Cambridge University Press
978-1-107-46277-9 — River Mechanics
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Excerpt
More Information

1

Physical Properties

As a natural science, the variability of river processes must be examined through the measurement of physical parameters. This chapter describes dimensions and units (Section 1.1), physical properties of water (Section 1.2), and sediment (Section 1.3).

1.1 Dimensions and Units

Physical properties are usually expressed in terms of the following fundamental dimensions: mass (M), length (L), and time (T). Temperature ($T°$) is also sometimes considered. The fundamental dimension of mass is preferred to the corresponding force.

The fundamental dimensions are measurable in quantifiable units. In the SI system of units, the units for mass, length, time, and temperature are the kilogram (kg), the meter (m), the second (s), and degrees Kelvin (K). The Celsius scale (°C) is commonly preferred in river engineering because it refers to the freezing point of water as 0°C. The abbreviations for cubic meters per second (1 cms = 1 m^3/s) and cubic feet per second (1 cfs = 1 ft^3/s) are commonly used to describe the flow discharge of a river.

A Newton (N) is the force required to accelerate 1 kg at 1 m/s^2, or 1 N = 1 kg m/s^2. The gravitational acceleration at the Earth's surface is $g = 9.81$ m/s^2. The weight of one kilogram is F = mass × g = 1 kg × 9.81 m/s^2 = 9.81 N. The pressure is given in pascals from 1 Pa = 1 N/m^2. The unit of work (or energy) is the joule (J), which equals the product of 1 N × 1 m. The unit of power is a watt (W), which is 1 J/s. Prefixes indicate multiples or fractions of units by powers of 10:

$$\mu(\text{micro}) = 10^{-6}, \qquad \text{k(kilo)} = 10^3,$$
$$\text{m(milli)} = 10^{-3}, \qquad \text{M(mega)} = 10^6,$$
$$\text{c(centi)} = 10^{-2}, \qquad \text{G(giga)} = 10^9.$$

For example, sand particles are coarser than 62.5 μm or microns; gravels are coarser than 2 mm; and 1 megawatt (MW) equals 1 million watts (1,000,000 or 10^6 W).

In the English system of units, the time unit is a second, the fundamental units of length and mass are, respectively, the foot (ft), equal to 30.48 cm, and the slug, equal to 14.59 kg. The force to accelerate a mass of one slug at 1 ft/s^2 is a pound force (lb). In this text, a pound always refers to a force, not a mass. Temperature in degrees Celsius, T°C, is converted to the temperature in degrees Fahrenheit, T°F, by T°F = 32.2°F + 1.8 T°C.

Variables are classified as geometric, kinematic, dynamic, and dimensionless variables. As shown in Table 1.1, geometric variables describe the geometry in terms of length, area, and volume. Kinematic variables describe the

Table 1.1. *Geometric, kinematic, dynamic, and dimensionless variables*

Variable	Symbol	Fundamental dimensions	SI units
Geometric (L)			
Length	L, x, h, d_s	L	m
Area	A	L^2	m^2
Volume	$\forall$	L^3	m^3
Kinematic (L, T)			
Velocity	v_x, V, u_*	LT^{-1}	m/s
Acceleration	a, a_x, g	LT^{-2}	m/s^2
Kinematic viscosity	ν	L^2T^{-1}	m^2/s
Unit discharge	q	L^2T^{-1}	m^2/s
Discharge	Q	L^3T^{-1}	m^3/s
Dynamic (M, L, T)			
Mass	m	M	1 kg
Force	$F = ma, mg$	MLT^{-2}	1 kg m/s^2 = 1 N
Pressure	$p = F/A$	$ML^{-1}T^{-2}$	1 N/m^2 = 1 Pa
Shear stress	$\tau_{xy}, \tau_0, \tau_c$	$ML^{-1}T^{-2}$	1 N/m^2 = 1 Pa
Work or energy	$E = Fd$	ML^2T^{-2}	1 Nm = J
Mass density	ρ, ρ_s	ML^{-3}	kg/m^3
Specific weight	$\gamma, \gamma_s = \rho_s g$	$ML^{-2}T^{-2}$	N/m^3
Dynamic viscosity	$\mu = \rho v$	$ML^{-1}T^{-1}$	1 kg/m s = 1 Pa s
Dimensionless			
Slope	S_0, S_f	–	–
Specific gravity	$G = \gamma_s/\gamma$	–	–
Reynolds number	$\mathrm{Re} = Vh/\nu$	–	–
Grain shear			
Reynolds number	$\mathrm{Re}_* = u_* d_s/\nu$	–	–
Froude number	$\mathrm{Fr} = u/(gh)^{0.5}$	–	–
Shields parameter	$\tau_* = \tau/(\gamma_s - \gamma)d_s$	–	–
Concentration	C_v, C_w	–	–

