CIVL3140 Introduction to Open Channel Hydraulics - TUTORIAL 2

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 in semester 2, 2nd Year (CIVL2131).

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.

More exercises in textbook pp. 46-49, 87-93, 111-118.
"The Hydraulics of Open Channel Flow: An Introduction", *Butterworth-Heinemann Publ.*, Oxford, UK, 2004.

1. Application of the Bernoulli principle

1.1. Considering a trapezoidal channel (1V:3H sideslopes, 1.5 m bottom width), calculate the critical depth d_c for Q = 3 m^3/s and 10 m^3/s.

Solution: see textbook pp. 44-46

1.2. Considering a smooth transition, the flow rate is 7.2 m^3/s. The channel upstream and downstream cross-sections are:

upstream: rectangular, B = 5 m, z_o = 0.5 m
downstream: rectangular, B = 3.9 m, z_o = 0.2 m

(a) if the upstream water depth equals 1.9 m, calculate the downstream water depth

(b) if the upstream water depth equals 0.8 m, calculate the downstream Froude number

Numerical solution: (a) d_1 = 1.9 m $\Rightarrow$ d_2 = 2.19 m (b) d_1 = 0.8 m $\Rightarrow$ d_2 = 1.13 m

2. Application of the Momentum principle

2.1 Application of the continuity and momentum principles to a hydraulic jump
A hydraulic jump takes place in a rectangular channel (10-m wide). The total flow rate is 187,500 l/s and the upstream flow depth is 1.4 m. Compute and give the values (and units) of the following quantities : (a) upstream Froude number, (b) type of jump, (c) downstream flow depth, (d) downstream flow velocity, (e) total head loss, (f) hydraulic power dissipated in the jump, (g) If the dissipated power could be transformed into electricity, how many 100-W bulbs could be lighted ?

Numerical solution: Fr_1 = 3.62, d_2 = 6.49 m (d/s depth), ΔH = 3.63 m

Photograph of a hydraulic jump in laboratory (Fr_1 = 11) - Flow direction from right to left

2.2 At the end of a steep chute, a hydraulic jump is forced in the downstream stilling basin. The basin is a horizontal rectangular channel (B = 22.5 m). The observed downstream flow depth is 2.1 m and the discharge is 46 m^3/s.
(2.2.1) Compute and give the values (<u>and</u> units) of the following quantities : (a) upstream Froude number, (b) type of jump, (c) hydraulic power dissipated in the jump.
(2.2.2) What basic principle(s) was (were) used to compute the upstream flow depth ?
(2.2.3) Describe (in words) the characteristics of this type of hydraulic jump

Solution: the flow conditions correspond to a steady hydraulic jump. See textbook pp. 60 & 412-417.
Numerical solution: Fr_1 = 8.7, d_1 = 0.18 m, ΔH = 4.76 m

Hydraulic jump at the downstream of a steep spillway chute in Canada during a flood (Courtesy of John REMI)

2.3 Considering the flow upstream of a sluice gate, the gate closes suddenly. The initial flow conditions were: Q = 5.2 m^3/s, d = 2 m, B = 3 m. The new discharge is: Q = 2.2 m^3/s. Compute the new flow depth and flow velocity. *The channel is smooth, rectangular, and horizontal*.

Solution: Upstream of the gate, the flow conditions associated with a reduction in discharge correspond to the formation of a positive surge.
Numerical solution: V_{srg} = 3.97 m/s, V_2 = 0.33 m/s, d_2 = 2.25 m

2.4 A bore is a positive surge of tidal origin which may form with large tidal ranges in a converging channel forming a funnel shape. The front of the surge absorbs random disturbances on both sides and this makes the wave stable and

