CIVL4120 Advanced open channel hydraulics and design - Tutorail (2)
Sediment transport in open channels

The course is a professional subject in which the students are expected to have a sound knowledge of the basic principles of continuity, energy and momentum, and understand the principles of fluid flow motion. The students should have completed successfully the core course Introduction to Fluid mechanics (CIVL3130) and have a solid knowledge in the core course Catchment Hydraulics (CIVL3140).

Attendance to tutorials is very strongly advised. Repeated absences by some individuals will be noted and these would demonstrate some disappointing responsible behaviour.

Past course results demonstrated a very strong correlation between the attendance of tutorials during the semester, the performances at the end-of-semester examination, and the overall course result.

Part 2-1 - Introduction to sediment transport in rivers

1- Sediment particle properties

(a) What is the density of clay mineral particles ? (b) What is the porosity of sand ? (c) What is the wet density of a sand mixture ? (d) What is the relative density of sediment (clay minerals) in air ? (e) What is the angle of repose of a sphere, a cube, and a sand particle ?

2- Settling velocity

(a) Calculate the settling velocity of a 1.2-mm sand particle in air. *The air is at rest. Calculate the drag coefficient using Figure 7.3, p. 160 (textbook).* (b) Compute the settling velocity of a heavy particle (d_s = 0.5 mm, ρ_s = 2,970 kg/m^3) in water. (c) Compute the settling velocity of the same heavy particle (d_s = 0.5 mm, ρ_s = 2,970 kg/m^3) in crude oil (ρ = 860 kg/m^3, μ = 8 E-3 Pa.s).

3. Settling velocity and particle size distribution

The size properties of a sand mixture are recorded using a VAT test. In the VAT settling tube, the settling time in water over a known settling distance is recorded. The results are :

Settling rate (cm/s) :	32	16	10.7	8	5.33	4	3.2	2.7
Mass (g) :	0.4	1.2	4.3	7.00	16.0	31.6	38.1	42.6
Settling rate (cm/s) :	2.29	2	1.78	1.6	1.45	1.3	1.23	1.14
Mass (g) :	44.8	48.	49.1	49.6	49.8	49.9	49.9	50.0

(a) Compute the median grain size and the sorting coefficient $S = \sqrt{d_{90}/d_{10}}$. (b) Plot the particle size distribution as : (b1) percentage sampling as a function of Log(d_s) and (b2) cumulative percentage passing as a function of sedimentological size parameter (ϕ-scale).

4. We consider a stream with a flow depth of 1.7 m and a bed slope $\sin\theta$ = 0.002.

(a) Will a 5-mm gravel bed be subjected to bed load motion ? (b) Calculate the critical particle size for bed load motion in the stream. (*That is, no bed load motion for d_s > critical particle size.*)

5. A wind storm blows over a sandy beach (0.28-mm sand particle) of the Gold Cost and the atmospheric boundary layer is about 100-m high at the beach. The boundary layer free-stream velocity (i.e. at the outer edge of wind boundary layer) is 30-m./s. Estimate the risk (or not) of beach sand erosion.
Note
Compute the bed shear stress as :

$$\tau_o = 0.0225 * \rho * V^2 * \left(\frac{\nu}{V * \delta}\right)^{1/4}$$

where δ is the boundary layer thickness and V is the free-stream velocity.

6. A channel of trapezoidal cross-section (bottom width 2 m, sidewall slope 1V:3H) has a longitudinal slope of 0.012. The channel bed and sloping sidewall consist of a mixture of fine sands (k_s = 0.2 mm). Uniform equilibrium flow conditions are achieved and the flow depth is 0.478-m.
(a) Compute and give the values (and units) of the following quantities : uniform equilibrium flow velocity, boundary shear stress, and shear Reynolds number. (b) Compute the Shields parameter. (c) Using the modified Shields diagram, predict whether bed-load motion occurs or not. (d) Compute the settling velocity of the sand particle in water (at rest). (e) Predict whether suspension occurs or not.

7. Prototype application
Measurements in the North Fork Toutle river were performed on 28 March 1989 at the Hoffstadt Creek bridge. At that location the river is 18-m wide. Hydraulic measurements indicated that the flow depth was 0.83 m, the depth-averaged velocity was 3.06 m/s and the bed slope was $\sin\theta$ = 0.0077. The channel bed was a sediment mixture with a median grain size of 15-mm and d_{84} = 55 mm.
(a) Compute the flow rate. (b) Compute the bed shear stress. (c) Calculate the Shields parameter. (d) Predict the occurrence (or not) of bed-load motion. (e) Predict the occurrence (or not) of suspension motion.

Part 2-2 - Sediment transport calculations

1- Particle settling velocity
a- Calculate the settling velocity of a 2-mm size quartz particle in air.
b- Calculate the settling velocity of a heavy metal particle (ρ_s = 7,500 kg/m^3) of 1-mm diameter in water.
Use Figure 7.3 of the textbook to estimate C_d.

2 Inception of suspension
Considering a stream with a flow depth of 3.2 m and a bed slope $\sin\theta$ = 0.001, indicate whether a 3-mm gravel bed will be subjected to sediment motion. In the affirmative, indicate whether the sediment motion is bed-load, saltation or suspension.

3. Bed load transport rate
The bed-load transport rate must be estimated for the Danube river (Central Europe) at a particular cross-section. The known hydraulic data are : flow rate of about 530 m^3/s, flow depth of 4.27 m, bed slope being about 0.0011. The channel bed is a sediment mixture with a median grain size of 0.012 m and the channel width is about 34-m.
Predict the sediment-load rate using equation (10.5) using NIELSEN coefficients.

4. Continuity equation for sediment material
A 1-km long reach of a river has a longitudinal slope $\sin\theta$ = 0.0014. The water discharge is 8.5 m^2/s and the mean sediment concentration of the inflow is 0.25%. The sediment transport capacity of the reach is 0.13 m^2/s. Deduce the rate of erosion (or accretion) of the channel bed for the 1-km long reach.

More exercises in textbook pp. 166-168, 182, 187, 198-203, 211-214, 216-217, 235-238, 239-240.
"The Hydraulics of Open Channel Flow: An Introduction", *Butterworth-Heinemann Publ.*, 2nd edition, Oxford, UK, 2004.

Tutorial - Solutions

Part 2-1

1. Textbook pp. 155-165
2. (a) 4.7 m/s (b) 8 cm/s (c) 3 cm/s
3. d_{50}=0.31 mm, S = 2.15, Textbook p. 164.
4. 5-mm particles will move. Textbook pp. 179.
5. Onset of sediment motion. Textbook p. 180
7. τ_* = 0.26, Textbook pp. 200-202.

Part 2-2

1a w_o = 6.14 m/s
1b w_o = 0.23 m/s
2. Bed load & saltation, Textbook p. 184-185
3. q_s = 8.3 E-4 m^2/s, Textbook pp. 196-198
4. Erosion rate = 0.65 m/hour, Textbook pp. 226