Table 1.2. *Unit conversions*

Unit	kg, m, s	N, Pa, W
1 acre	4,047 m^2	
1 acre-foot (acre-ft)	1,233 m^3	
1 atmosphere (atm)	101,325 kg/m s^2	101.3 kPa
1 bar	100,000 kg/m s^2	100 kPa
1 barrel (US, dry) (bbl)	0.1156 m^3	
1 cubic foot per second (ft^3/s) (1 m^3/s = 35.32 ft^3/s)	0.0283 m^3/s	
1 degree Celsius (°C) = (T°F – 32°) 5/9	1 degree Kelvin (K)	
1 degree Fahrenheit (°F) = 32 + 1.8 T°C	0.5556 degree Kelvin	
1 drop	61.6 mm^3	
1 dyne (dyn)	0.00001 kg m/s^2	10 μN
1 dyne per square centimeter (dyn/cm^2)	0.1 kg/m s^2	0.1 Pa
1 fathom (fath)	1.829 m	
1 foot (ft)	0.3048 m	
1 gallon (US gal) (1 US gal = 3.785 l)	0.003785 m^3	
1 horsepower (hp) = 550 lb ft/s	745.7 kg m^2/s^3	745.7 W
1 inch (in.) (1 ft = 12 in.)	0.0254 m	
1 inch of mercury (in. Hg)	3,386 kg/m s^2	3,386 Pa
1 inch of water	248.8 kg/m s^2	248.8 Pa
1 kip (1 kip = 1,000 lb)	4,448 kg m/s^2	4,448 N
1 knot	0.5144 m/s	
1 liter (1) (1 m^3 = 1,000 l)	0.001 m^3	
1 micrometer or micron (μm)	1×10^{-6} m	
1 mile (nautical)	1,852 m	
1 mile (statute) (1 mile = 5,280 ft)	1,609 m	
1 million gallons per day (mgd) = 1.55 ft^3/s	0.04382 m^3/s	
1 ounce (avoirdupois) (oz)	0.02835 kg	
1 fluid ounce (US)	2.957×10^{-5} m^3	
1 pascal (Pa)	1 kg/m s^2	1 N/m^2
1 pint (US pint)	0.0004732 m^3	
1 poise (P)	0.1 kg/m s	0.1 Pa s
1 pound-force (lb) (1 lb = 1 slug × 1 ft/s^2)	4.448 kg m/s^2	4.448 N
1 pound-force per cubic foot (lb/ft^3)	157.1 kg/m^2 s^2	157.1 N/m^3
1 pound-foot (lb-ft)	1.356 kg m^2/s^2	1.356 N m
1 pound per square foot (lb/ft^2 or psf)	47.88 kg/m s^2	47.88 Pa
1 pound per square inch (lb/in.^{2} or psi)	6,895 kg/m s^2	6,895 Pa
1 quart (US) (1 qt = 2 pint)	0.0009463 m^3	
1 slug	14.59 kg	
1 slug per cubic foot (slug/ft^3)	515.4 kg/m^3	
1 stoke (S) = 1 cm^2/s	0.0001 m^2/s	
1 ton (UK long)	1,016 kg	
1 ton (SI metric) (1,000 kg = 1 Mg)	1,000 kg	
1 ton (US short) = 2,000 lb	8,900 kg m/s^2	8.9 kN
1 yard (yd) (1 yd = 3 ft)	0.9144 m	

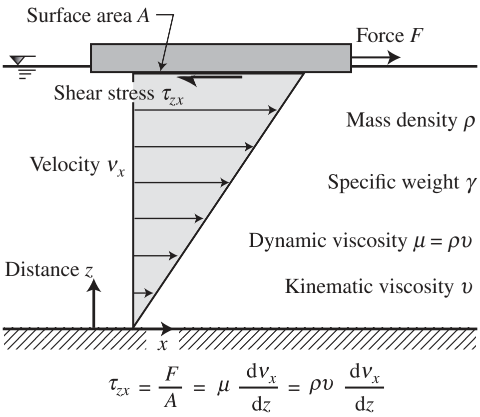

Figure 1.1. Newtonian fluid properties

motion of fluids and solids, and are depicted by only two fundamental dimensions: L and T. Dynamic variables always include mass M terms. Force, pressure, shear stress, work, energy, power, mass density, specific weight, and dynamic viscosity are common examples of dynamic variables. Several conversion factors are listed in Table 1.2.

