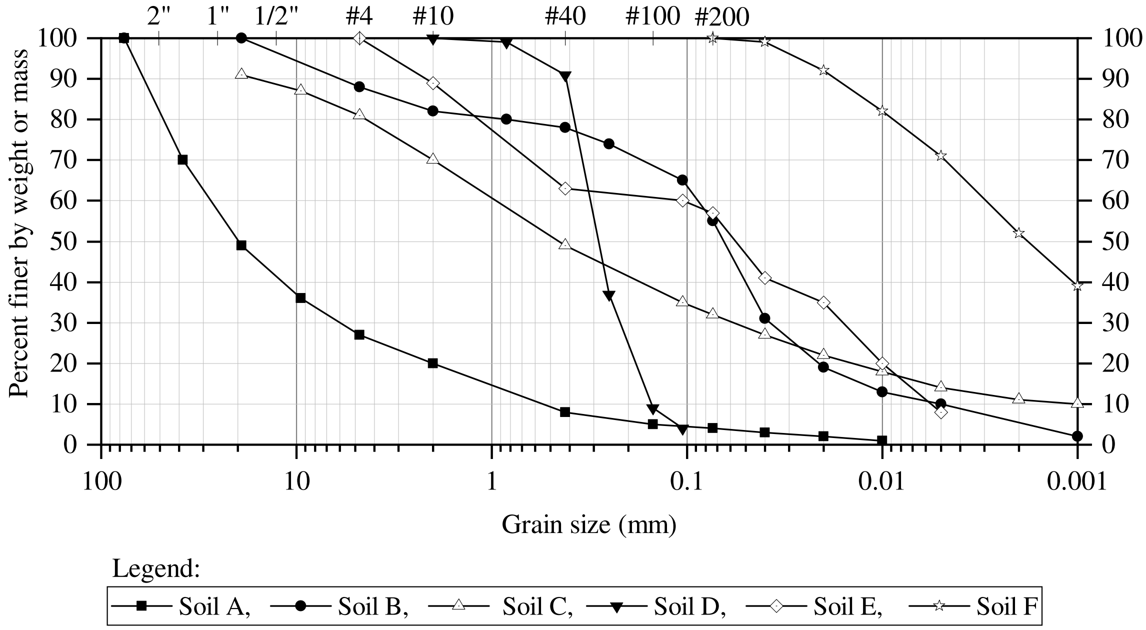
Solution:

$$C_u = \frac{D_{60}}{D_{10}} \tag{2.24}$$

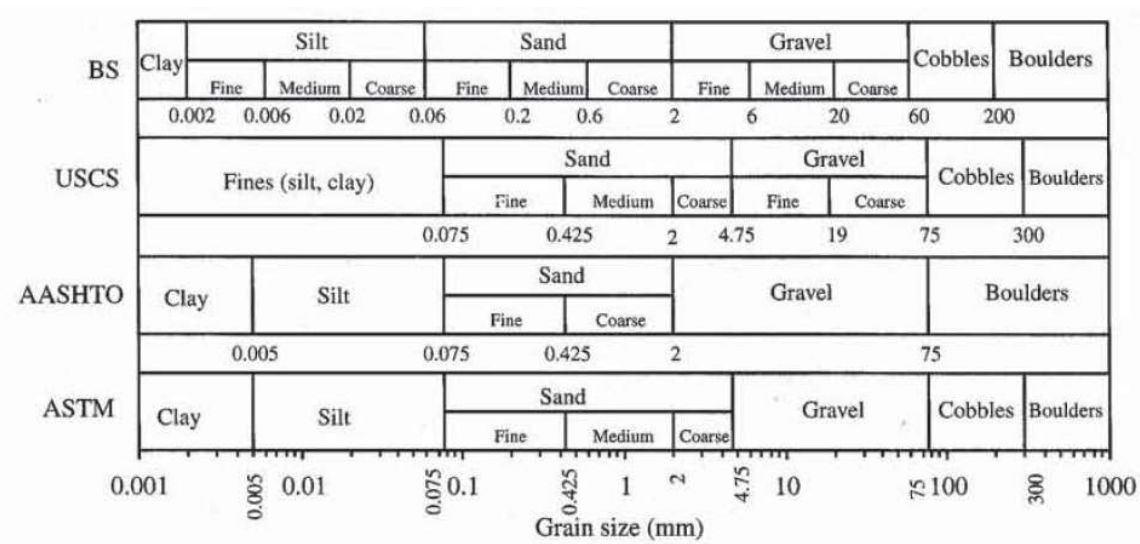
$$C_c = \frac{D_{30}^2}{D_{60} \times D_{10}} \tag{2.25}$$

Effective size, uniformity coefficient and coefficient of curvature:

Soil	Effective size D_{10} (mm)	D_{30} (mm)	D_{60} (mm)	C_u	C_c
A	0.6	6	28	46.7	2.1
B	0.005	0.04	0.09	18.0	3.6
C	0.001	0.06	1	1000.0	3.6
D	0.16	0.22	0.3	1.9	1.0
E	0.006	0.015	0.1	16.7	0.4
F	N/D	N/D	0.003	N/D	N/D



P. 2.35. Granulometric curve



P. 2.35. Soil classification chart after (Bardet and Jean-Pierre, 1997)

(a) Table. Percentages according to ASTM

Percentage (%)	Soil A	Soil B	Soil C	Soil D	Soil E	Soil F
Gravel	73	12	19	0	0	0
Sand	23	33	49	100	43	0
Silt	4	45	18	0	49	29
Clay	0	10	14	0	8	71
Fines (silt+clay)	4	55	32	0	57	100
Check:	100	100	100	100	100	100