self-perpetuating (HENDERSON 1966, CHANSON 1999). With appropriate boundary conditions, a tidal bore may travel long distances upstream: e.g., the tidal bore on the Pungue River (Mozambique) is still about 0.7 m high about 50 km upstream of the mouth and it may reach 80 km inland. Famous bores include the Hangzhou (or Hangchow) bore on the Qiantang River, the Amazon bore called *pororoc*a, the tidal bore on the Seine River *(mascare*t) and the Hoogly (or Hooghly) bore on the Gange. Smaller tidal bores occur on the Severn River near Gloucester, England, on the Dordogne River, France, in the Bay of Fundy (at Petitcodiac and Truro), on the Styx and Daly Rivers (Australia), and at Batang Lupar (Malaysia) (se Figure below). A tidal bore affects shipping industries. For example, the *mascaret* of the Seine River had had a sinister reputation. More than 220 ships were lost between 1789 and 1840 in the Quilleboeuf-Villequier section (MALANDAIN 1988). The height of the *mascaret* bore could reach up to 7.3 m and the bore front travelled at a celerity of about 2 to 10 m/s. Even in modern times, the Hoogly and Hangzhou bores are hazards for small ships and boats. Tidal bores affect also
estuarine eco-systems. The effect on sediment transport was studied at Petitcodiac and Shubenacadie Rivers, on the Sée and Sélune Rivers and on the Hangzhou bay. The impact on the ecology is acknowledged in the Amazon where piranhas eat matter in suspension after the passage of the bore, at Turnagain Arm where bald eagles fish behind the bore, in the Severn River (sturgeons in the past, elvers) and in the Bay of Fundy (striped bass spawning) (CHANSON 2011).

On the 27 Sept. 2000, the flow conditions of the tidal bore of the Dordogne River were: initial water depth = 1.5 m, initial flow velocity = +0.22 m/s, observed bore celerity: 4.8 m/s. Assuming a wide rectangular channel, calculate the flow velocity after the passage of the bore. (Use the downstream flow direction as positive axis.)

Numerical solution: V_2 = -1.26 m/s (flow reversal), d_2 = 2.13 m.

Photograph of the tidal bore of the Dordogne River in 2015

Additional references
CHANSON, H. (2011). "Tidal Bores, Aegir, Eagre, Mascaret, Pororoca: Theory and Observations." *World Scientific*, Singapore (ISBN 9789814335416).
MALANDAIN, J.J. (1988). "La Seine au Temps du Mascaret." ('The Seine River at the Time of the Mascaret.') *Le Chasse-Marée*, No. 34, pp. 30-45 (in French).

2.6 A hydraulic jump is formed below a vertical sluice gate. The channel is bed is smooth and horizontal and the channel cross-section is rectangular (B = 5.5 m). The depths upstream and downstream of the jumps are respectively 0.95 m and 2.2 m. Calculate: (a) the specific energy upstream of the sluice gate, (b) the total discharge and (c) the head loss along the hydraulic jump.

Numerical solution: Fr_1 = 1.96, E = 2.8 m, Q = 31.2 m^3/s.

2.7 The depth and velocity of the flow in a horizontal rectangular channel are 4 m and 3.2 m/s respectively. The channel is 12 m wide. If the discharge at the upstream of the channel is increased suddenly such that the new flow depth equals twice the initial flow depth, calculate the surge celerity.

Numerical solution: Fr_1 = 1.73, V_{srg} = 14.0 m/s.

Photograph of the tidal bore of the Qiantang River in October 2014

3. Application of the momentum principle to uniform equilibrium flow

3.1 In a rectangular concrete channel, the uniform equilibrium flow depth is 3.2 m. The channel is 2 m wide and the bed slope is 0.0006. Compute and give the values (and units) of the following quantities: (a) uniform equilibrium flow velocity, (b) Darcy friction factor, (c) discharge.

Solution: The problem is solved using the momentum principle. The bed shear stress must be estimated using the Darcy-Weisbach friction factor. See textbook pp. 69-77. Note that the calculations are iterative.
Numerical solution: V_o = 1.53 m/s , d_o = 3.2 m, f = 0.0154 (k_s = 1 mm), τ_o = 4.43 Pa

3.2. A rectangular channel (12-m wide) is faced with rubble masonry (k_s = 50 mm). The total flow rate is 12.5 m^3/s and the bed slope is 0.001.
(3.2.1) Compute and give the values and units of the following quantities : (a) uniform equilibrium flow depth, (b) Darcy friction factor, (c) boundary shear stress
(3.2.2) Is the uniform equilibrium flow sub- or super-critical?
(3.2.3) From where would you control the flow?