1.2 Water Properties

Rivers carry water to the oceans. The properties of water are sketched in Figure 1.1.

Mass density of water ρ. The mass of water per unit volume defines the mass density ρ. The maximum mass density of water is 1,000 kg/m^3 at 4°C and decreases slightly with temperature, as shown in Table 1.3. In comparison, the mass density of sea water is approximately 1,025 kg/m^3, and the mass density of air at sea level is 1.29 kg/m^3 at 0°C. The conversion factor for mass density is 1 slug/ft^3 = 515.4 kg/m^3. The density of ice is approximately 10 percent less than that of water and it increases as the subzero temperature decreases. For instance, the ice cover on lakes can crack during winter nights and expand in daytime. When the cracks fill up with water at night, very large forces will be applied on the banks of rivers, lakes, and reservoirs.

Specific weight of water γ. The weight per unit volume is the specific weight γ. At 10°C, water has a specific weight, γ = 9,810 N/m^3 or 62.4 lb/ft^3

Table 1.3. *Physical properties of clear water at atmospheric pressure*

Temperature (°C)	Density ρ (kg/m^3)	Specific weight γ (N/m^3)	Dynamic viscosity μ (N s/m^2 or kg/m s)	Kinematic viscosity ν (m^2/s)
–30	921	9,035	Ice	Ice
–20	919	9,015	Ice	Ice
–10	918	9,005	Ice	Ice
0	999.9	9,809	1.79×10^{-3}	1.79×10^{-6}
4	**1,000**	**9,810**	1.56×10^{-3}	1.56×10^{-6}
5	999.9	9,809	1.51×10^{-3}	1.51×10^{-6}
10	999.7	9,807	1.31×10^{-3}	1.31×10^{-6}
15	999	9,800	1.14×10^{-3}	1.14×10^{-6}
20	998	9,790	$\mathbf{1.0 \times 10^{-3}}$	$\mathbf{1.0 \times 10^{-6}}$
25	997	9,781	8.91×10^{-4}	8.94×10^{-7}
30	996	9,771	7.97×10^{-4}	8.00×10^{-7}
35	994	9,751	7.20×10^{-4}	7.25×10^{-7}
40	992	9,732	6.53×10^{-4}	6.58×10^{-7}
50	988	9,693	5.47×10^{-4}	5.53×10^{-7}
60	983	9,643	4.66×10^{-4}	4.74×10^{-7}
70	978	9,594	4.04×10^{-4}	4.13×10^{-7}
80	972	9,535	3.54×10^{-4}	3.64×10^{-7}
90	965	9,467	3.15×10^{-4}	3.26×10^{-7}
100	958	9,398	2.82×10^{-4}	2.94×10^{-7}
°F	slug/ft^3	lb/ft^3	lb s/ft^2	ft^2/s
0	1.7844	57.40	Ice	Ice
10	1.7839	57.34	Ice	Ice
20	1.7816	57.31	Ice	Ice
30	1.7787	57.25	Ice	Ice
32	1.938	62.40	3.75×10^{-5}	1.93×10^{-5}
40	**1.94**	62.43	3.23×10^{-5}	1.66×10^{-5}
50	1.938	**62.4**	2.73×10^{-5}	1.41×10^{-5}
60	1.936	62.37	2.36×10^{-5}	1.22×10^{-5}
70	1.935	62.30	$\mathbf{2.0 \times 10^{-5}}$	$\mathbf{1.0 \times 10^{-5}}$
80	1.93	62.22	1.80×10^{-5}	0.930×10^{-5}
100	1.93	62.00	1.42×10^{-5}	0.739×10^{-5}
120	1.92	61.72	1.17×10^{-5}	0.609×10^{-5}
140	1.91	61.38	0.981×10^{-5}	0.514×10^{-5}
160	1.90	61.00	0.838×10^{-5}	0.442×10^{-5}
180	1.88	60.58	0.726×10^{-5}	0.385×10^{-5}
200	1.87	60.12	0.637×10^{-5}	0.341×10^{-5}
212	1.86	59.83	0.593×10^{-5}	0.319×10^{-5}