(b) Table. Percentages according to AASHTO

Percentage (%)	Soil A	Soil B	Soil C	Soil D	Soil E	Soil F
Gravel	80	18	30	0	11	0
Sand	16	27	38	100	32	0
Silt	4	45	18	0	49	29
Clay	0	10	14	0	8	71
Fines (silt+clay)	4	55	32	0	57	100
Check:	100	100	100	100	100	100

(c) Table. Percentages according to USCS

Percentage (%)	Soil A	Soil B	Soil C	Soil D	Soil E	Soil F
Gravel	73	12	19	0	0	0
Sand	23	33	49	100	43	0
Silt	-	-	-	-	-	-
Clay	-	-	-	-	-	-
Fines (silt+clay)	4	55	32	0	57	100
Check:	100	100	100	100	100	100

(d) Table. Percentages according to the British Standard

Percentage (%)	Soil A	Soil B	Soil C	Soil D	Soil E	Soil F
Gravel	80	18	30	0	11	0
Sand	16	27	38	100	32	0
Silt	4	45	21	0	57	48
Clay	0	10	11	0	0	52
Fines (silt+clay)	4	55	32	0	57	100
Check:	100	100	100	100	100	100

2.37 The soils in Problem 2.35 have the following Atterberg limits and natural water contents. Determine the PI and LI for each soil and comment on their general activity.

Solution:

From equations:

Soil A: very sensitive, highly active
Soil B: most likely a clay above the water table that has experienced a decrease in moisture
Soil C: most likely a clay above the water table that has experienced a decrease in moisture
Soil D: most likely a fine sand
Soil E: most likely a silt
Soil F: slightly sensitive and active

P. 37

Property	Soil A	Soil B	Soil C	Soil D	Soil E	Soil F
w_n (%)	27	14	14	11	8	72
LL	13	35	35	—	28	60
PL	8	29	18	NP	NP	28
PI	5	6	17	0	0	32
LI	3.8	-2.5	-0.24	-	-	1.38

2.38 Comment on the validity of the results of Atterberg limits on soils G and H.

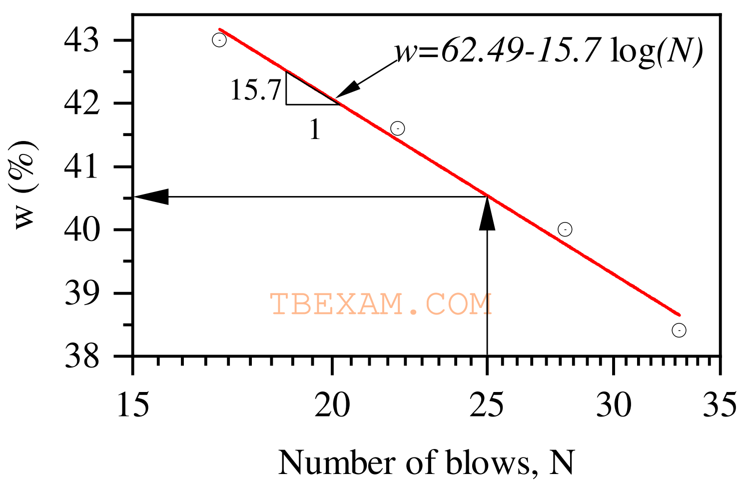
Solution:

Based on Atterberg's definitions: LL > > PL > SL. Soil G violates the definitions because the SL > PL (25 > 20). Soil H violates the definitions because the PL > LL (42 > 38).

2.39 The following data were obtained from a liquid-limit test on a silty clay.

Two plastic-limit determinations had water contents of 24.2% and 23.5%. Determine the LL, PI, the flow index, and the toughness index. The flow index is the slope of the water content versus log of number of blows in the liquid-limit test, and the toughness index is the PI divided by the flow index.

Solution:



P. 2.39.

$LL = 62.49 - 15.47N = 62.49 - 15.47log(25) = \underline{\underline{40.5\%}}$

P. 2.38

	Soil G	Soil H
LL	55	38
PL	20	42
SL	25	—
PI	35	-4

P. 2.39

No. of Blows	Water Content, %
33	38.4
28	40
22	41.6
17	43

$$PL_{avg} = \frac{24.2 + 23.5}{2} = 23.85\%$$

$$PL = PL_{avg} \pm 0.05PL_{avg} = \underline{\underline{23.85 \pm 1.19\%}} \qquad (2.26)$$

The flow index is the slope of the trend line equal to $\underline{\underline{15.7\%}}$

The toughness index is defined as: $= \frac{PI}{\text{flow index}} = \frac{LL - PL}{15.7} = \frac{15.5 \pm 1.19}{15.7} = \underline{\underline{\{0.9; 1.1\}}}$

2.40 Classify the following soils according to the USCS:

(a) A sample of well-graded gravel with sand has 73% fine to coarse subangular gravel, 25% fine to coarse subangular sand, and 2% fines. The maximum size of the particles is 75 mm. The coefficient of curvature is 2.7, while the uniformity coefficient is 12.4.

Solution: GW – Well-graded gravel with sand.

(b) A dark brown, wet, organic-odor soil has 100% passing the No. 200 sieve. The liquid limit is 32% (not dried, and is 21% when oven dried!) and the plastic index is 21% (not dried).

Solution: OL – Organic clay or Organic silt.

(c) This sand has 61% predominately fine sand, 23% silty fines, and 16% fine subrounded gravel size. The maximum size is 20 mm. The liquid limit is 33% and the plastic limit is 27%.

Solution: SM – Silty sand with gravel

(d) This material has 74% fine to coarse subangular reddish sand and 26% organic and silty dark brown fines. The liquid limit (not dried) is 37% while it is 26% when oven dried. The plastic index (not dried) is 6.