Numerical solution: V_o = 1.17 m/s , d_o = 0.891 m (for k_s = 50 mm)

3.3 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.
(3.3.1) Compute and give the values and units of the following quantities: (a) flow rate, (b) uniform equilibrium flow velocity, (c) Darcy friction factor, (d) boundary shear stress, (e) shear Reynolds number, (f) critical flow depth.
(3.3.2) From where should the uniform equilibrium flow be controlled (upstream or downstream)? Justify your answer.

Numerical solution: V_o = 4.82 m/s, d_o = 0.478 m, τ_o = 38.4 Pa, d_c = 0.80 m

3.4. A channel of rectangular cross-section (bottom width 15 m) has a longitudinal slope of 0.002. The channel bed and sloping sidewall consist of a bush ($n_{Manning}$ = 0.05 s/$m^{1/3}$). Uniform equilibrium flow conditions are achieved and the total flow rate equals 21 m^3/s. Compute and give the values (<u>and</u> units) of the following quantities: (a) uniform equilibrium flow depth (i.e normal depth), (b) uniform equilibrium flow velocity, (c) critical flow depth.

Numerical solution: V_o = 1.0 m/s, d_o = 1.4 m

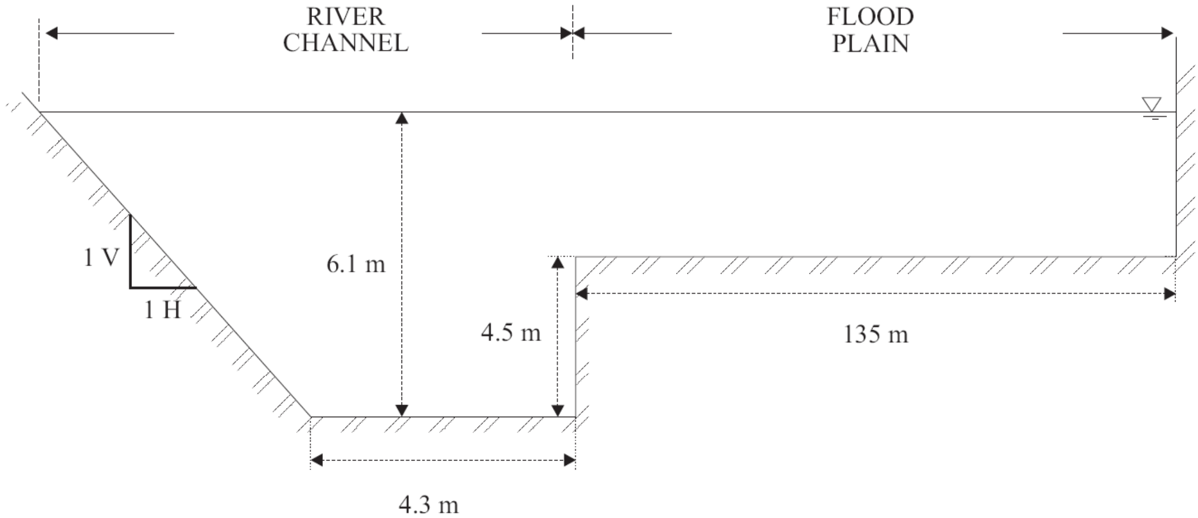
3.5 Flood plain calculations

Considering the flood plain, sketched in figure E.4.2 (textbook, p. 92), the mean channel slope is 0.05 degrees. The river channel is lined with concrete and the flood plain is riprap material (equivalent roughness height: 8 cm). The fluid is water with a heavy load of suspended sediment (fluid density: 1,080 kg/m^3). The flow is assumed uniform equilibrium. Compute and give the values and units of the following quantities:

(a) Volume discharge in the river channel. (b) Volume discharge in the flood plain. (c) Total volume discharge (river channel + flood plain). (d) Total mass flow rate (river channel + flood plain). (e) Is the flow subcritical or supercritical? Justify your answer clearly.

Assume no friction (and energy loss) at the interface between the river channel flow and the flood plain flow.

Numerical solution: V_o = 3.8 m/s (river), V_o = 1.62 m (flood plain), Q = 170 m^3/s (river), Q = 350 m^3/s (flood plain)



Sketch of the flood plain (not at scale)