(1 lb/ft^3 = 157.09 N/m^3). Specific weight varies with temperature as given in Table 1.3. The specific weight γ equals the product of mass density ρ and gravitational acceleration $g = 32.2$ ft/s^2 = 9.81 m/s^2:

$$\gamma = \rho g. \tag{1.1}$$

Dynamic viscosity μ. As a fluid is brought into low rates of deformation, the velocity of the fluid at any boundary equals the velocity of the boundary. The ensuing rate of fluid deformation causes a shear stress τ_{zx} that is proportional to the dynamic viscosity μ and the rate of deformation of the fluid, $\mathrm{d}v_x/\mathrm{d}z$:

$$\tau_{zx} = \mu \frac{\mathrm{d}v_x}{\mathrm{d}z}. \tag{1.2}$$

The fundamental dimension of the dynamic viscosity μ is M/LT. In Table 1.3, the dynamic viscosity of water decreases with temperature. The dynamic viscosity of clear water at 20°C is 1 centipoise: 1 cP = 0.01 P = 0.001 kg/m s = 0.001 N s/m^2 = 0.001 Pa s. The conversion factor for the dynamic viscosity is 1 lb s/ft^2 = 47.88 N s/m^2 = 47.88 Pa s.

Kinematic viscosity of water υ. The kinematic viscosity is obtained when the dynamic viscosity of a fluid μ is divided by its mass density ρ. The kinematic viscosity υ of water in L^2/T is shown in Table 1.3 to decrease with temperature. The viscosity of clear water at 20°C is 1 centistokes = 1 cS = 0.01 cm^2/s = 1 × 10^{-6} m^2/s. The conversion factor is 1 ft^2/s = 0.0929 m^2/s. The change in kinematic viscosity of water υ with temperature $T°$ in degrees Celsius can be roughly estimated from

$$\upsilon = \frac{\mu}{\rho} = (1 + 0.0337 T^{\circ}_{C} + 0.0002217 T^{\circ 2}_{C})^{-1} \times 1.78 \times 10^{-6} \mathrm{m}^2/\mathrm{s} \tag{1.3}$$

1.3 Sediment Properties

Rivers also carry vast amounts of sediment that helps shape their own morphology. The physical properties of sediment are classified into single particles (Section 1.3.1), sediment mixtures (Section 1.3.2), sediment suspensions (Section 1.3.3), and sediment deposits (Section 1.3.4).

1.3.1 Sediment Particles

The physical properties of a single solid particle of volume $\forall_s$ are sketched in Figure 1.2. The mass density of a solid particle ρ_s describes the solid mass per volume of solids. The mass density of quartz particles is ρ_s = 2,650 kg/m^3 (1 slug/ft^3 = 515.4 kg/m^3).

Specific weight of sediment γ_s. The particle specific weight γ_s corresponds to the solid weight per unit volume of solid. Typical values of γ_s are 26.0 kN/m^3 or 165.4 lb/ft^3 and the conversion factor is 1 lb/ft^3 = 157.09 N/m^3. The specific

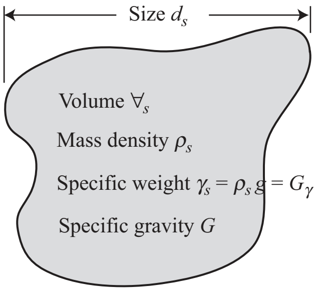

Figure 1.2. Physical properties of a single solid particle

weight of a solid γ_s is the product of the mass density of a solid particle ρ_s and gravitational acceleration g

$$\gamma_s = \rho_s g. \tag{1.4}$$

Specific gravity of sediment G. The ratio of the specific weight of a solid particle to the specific weight of fluid at a standard reference temperature defines the specific gravity G. With reference to water at 4°C, the specific gravity of quartz particles is $G = 2.65$

$$G = \frac{\gamma_s}{\gamma} = \frac{\rho_s}{\rho} = 2.65. \tag{1.5}$$

The specific gravity is a dimensionless parameter independent of the system of units.

Submerged specific weight of sediment $\tilde{\gamma}_s$. The specific weight of a solid particle γ_s submerged in a fluid of specific weight γ equals the difference

$$\tilde{\gamma}_s = \gamma_s - \gamma = (G - 1)\gamma. \tag{1.6}$$

Sediment size d_s. The most important physical property of a sediment particle is its size. The first two columns of Table 1.4 show the grade scale commonly used in sedimentation (1 in. = 25.4 mm). The size of sediment particles can be determined in a number of ways described in detail in Julien (2010). Some of the main characteristics associated with particle size are listed in Table 1.4.