Solution: SM – Silty sand with organic fines

(e) Although this soil has only 6% nonplastic silty fines, it has everything else! It has gravel content of 78% fine to coarse subrounded to subangular gravel, and 16% fine to coarse subrounded to subangular sand. The maximum size of the subrounded boulders is 500 mm. The uniformity

Sieve	Percent Finer by Weight
1/2–	83
No. 4	52
No. 10	40
No. 20	32
No. 40	17
No. 60	10
No. 100	8

coefficient is 40, while the coefficient of curvature is only 0.8. (After U.S. Dept. of the Interior, 1990.)

Solution: GP-GM – Poorly graded gravel with silt, sand, cobbles, and boulders (or GP-GC)

2.41 You know what is coming. Classify the five soils in the preceding question according to the AASHTO method of soil classification. You can find procedures for doing this in the references given in Section 2.9 or on the Web

Solution:

(a) A-1-a
(b) A-8
(c) A-2-4
(d) A-2-4 or A-8
(e) A-1-a

2.42 The results of a sieve test below give the percentage passing through the sieve.

(a) Using a spreadsheet, plot the particle-size distribution.
(b) Calculate the uniformity coefficient.
(c) Calculate the coefficient of curvature.

Solution:

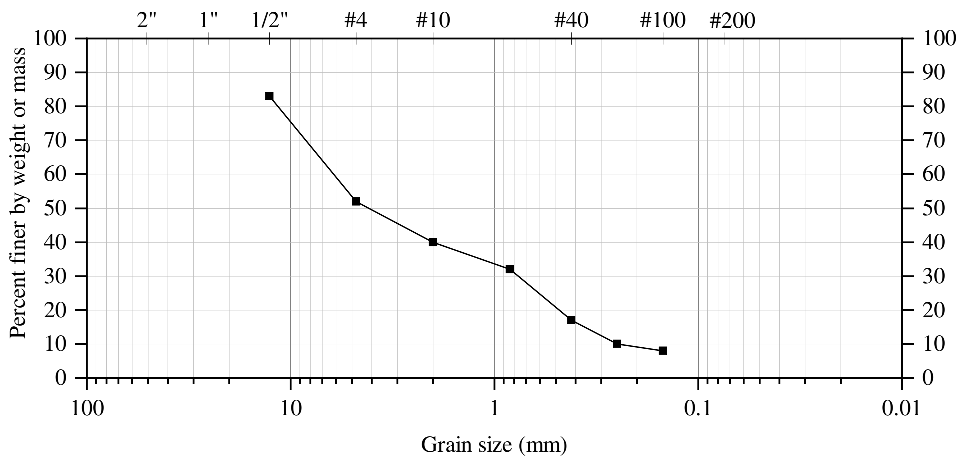
(a) particle-size distribution

(b) Uniformity coefficient:

$$C_u = \frac{D_{60}}{D_{10}} = \frac{6\,\text{mm}}{0.25\,\text{mm}} = \underline{\underline{24}} \tag{2.24}$$

(c) coefficient of curvature:

$$C_c = \frac{D_{30}^2}{D_{60} \times D_{10}} = \frac{0.8^2}{6 \times 0.25} = \underline{\underline{0.43}} \tag{2.25}$$



P. 2.42. Particle-size distribution

2.43 For the data given below, classify the soils according to the USCS. For each soil, give both the letter symbol and the narrative description.

(a) 65% material retained on No. 4 sieve, 32% retained on No. 200 sieve. Cu = 3, Cc = 1.

Solution: GP – Poorly graded gravel with sand
(b) 100% material passed No. 4 sieve, 90% passed No. 200 sieve. LL = 23, PL = 17.

Solution: CL-ML – Silty clay

(c) 70% material retained on No. 4 sieve, 27% retained on No. 200 sieve. Cu = 5, Cc = 1.5.

Solution: GW – Well-grade gravel with sand

2.44 A sample of soil was tested in the laboratory and the following grain-size analysis results were obtained. LL = 34, PL = 21, 28% is coarser than the 1/2-inch sieve. Classify this soil according to the USCS, providing the group symbol for it.

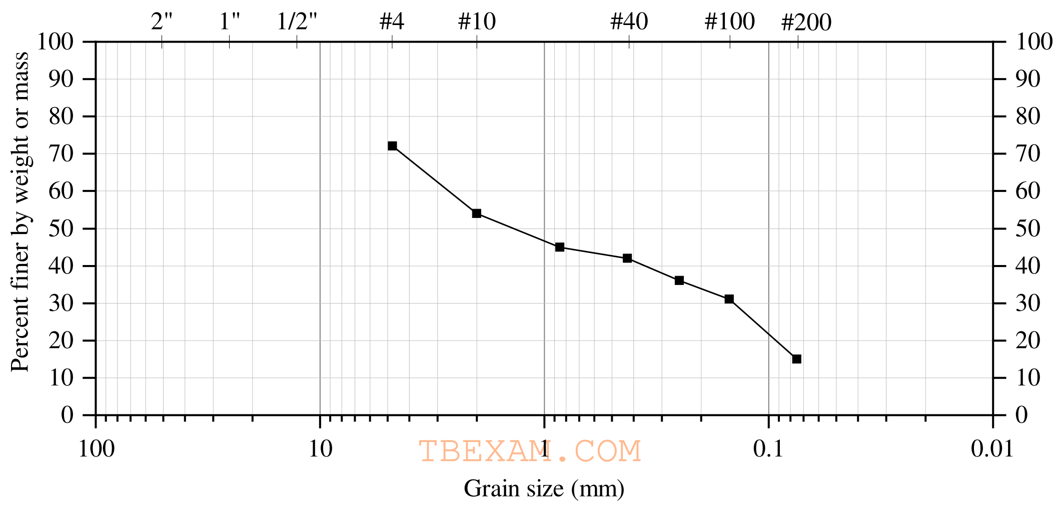
Solution:

$$PI = LL - PL = 34 - 21 = 13\%$$

$$C_u = \frac{D_{60}}{D_{10}} = \frac{2.8}{0.065} = 43.1 \tag{2.24}$$

$$C_c = \frac{D_{30}^2}{D_{60} \times D_{10}} = \frac{0.15^2}{2.8 * 0.065} = 0.12 \tag{2.25}$$

