CHAPTER 4

CLAY MINERALS, SOIL AND ROCK STRUCTURES, AND ROCK CLASSIFICATION

4-1. *Calculate the specific surface of a cube (a) 10 mm, (b) 1 mm, (c) and (d) 1 nm on a side. Calculate the specific surface in terms of both areas and m^2/kg. Assume for the latter case that ρ_s = 2.65 Mg/m^3.*

SOLUTION:

Solve using Eq. 4.2: specific surface = $\text{surface area} / \text{unit volume}$

(a) $\text{specific surface} = \dfrac{6(100\ \text{mm}^2)}{10\ \text{mm}^3} = \underline{\underline{60\ /\text{mm}}}$

and $\text{specific surface} = \dfrac{(60\ /\text{mm})(1000\ \text{mm}/\text{m})}{2.65\ \text{Mg}/\text{m}^3} = 22{,}641\ \text{m}^2/\text{Mg} = \underline{\underline{22.6\ \text{m}^2/\text{kg}}}$

(b) $\text{specific surface} = \dfrac{6(1\,\text{mm}^2)}{1\,\text{mm}^3} = \underline{\underline{6\ /\text{mm}}}$

and $\text{specific surface} = \dfrac{(6\ /\text{mm})(1000\ \text{mm}/\text{m})}{2.65\ \text{Mg}/\text{m}^3} = 2264\ \text{m}^2/\text{Mg} = \underline{\underline{2.26\ \text{m}^2/\text{kg}}}$

(c) $\text{specific surface} = \dfrac{6(1\,\mu\text{m}^2)}{1\,\mu\text{m}^3} = \underline{\underline{6\ /\mu\text{m} = 6000\ /\text{mm}}}$

and $\text{specific surface} = \dfrac{(6000\ /\text{mm})(1000\ \text{mm}/\text{m})}{2.65\ \text{Mg}/\text{m}^3} = 2{,}264{,}151\ \text{m}^2/\text{Mg} = \underline{\underline{2264\ \text{m}^2/\text{kg}}}$

(d) $\text{specific surface} = \dfrac{6(1\,\text{nm}^2)}{1\,\text{nm}^3} = \underline{\underline{6\ /\text{nm} = 6{,}000{,}000\ /\text{mm}}}$

and $\text{specific surface} = \dfrac{(6{,}000{,}000\ /\text{mm})(1000\ \text{mm}/\text{m})}{2.65\ \text{Mg}/\text{m}^3} = 2{,}264{,}151{,}943\ \text{m}^2/\text{Mg} = \underline{\underline{2{,}264{,}151\ \text{m}^2/\text{kg}}}$

4-2. *Calculate the specific surface of (a) tennis balls, (b) ping pong balls, (c) ball bearings 1.5 mm in diameter, and (d) fly ash with approximately spherical particles 60 υm in diameter.*

SOLUTION:

Solve using Eq. 4.2: specific surface = $\text{surface area} / \text{unit volume}$

$\text{sphere surface area} = 4\pi r^2$; $\text{sphere volume} = \frac{4}{3}\pi r^3$

(a) tennis ball (Dia. = 67 mm): specific surface = $\dfrac{(3)(4)\pi(67/2\ \text{mm})^2}{(4)\pi\left(67\ \text{mm}/2\right)^3} = \underline{\underline{0.089\ /\text{mm}}}$

(b) ping pong ball (Dia. = 40 mm): specific surface = $\dfrac{3}{\left(40/2\right)} = \underline{\underline{0.15\ /\text{mm}}}$

(c) ball bearings (Dia. = 1.5 mm): specific surface = $\dfrac{3}{\left(1.5/2\right)} = \underline{\underline{4.0\ /\text{mm}}}$

(d) fly ash (Dia. = 60 μm): specific surface = $\dfrac{3}{\left(60/2\right)} = \underline{\underline{0.10\ /\mu\text{m} = 1\times10^5\ /\text{mm} = 100{,}000\ /\text{mm}}}$

4-5. *Verify that the maximum and minimum void ratios for perfect spheres given in Table 4.5 are reasonable.*

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. 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 $V_t = 1.0, \quad V_v = 0.48, \quad \text{and} \quad V_s = 1 - 0.48 = 0.52$

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

$V_s = 0.7405, \quad V_v = 1.0 - 0.7405 = 0.2595$

thus;

$$n_{min} = \frac{0.2595}{1.0} \times 100 = \underline{\underline{26\%}}$$

$$e_{min} = \frac{0.2595}{0.7405} = \underline{\underline{0.35}}$$

These agree with the values of e_{max} and e_{min} in Table 4.5 for equal spheres.

4-7. *A specially processed clay has particles that are 500 nm thick and 10,000 nm x 10,000 nm wide. The specific gravity of solids is 2.80. The particles lie perfectly parallel with an edge-to-edge spacing of 400 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 cm³ 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?*

SOLUTION:

Assume symmetrical edge-to-edge spacing of 400 nm and only include whole particles.