1.3.2 Sediment Mixtures

The properties of a sediment mixture are sketched in Figure 1.3. The total volume, $\forall_t$, is the total of the volume of solids $\forall_s$ and the volume of voids $\forall_v$.

Table 1.4. *Sediment grade scale and approximate properties*

Class name	Particle diameter d_s (mm)	Angle of repose ϕ (deg)	Critical shear stress τ_c (N/m^2)	Critical shear velocity u_{*c} (m/s)	Settling velocity ω_0 (mm/s)
Boulder					
Very large	>2,048	42	1,790	1.33	5,430
Large	>1,024	42	895	0.94	3,839
Medium	>512	42	447	0.67	2,715
Small	>256	42	223	0.47	1,919
Cobble					
Large	>128	42	111	0.33	1,357
Small	>64	41	53	0.23	959
Gravel					
Very coarse	>32	40	26	0.16	678
Coarse	>16	38	12	0.11	479
Medium	>8	36	5.7	0.074	338
Fine	>4	35	2.71	0.052	237
Very fine	>2	33	1.26	0.036	164
Sand					
Very coarse	>1.000	32	0.47	0.0216	109
Coarse	>0.500	31	0.27	0.0164	66.4
Medium	>0.250	30	0.194	0.0139	31.3
Fine	>0.125	30	0.145	0.0120	10.1
Very fine	>0.062	30	0.110	0.0105	2.66
Silt					
Coarse	>0.031	30	0.083	0.0091	0.67
Medium	>0.016	30	0.065	0.0080	0.167[a]
Fine	>0.008				0.042[a]
Very fine	>0.004				0.010[a]
Clay					
Coarse	>0.0020				2.6×10^{-3}[a]
Medium	>0.0010		Cohesive		6.5×10^{-4}[a]
Fine	>0.0005		material		1.63×10^{-4}[a]
Very fine	>0.00024				4.1×10^{-5}[a]

[a]Possible flocculation.

Sediment particle-size distribution. The example of particle-size distribution in Figure 1.3 also shows the percentage by weight of material finer than a given sediment size. The median grain diameter is the size d_{50} for which 50 percent of the material is finer. Likewise d_{90} and d_{10} are sediment sizes for which 90 percent and 10 percent of the material are finer.

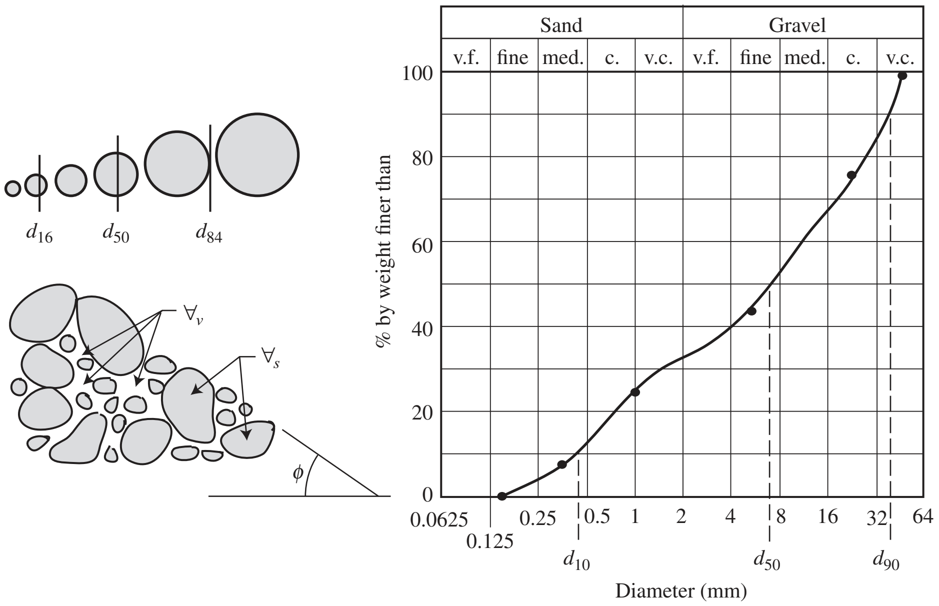

Figure 1.3. Particle-size distribution

Gradation coefficients σ_g and Gr. The gradation of the sediment mixture is a measure of the particle-size distribution of a sediment mixture. It can be described as

$$\sigma_g = \left(\frac{d_{84}}{d_{16}}\right)^{1/2} \tag{1.7a}$$

or

$$\mathrm{Gr} = \frac{1}{2}\left(\frac{d_{84}}{d_{50}} + \frac{d_{50}}{d_{16}}\right). \tag{1.7b}$$