Sieve No.	Sieve Opening (mm)	Percent Coarser by Weight	Percent finer by weight
4	4.75	28	72
10	2	46	54
20	0.85	55	45
40	0.425	58	42
60	0.25	64	36
100	0.15	69	31
200	0.075	85	15
Pan	—	100	0



P. 2.44. Particle-size distribution

SC-CL – Clayey sand with gravel

2.45 A minus No. 40 material had a liquidity index of 0.67, a natural water content of 38.7%, and a plasticity index of 18.9. Classify this soil according to the USCS, providing the group symbol for it. You do not need to graph this data; use linear interpolation if you need specific values not given.

Solution:

$$LI = \frac{w_n - PL}{PI} = 0.67 \Rightarrow PL = w_n - LI \times PI = 38.7 - (0.67)(18.9) = 26.0\%$$

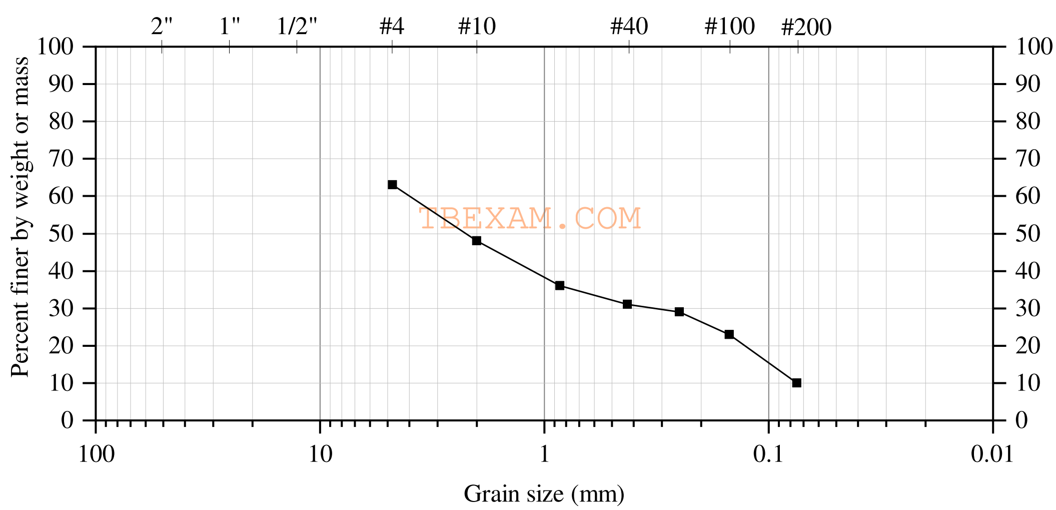
$$PI = LL - PL \Rightarrow LL = PI + PL = 44.9\%$$

CL – Lean clay.

Sieve No.	Sieve Opening (mm)	Percent Coarser by Weight	Percent finer by weight
4	4.75	37	63
10	2	52	48
20	0.85	64	36
40	0.425	69	31
60	0.25	71	29
100	0.15	77	23
200	0.075	90	10
Pan	—	100	0

2.46 A sample of soil was tested in the laboratory and the following grain-size analysis results were obtained. LL = 60, PL = 26. Classify this soil according to the USCS, providing the group symbol for it.

Solution:



P. 2.46. Particle-size distribution

$PI = LL - PL = 60 - 26 = 34\%$

$$C_u = \frac{D_{60}}{D_{10}} = \frac{4.75}{0.075} = 63 \quad (2.24)$$

$$C_c = \frac{D_{30}^2}{D_{60} \times D_{10}} = \frac{0.425^2}{4.75 * 0.075} = 0.5 \Rightarrow \text{Well graded} \quad (2.25)$$

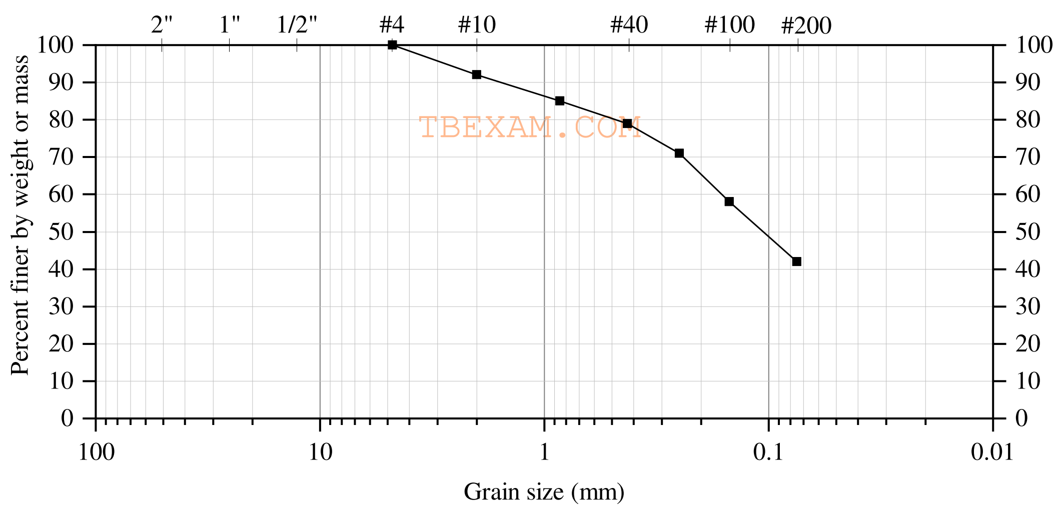
P. 2.47

Sieve No.	Sieve Opening (mm)	Percent Finer by Weight
4	4.75	100
10	2	92
20	0.85	85
40	0.425	79
60	0.25	71
100	0.15	58
200	0.075	42
Pan	—	0

SW-SC – Well-graded sand with clay

2.47 A sample of soil was tested in the laboratory and the following grain-size analysis results were obtained. Atterberg limits on minus No. 40 material were: LL = 38, PL = 19.