(a) no. of particles in horizontal plane along one edge = $\dfrac{(1\times10^7)-(2)(10{,}000)}{10{,}000+400}=959.6$

truncate and add 2 for edges = $959+2=961$

no. of particles in plan = $961\times961=\underline{923{,}521}$

no. of particles in vertical plane along one edge = $\dfrac{(1\times10^7)-(2)(500)}{500+1500}=4999.5$

truncate and add 2 for edges = $4999+2=\underline{5001}$

total number of particles = $923{,}521\times5001=4{,}618{,}528{,}521=\underline{\underline{4618.53\times10^6}}$

volume of one particle = $10{,}000\times10{,}000\times500=5.0\times10^{10}\text{ nm}^3=5\times10^{-11}\text{ cm}^3$

$V_s=4{,}618{,}528{,}521\times(5.0\times10^{10})=2.30926\times10^{20}\text{ nm}^3=0.23093\text{ cm}^3$

For S = 100%: $V_w=V_v=V_t-V_s=1-0.23093=0.7691\text{ cm}^3$; $e=\dfrac{V_v}{V_s}=\dfrac{0.7691}{0.23093}=\underline{\underline{3.33}}$

$M_s=G_s\times V_s\times\rho_s=(2.80)(0.23093)(1\,{}^{g}\!/_{cm^3})=0.6466\text{ g}$; $M_w=V_w\times\rho_w=(0.7691)(1\,{}^{g}\!/_{cm^3})=0.7691\text{ g}$

$w=\dfrac{M_w}{M_s}\times100\%=\dfrac{0.7691}{0.6466}\times100\%=118.9=\underline{\underline{119\%}}$

(b) assume the-face-to-face spacing doubles for a cation valence of +2

no. of particles in horizontal plane along one edge = $\dfrac{(1\times10^7)-(2)(10{,}000)}{10{,}000+400}=959.6$

truncate and add 2 for edges = $959+2=961$

no. of particles in plan = $961\times961=\underline{923{,}521}$ (same as part a)

no. of particles in vertical plane along one edge = $\dfrac{(1\times10^7)-(2)(500)}{500+3000}=2856.9$

truncate and add 2 for edges = $2856+2=\underline{2858}$

total number of particles = $923{,}521\times2858=2{,}639{,}423{,}018=\underline{\underline{2639.423\times10^6}}$

volume of one particle = $10{,}000\times10{,}000\times500=5.0\times10^{10}\text{ nm}^3=5\times10^{-11}\text{ cm}^3$

$V_s=2{,}639{,}423{,}018\times(5.0\times10^{10})=1.31971\times10^{20}\text{ nm}^3=0.13197\text{ cm}^3$

For S = 100%: $V_w=V_v=V_t-V_s=1-0.13197=0.868\text{ cm}^3$; $e=\dfrac{V_v}{V_s}=\dfrac{0.868}{0.13197}=\underline{\underline{6.58}}$

$M_s=G_s\times V_s\times\rho_s=(2.80)(0.13197)(1\,{}^{g}\!/_{cm^3})=0.3695\text{ g}$; $M_w=V_w\times\rho_w=(0.868)(1\,{}^{g}\!/_{cm^3})=0.868\text{ g}$

$w=\dfrac{M_w}{M_s}\times100\%=\dfrac{0.868}{0.3695}\times100\%=234.9=\underline{\underline{235\%}}$

4-15. *Three sections of rock core are shown in Fig. 4.32. The rock comes from near Cumberland, RI, and is called Corbormite (Capt. James T. Kirk, personal communication, 2007). The length of the first (top) run is 56 in. and the computed RQD is 82%. For the second run (middle), a length of 60 in. was recovered and the RQD is 100%. Finally, the third run (bottom) is also 5 ft long and the RQD is 95%.Verify that the calculated RQD values for the top and bottom runs are correct.*

SOLUTION:

$$\text{RQD} = \frac{\sum \text{Length of sound pieces > 4 in}}{\text{Total core run length}}$$

Determine numerator values by closely examing photographs in Fig. 4.32

(a) Top run RQD $= \frac{7+9+4+8.5+8+9}{56} \times 100 = \frac{45.5}{56} \times 100 = \underline{\underline{81.3\%}}$

Thus, the given value of 82% appears reasonable.

(b) Bottom run RQD $= \frac{7.5+8.5+7+11}{60} \times 100 = \frac{34}{60} \times 100 = \underline{\underline{57\%}}$

The RQD value of 57% assumes all joints are natural (i.e., no mechanical breaks in this core run). Even if all the breaks and joints shown in Fig. 4.32 are mechanical, the reported value of 95% is still too high based on the percent recovery visible in the photo.

4-16. *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?*

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 =	Sum =

SOLUTION:

(a) Core Recovery, CR = $\dfrac{\text{Total length of rock recovered}}{\text{Total core run length}} \times 100$

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

(b) RQD = $\dfrac{\sum \text{Length of sound pieces} > 100 \text{ mm}}{\text{Total core run length}} \times 100$

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

Based on the Rock Mass Classifications shown in Table 4.13,
the limestone rock quality would be deemed fair.