Both gradation coefficients reduce to unity for uniform sediment mixtures, i.e. when $d_{84} = d_{50} = d_{16}$. The gradation coefficient increases with nonuniformity, and high gradation coefficients describe well-graded mixtures.

Angle of repose ϕ. Typical values of the angle of repose ϕ of granular material are shown in Figure 1.4. The angle of repose varies with grain size and angularity of the material. Typical values of the angle of repose are also given in column three of Table 1.4 for material coarser than medium silt.

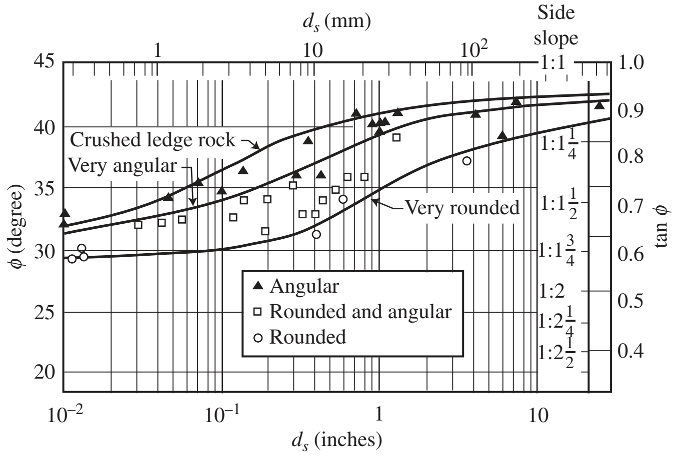

Figure 1.4. Angle of repose of granular material (after Simons, 1957)

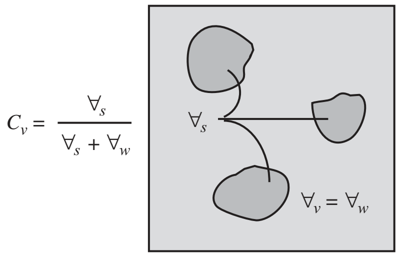

Figure 1.5. Properties of a sediment suspension

1.3.3 Sediment Suspensions

The properties of a sediment suspension are sketched in Figure 1.5, with the volume of void $\forall_v$ completely filled with water $\forall_w$, i.e. without air in the mixture.

Sediment concentration. The volumetric sediment concentration C_v is the ratio of the volume of solids $\forall_s$ to the total volume $\forall_t = \forall_s + \forall_w$.

$$C_v = \frac{\text{sediment volume}}{\text{total volume}} = \frac{\forall_s}{\forall_s + \forall_w}. \tag{1.8a}$$

The sediment concentration is commonly measured in milligrams per liter $C_{\text{mg/l}}$ while other measurements include the concentration by weight C_w and the concentration in parts per million (ppm). The following conversions from Julien (2010) are

$$C_w = \frac{\text{sediment weight}}{\text{total weight}} = \frac{C_v G}{1 + (G-1)C_v}, \tag{1.8b}$$

Table 1.5. *Equivalent concentrations for C_v, C_w, C_{ppm}, $C_{\text{mg/l}}$, p_0, and γ_{md}*

C_v	C_w	C_{ppm}	$C_{\text{mg/l}}$	p_0	γ_{md} lb/ft^3	γ_{md} kN/m^3
Suspension						
0.0001	0.00026	265	265			
0.001	0.00264	2,645	2,650			
0.0025	0.00659	6,598	6,625			
0.005	0.01314	13,141	13,250			
0.0075	0.01963	19,632	19,875			
0.01	0.02607	26,069	26,500			
0.025	0.06363	63,625	66,250			
Hyperconcentrations						
0.05	0.12240	122,401	132,500	0.95		
0.075	0.17700	176,863	198,750	0.925		
0.1	0.22750	227,467	265,000	0.9	16.5	2.6
0.20	0.39850	398,496	530,000	0.8	33.0	5.2
0.25	0.46900	469,027	662,500	0.75	41.3	6.5
0.30	0.53200	531,772	795,000	0.70	49.6	7.8
0.40	0.63900	638,554	1,060,000	0.60	66.2	10.4
Sediment deposits						
0.5	0.72600	726,027	1,325,000	0.50	82.7	13
0.6	0.79900	798,995	1,590,000	0.40	99.2	15.6
0.7	0.86080	860,788	1,855,000	0.30	116	18.2
0.75	0.88800	888,268	1,987,500	0.25	124	19.5