Solution:



P. 2.47. Particle-size distribution

$PI = LL - PL = 38 - 19 = 19\%$

SC-CL– Clayey sand

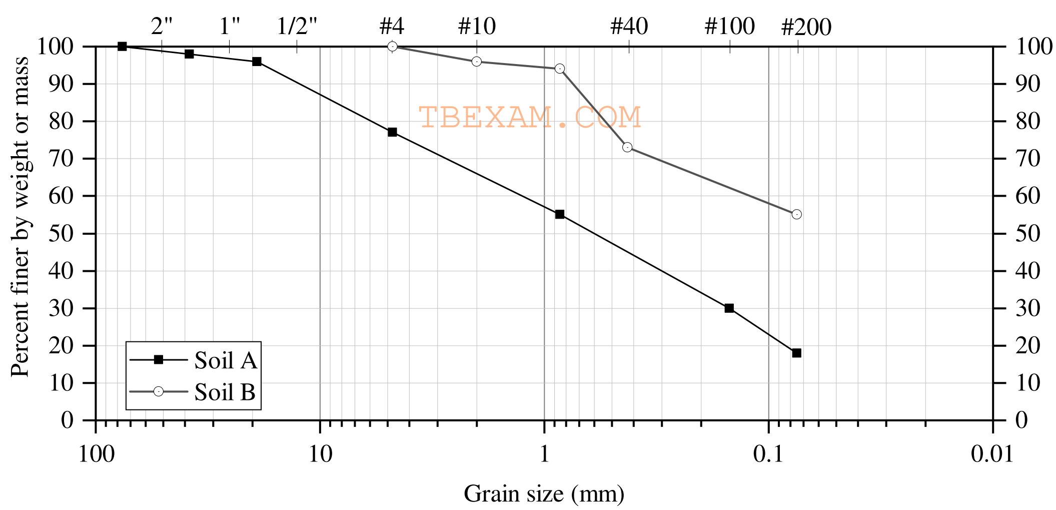
2.48 Laboratory testing was performed on two soil samples (A and B) and the data is summarized in the table. Determine the USCS classification for samples A and B. Use log interpolation as

P. 2.48

Sieve No.	Sample A-% Passing (mm)	Sample B-% Passing
3 in. (76.2 mm)	100	-
1.5 in. (38.1 mm)	98	-
0.75 in. (19.1 mm)	96	-
4 (4.75 mm)	77	100
10 (2.00 mm)	Not used	96
20 (0.85 mm)	55	94
40 (0.425 mm)	Not used	73
100 (0.150 mm)	30	Not used
200 (0.075 mm)	18	55
Liquid limit	32	52
Plastic limit	25	32

necessary.

Solution:



P. 2.48. Particle-size distribution

(a) For Sample A:

$$PI = LL - PL = 32 - 25 = 7\%$$

$$C_u = \frac{D_{60}}{D_{10}} = \frac{1.3}{0.044} = 29.5 \tag{2.24}$$

$$C_c = \frac{D_{30}^2}{D_{60} \times D_{10}} = \frac{0.15^2}{1.3(0.044)} = 0.393 \Rightarrow \text{Poorly graded} \tag{2.25}$$

SM — Silty sand with gravel.

(b) For Sample B:

$PI = LL - PL = 52 - 32 = 20\%$

MH or OH — Elastic sandy silt or organic sandy silt/clay.

2.49 A sample of soil was tested in the laboratory and the following grain-size analysis results were obtained. Atterberg limits on minus No. 40 material: LL = 56, PL = 25. Determine the USCS letter symbol (e.g., GP) for this soil.

$PI = LL - PL = 56 - 25 = 31\%$

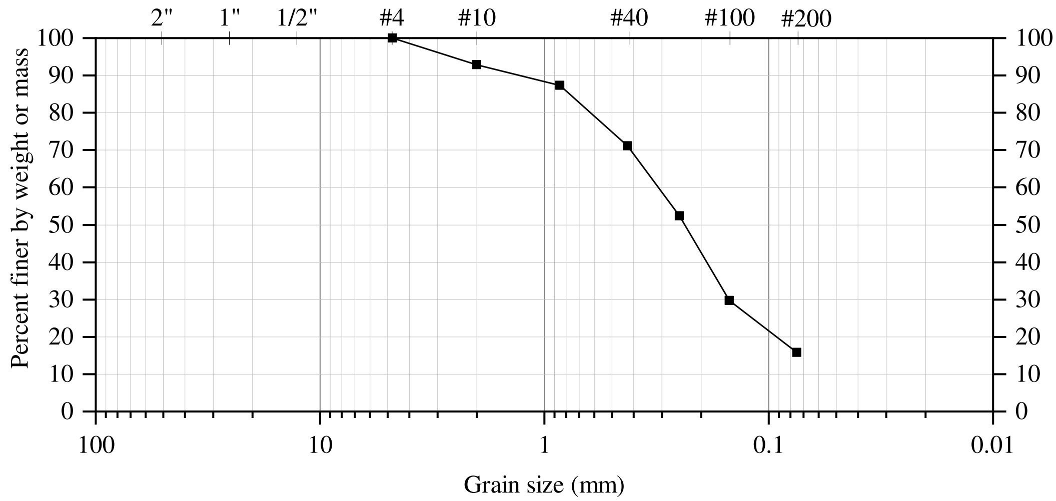
$$C_u = \frac{D_{60}}{D_{10}} = \frac{0.31}{0.055} = 5.6 \tag{2.24}$$

$$C_c = \frac{D_{30}^2}{D_{60} \times D_{10}} = \frac{0.15^2}{0.31(0.055)} = 1.3 \Rightarrow \text{Well-graded} \tag{2.25}$$

SC-CH — Clayey sand

P. 2.49

Sieve No.	Sieve Opening (mm)	Percent Coarser by Weight	Percent finer by weight
4	4.75	0	100
10	2	7.2	92.8
20	0.85	12.7	87.3
40	0.425	28.9	71.1
60	0.25	47.6	52.4
100	0.15	70.3	29.7
200	0.075	84.2	15.8
Pan	—	100	0



P. 2.49. Particle-size distribution

2.50 A sample of a brown sandy clay was obtained to determine its Atterberg limits and then classify its soil type according to the Unified Soil Classification System. For one of the PL determinations, the wet weight + dish = 11.53 g and the dry weight + dish = 10.49 g. The dish only weighed 4.15 g. Compute the plastic limit. Another plastic limit was 16.9%. Three determinations of the liquid limit were made. For 17 blows, the water content was 49.8%; for 26 blows, the water content was 47.5%; and for 36 blows, the water content was 46.3%. Evaluate the soil type, indicate the information on a plasticity chart, and give the Unified Soil Classification symbol.

Solution:

$M_w = 11.53 - 10.49 = 1.04\,\text{g}$

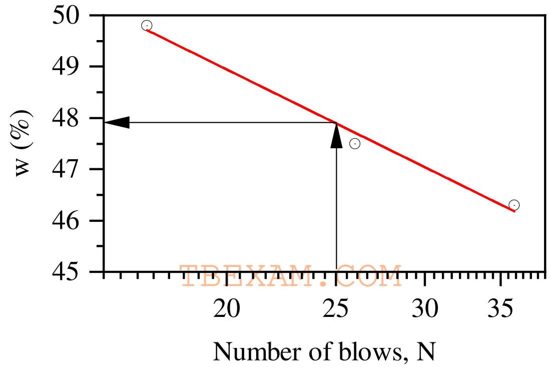
$M_s = 10.49 - 4.15 = 6.34\,\text{g}$

$$w_{PL} = PL = \frac{M_w}{M_s} \times 100 = \frac{1.04}{6.34} \times 100 = 16.4$$

$$PL_{avg} = \frac{16.4 + 16.9}{2} = 16.65; \quad \text{From plot below: LL=48}$$

$PI = 48 - 16.7 = 31$

Based on Casagrande's plasticity chart, the soil fines classify as CL — Sandy lean clay.



P. 2.50

CHAPTER 3: GEOLOGY, LANDFORMS, AND THE ORIGIN OF GEOMATERIALS

CHAPTER 3: PROPERTIES OF ROCK MASSES, SOIL PARTICLES

3.15 In one core run of 1500 mm selected from cores obtained during drilling for a bridge foundation in hard limestone, the following core recovery information was obtained:
Determine (a) the percent core recovery, and (b) the RQD. Based on this RQD, what is the rock quality? Why?

P.3.15

Core Recovery (mm)	Length of Core Pieces >100 mm
250	150
50	
50	
75	
100	100
125	125
75	
100	100
150	150
100	100
50	
125	125
Sum =1250	Sum= 850

Solution:

(a) Core recovery:

$$CR = \frac{\text{Total length of rock recovered}}{\text{Total core run length}} \times 100$$

$$CR = \frac{250+50+50+75+100+125+75+100+150+100+50+125}{1500} = \frac{1250}{1500} \times 100 = 83.3\%$$

(b) RQD:

$$RQD = \frac{\sum \text{Length of sound pieces}}{\text{Total core run length}} \times 100$$

$$RQD = \frac{150 + 100 + 125 + 100 + 125}{1500} = \frac{850}{1500} \times 100 = \underline{\underline{56.7\%}}$$

Based on the Rock Mass Classifications shown in Table 3.6, the limestone rock quality would be deemed fair.

3.16 Calculate the specific surface of a cube (a) 25 mm, (b) 2.5 mm, (c) 2.5 µm, and (d) 2.5 nm on a side. Calculate the specific surface in terms of both areas and m^2/kg. Assume for the latter case that $\gamma_s = 2710\ \text{kg/m}^3$.

Solution:

Solve using the following equation:

$$\text{specific surface} = \frac{\text{surface area}}{\text{unit volume}}$$

(a) $$\text{specific surface} = \frac{6(625\,\text{mm}^2)}{25^3\,\text{mm}^3} = \frac{3750\,\text{mm}^2}{15625\,\text{mm}^3} = \underline{\underline{0.24/\text{mm}}}$$

in terms of mass: $$\text{specific surface} = \frac{0.24/\,\text{mm} \times (1000\,\text{mm}/1\,\text{m})}{2710\,\text{kg/m}^3} = \underline{\underline{0.089\,\text{m}^2/\text{kg}}}$$

(b) $$\text{specific surface} = \frac{6(6.25\,\text{mm}^2)}{2.5^3\,\text{mm}^3} = \frac{37.5\,\text{mm}^2}{15.625\,\text{mm}^3} = \underline{\underline{2.4/\text{mm}}}$$

in terms of mass: $$\text{specific surface} = \frac{2.4/\,\text{mm} \times (1000\,\text{mm}/1\,\text{m})}{2710\,\text{kg/m}^3} = \underline{\underline{0.89\,\text{m}^2/\text{kg}}}$$