Note: Calculations based on $G = 2.65$.

$$C_{\text{ppm}} = 10^6 C_w, \tag{1.8c}$$

$$C_{\text{mg/l}} = \frac{\text{sediment mass}}{\text{total volume}} = \rho G C_v. \tag{1.8d}$$

Equivalent sediment concentrations are listed in columns one to four of Table 1.5. In practice, there is a negligible difference (<10 percent) between C_{ppm} and $C_{\text{mg/l}}$ when $C_{\text{ppm}} < 145{,}000$.

Specific weight of a mixture γ_m. The specific weight of a submerged mixture is the total weight of solid and water in the voids-per-unit total volume. The specific weight of a mixture γ_m is a function of the volumetric concentration C_v as

$$\gamma_m = \frac{\text{total weight}}{\text{total volume}} = \gamma_s C_v + \gamma(1 - C_v). \tag{1.9}$$

The specific mass ρ_m of a submerged mixture is the total mass of solid and water in the voids-per-unit total volume. The specific mass is given by $\rho_m = \gamma_m/g$.

1.3.4 Sediment Deposits

The properties of sediment deposits usually include the porosity p_0 and the dry specific weight γ_{md} of sediment mixtures.

Porosity p_0. The porosity p_0 is the volume of void $\forall_v$ per total volume $\forall_t$.

$$p_0 = \frac{\forall_v}{\forall_t}. \tag{1.10}$$

The values of porosity are listed in column five of Table 1.5.

Dry specific weight of a mixture γ_{md}. The dry specific weight of a mixture is the weight of solid-per-unit total volume, including the volume of solids and voids. The dry specific weight of a mixture γ_{md} is a function of porosity p_0 as

$$\gamma_{md} = \frac{\text{sediment weight}}{\text{total volume}} = \gamma G C_v = \gamma_s(1 - p_0). \tag{1.11}$$

The dry specific weight of sand deposits is approximately $\sim$14.75 kN/m^3 or 93 lb/ft^3. The dry specific mass of a mixture is the mass of solid-per-unit total volume. The dry specific mass of a mixture is $\rho_{md} = \gamma_{md}/g$.

Problem 1.1

Determine the mass density, specific weight, dynamic viscosity, and kinematic viscosity of clear water at 20°C (a) in SI units and (b) in the English system of units.
[*Answers*: (a) $\rho = 998$ kg/m^3, $\gamma = 9{,}790$ N/m^3, $\mu = 1.0 \times 10^{-3}$ N s/m^2, $\upsilon = 1 \times 10^{-6}$ m^2/s, (b) $\rho = 1.94$ slug/ft^3, $\gamma = 62.3$ lb/ft^3, $\mu = 2.1 \times 10^{-5}$ lb/ft^2, $\upsilon = 1.1 \times 10^{-5}$ ft^2/s]

◆Problem 1.2

Determine the sediment size, mass density, specific weight, submerged specific weight, and angle of repose of small quartz cobbles (a) in SI units and (b) in English units.

◆◆Problem 1.3

The volumetric sediment concentration of a sample is $C_v = 0.05$. Determine the corresponding: (a) concentration by weight C_w, (b) concentration in parts per million C_{ppm}, (c) concentration in milligrams per liter $C_{\text{mg/l}}$, (d) porosity p_0, and (e) void ratio e.
[*Answers*: The answers are found in Table 1.5.]

◆Problem 1.4

The porosity of a sandy loam is 0.45. Determine the corresponding soil properties: (a) volumetric concentration, (b) void ratio e, (c) specific weight γ_m, (d) specific mass ρ_m, (e) dry specific weight γ_{md}, and (f) dry specific mass ρ_{md}.

◆Problem 1.5

Calculate the gradation coefficients σ_g and Gr from the particle distribution in Figure 1.3.
[*Answer: It is a well-graded sediment mixture* $\sigma_g = 8$, *and* Gr = 10.]