(c) $$\text{specific surface} = \frac{6(6.25\,\mu\text{m}^2)}{2.5^3\,\mu\text{m}^3} = \frac{37.5\,\mu\text{m}^2}{15.625\,\mu\text{m}^3} = 2.4/\mu\text{m} = \underline{\underline{2400/\,\text{mm}}}$$

in terms of mass: $$\text{specific surface} = \frac{2400/\,\text{mm} \times (1000\,\text{mm}/1\,\text{m})}{2710\,\text{kg/m}^3} = \underline{\underline{885.6\,\text{m}^2/\text{kg}}}$$

(d) $$\text{specific surface} = \frac{6(6.25\,\text{nm}^2)}{2.5^3\,\text{nm}^3} = \frac{37.5\,\text{nm}^2}{15.625\,\text{nm}^3} = 2.4/\text{nm} = \underline{\underline{2,400,000/\,\text{mm}}}$$

in terms of mass: $$\text{specific surface} = \frac{2,400,000/\,\text{mm} \times (1000\,\text{mm}/1\,\text{m})}{2710\,\text{kg/m}^3} = \underline{\underline{885,608.8\,\text{m}^2/\text{kg}}}$$

3.18 A specially processed clay has particles that are 600 nm thick and 12, 000 nm × 12,000 nm wide. The specific gravity of solids is 2.72. The particles lie perfectly parallel with an edge-to-edge spacing of 375 nm (i.e., they look like thin bricks stacked perfectly parallel). (a) Initially, the cation valence in the double layer is + 1, resulting in a face-to-face spacing of 1500 nm. How many particles per cm^3 will there be at this spacing? What are the void ratio and water content, assuming that the soil is at 100% saturation? (b) Another sample of the clay is mixed such that the cation valence is + 2. What are the new void ratio and water content under these conditions? Assume the edge-to-edge spacing remains 375 nm and that S = 100%. (After C. C. Ladd.)

Solution:

Assume symmetrical edge-to-edge spacing of 375 nm and only include whole particles.

(a) the horizontal spacing between two particle is equal to: 12,000+375= 12,375 nm. Then, the number of particles in this plane is equal to:

$$\text{no. of particles in plan} = \frac{1,000,000 - 12,000}{12,375} + 1 = 808.1 = 808\,\text{particles}$$

$$\text{Total no. of particles in plan} = 808 * 808 = 652,864\,\text{particles}$$

The vertical space for two particles is equal to 600+1500=2100 nm. Then, the number of particles in the vertical is:

$$\text{no. of particles in vertical } = \frac{1,000,000 - 600}{2100} + 1 = 4762.6 = 4762\,\text{particles}$$

$$\text{Total no. of particles in 1 cm}^3 = 652,864 \times 4762 = 3108 \times 10^6\,\text{particles}$$

The volume of of each particle is:

$$V = 600 \times 1200 \times 1200\,\text{nm}^3 = 8.64 \times 10^{10}\,\text{nm}^3 = 8.64 \times 10^{-11}\,\text{cm}^3$$

the volume of the solids is: $V_s = 8.6 \times 10^{-11}\,\text{cm}^3 \times 3108 \times 10^6\,\text{particles} = 0.269\,\text{cm}^3$

For S=100 % $\Rightarrow V_w = V_v = 1\,\text{cm}^3 - 0.269\,\text{cm}^3 = 0.731\,\text{cm}^3$.

The void ratio can be calculate as:

$$e = \frac{V_v}{V_s} = \frac{0.731}{0.269} = \underline{\underline{2.72}}$$

For the water content:

$$M_s = V_s G_s \rho_w = (0.269)(2.72)(1\,\text{g/cm}^3) = 0.73$$

$$w = \frac{M_w}{M_s} = \frac{0.73}{0.73} \times 100 = \underline{\underline{100\%}}$$

(b) the only change respect to part a. is the vertical spacing, which is equal to = 600+1500*2= 3600 nm.

$$\text{no. of particles in vertical } = \frac{1,000,000 - 600}{3600} + 1 = 2778.6 = 2778\,\text{particles}$$

Total no. of particles in 1 $cm^3 = 652,864 \times 2778 = 1840 \times 10^6$ particles

the volume of the solids is

$V_s = 8.64 \times 10^{-11}\,\text{cm}^3 \times 1840 \times 10^6\,\text{particles} = 0.157\,\text{cm}^3$

For S=100 % $\Rightarrow V_w = V_v = 1\,\text{cm}^3 - 0.157\,\text{cm}^3 = 0.84\,\text{cm}^3$.

The void ratio can be calculate as:

$e = \frac{V_v}{V_s} = \frac{0.84}{0.157} = \underline{\underline{5.38}}$

For the water content:

$M_s = V_s G_s \rho_w = (0.157)(2.72)(1\,\text{g/cm}^3) = 0.426$

$w = \frac{M_w}{M_s} = \frac{0.84}{0.426} \times 100 = \underline{\underline{197.9\%}}$

3.21 Can a soil have a low void ratio and a high density at the same time? Explain.

Solution:

The specify gravity of the solids have to be very large.

CHAPTER 4: COMPACTION AND STABILIZATION OF SOILS

4.1 For the data in Fig. 4.2:

(a) Estimate the maximum unit weight and optimum water content for both the standard curve and the modified Proctor curve.

(b) What is the water content range to achieve 90% relative compaction for the modified Proctor curve and 95% relative compaction for the standard Proctor curve?

(c) If a higher compactive effort than the modified Proctor was used and achieved a maximum unit weight of 120 lb/ft^3, what is your prediction of the water content at which that was achieved?

Solution:

(a) For the standard proctor: $\rho_{d\,\max} = \underline{\underline{1730\,\text{kg/m}^3 = 108\,\text{lb/ft}^3}}$; $w_{\text{opt}} = \underline{\underline{16\%}}$

For the modified proctor: $\rho_{d\,\max} = \underline{\underline{1875\,\text{kg/m}^3 = 117\,\text{lb/ft}^3}}$; $w_{\text{opt}} = \underline{\underline{12\%}}$

(b) 95% of Standard Proctor curve: $0.95{\times}\rho_{d\,\max} = (0.95)(1730) = 1643\,\text{kg/m}^3$

water content range for Standard Proctor: $\underline{\underline{w = 11 \text{ to } 20\ \%}}$

90% of Modified Proctor curve: $0.90{\times}\rho_{d\,\max} = (0.90)(1875) = 1687\,\text{kg/m}^3$

water content range for Standard Proctor: $\underline{\underline{w = 5 \text{ to } 18\ \%}}$

(c) the water content for the maximun unit weight of 120 lb/ft^3 is $\underline{\underline{10.3\ \%}}$

4.2 The natural water content of a borrow material is known to be 12%. Assuming 4.75 kg of wet soil is used for laboratory compaction test points, compute the volume of water is to be added to other 4.75 samples to bring their water contents up to 14%, 17%, 20%, 23%, and 26%.

Solution:

$w = 0.12 = \dfrac{M_w}{M_s} \Rightarrow M_w = 0.12M_s; \quad M_t = 4.75\,\text{kg}$

M_s remains constant. Determine M_s for the natural moisture condition.

$M_t = M_w + M_s = 4.75\,\text{kg};$

$4.75 = 0.12M_s + M_s \Rightarrow M_s = 4.241\,\text{kg};$

M_w for natural condition: $M_w = (0.12)(4.241) = 0.509\,\text{kg}$

(a) $w = 14\,\%$

$M_w = wM_s = (0.14)(4.241) = 0.509\,\text{kg}$

additional water necessary for w= 14% : $0.594 - 0.509 = \underline{\underline{0.085\,\text{kg}}}$

(b) $w = 17\,\%$

$M_w = wM_s = (0.17)(4.241) = 0.721\,\text{kg}$

additional water necessary for w= 17% : $0.721 - 0.509 = \underline{\underline{0.212\,\text{kg}}}$

(c) $w = 20\,\%$

$M_w = wM_s = (0.20)(4.241) = 0.848\,\text{kg}$

additional water necessary for w= 20% : $0.848 - 0.509 = \underline{\underline{0.339\,\text{kg}}}$

(d) $w = 23\,\%$

$M_w = wM_s = (0.23)(4.241) = 0.975\,\text{kg}$

additional water necessary for w= 23% : $0.975 - 0.509 = \underline{\underline{0.467\,\text{kg}}}$

(e) $w = 26\,\%$

$M_w = wM_s = (0.26)(4.241) = 1.103\,\text{kg}$

additional water necessary for w= 26% : $1.103 - 0.509 = \underline{\underline{0.594\,\text{kg}}}$

4.3 For the soil shown in Fig. 4.2, a field density test provided the following information:

Water content = 13%
Wet unit weight = 115 lb/ft^3

Compute the percent relative compaction based on the modified Proctor and the standard Proctor curves.

Solution:

Dry unit weight in field: $\gamma_{\text{d field}} = \dfrac{\gamma_t}{1+w} = \dfrac{115}{1+0.13} = 101.77\,\text{pcf}$

From Fig. 4.2: Standard Proctor $\gamma_{\text{d max}}$ =108.0 pcf; Modified Proctor $\gamma_{\text{d max}}$ =117.1 pcf
The relative compaction is equal to:

$$\text{RC} = \frac{\gamma_{\text{d field}}}{\gamma_{\text{d max}}} \times 100$$

Standard Proctor $\text{RC} = \dfrac{101.77}{108.0} \times 100 = \underline{\underline{94.2\%}}$; Modified Proctor $\text{RC} = \dfrac{101.77}{117.1} \times 100 = \underline{\underline{86.9\%}}$

4.4 For the data given below $\rho_s = 2710$ kg/m^3:

(a) Plot the compaction curves.

(b) Establish the maximum dry density and optimum water content for each test.

(c) Compute the degree of saturation at the optimum point for data in Column A.

(d) Plot the 100% saturation (zero air voids) curve. Also plot the 70%, 80%, and 90% saturation curves. Plot the line of optimums.

P.4.4

A (modified)		B (modified)		C (low energy)	
ρ_d (kg/m^3)	w (%)	ρ_d (kg/m^3)	w (%)	ρ_d (kg/m^3)	w (%)
1873	9.3	1691	9.3	1627	10.9
1910	12.8	1715	11.8	1639	12.3
1803	15.5	1755	14.3	1740	16.3
1699	18.7	1747	17.6	1707	20.1
1641	21.1	1685	20.8	1647	22.4
		1619	23		

Solution:

(a) See Fig. P4.4.

(b)

P.4.4

Test	w_{opt} (%)	$\rho_{\max}$
Modified	12.0	1918
Standard	15.5	1761
Low energy	17.3	1747

(c) From Eq. 4.1:

$$S = \frac{w}{\dfrac{\rho_w}{\rho_d} - \dfrac{\rho_w}{\rho_s}} \times 100 = \frac{0.12}{\dfrac{1000}{1918} + \dfrac{1000}{2710}} \times 100 = \underline{\underline{78.75\%}}$$

(d) From Eq. 4.1: