CIVL3140 Introduction to Open Channel Hydraulics - TUTORIAL 1

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. 8, 19-20, 46-49, 111-118.

"The Hydraulics of Open Channel Flow: An Introduction", *Butterworth-Heinemann Publ.*, Oxford, UK, 2004.
UQ Library Ref.# TC175. C52 2004

1- Physical properties of fluids

1.1 Give the following fluid and physical properties (at 20 C and standard pressure) with a 3-digit accuracy.

	Value	SI Units
Air density :		
Water density :		
Water dynamic viscosity :		
Gravity constant (in Brisbane) :		
Surface tension (air and water) :		

Note: these fluid properties are assumed knowledge.

Solution: Textbook pp. xlv-xlvi &119-123. Also CROWE et al. (2005), pp. 9-24 & A-9 to A-14.

1.2 Considering a spherical air bubble (diameter R) submerged in water with hydrostatic pressure distribution:
- will the bubble rise or drop?
- is the pressure inside the bubble greater or smaller than the surrounding hydrostatic pressure?
- what is the magnitude of the pressure difference (between inside and outside the bubble) for a 1-mm diameter air bubbles in water?

Note: the last question requires some basic calculation.

Solution: $\Delta P = 4 \times \sigma / D$ where D is the bubble diameter (see CROWE et al. 2005, pp. 21-22)
Numerical solution: $\Delta P = 290$ Pa

2- Continuity equation

2.1 Considering a circular pipe (diameter 1.3 m), the total flow rate is 1,600 kg/s. The fluid is a bentonite suspension (density: 1,100 kg/m^3, viscosity: 0.15 Pa.s).
- What is the mean flow velocity?
- What is the flow Reynolds number?
- Would you characterise the flow as laminar or turbulent?

Numerical solution: V = 1.1 m/s, Re =1 E+4, turbulent

2.2 Water flows in a trapezoidal open channel (1V:3H sideslopes, 1-m bottom width) with a 1.2 m/s cross-sectional averaged velocity and a 0.9 m water depth at the channel centreline. Compute the volume discharge.

Numerical solution: Q = 4 m^3/s

2.3 During a cyclonic event, a debris flow (density 1,780 kg/m^3) discharges down a rectangular open channel (5.1 m bottom width). The estimated mass flow rate is 4,700 kg/s and the mean velocity is about 1.7 m/s.

Calculate the volume flow rate.

Compute the water depth on the channel centreline.

Note : For more information on debris flow, see textbook pages XXV 185-186, 214-217.

Numerical solution: d = 0.3 m.

Road warning sign for debris flows in Taiwan

2.4 In a 3.5-m wide rectangular channel, the volume flow rate is 14 m^3/s. Compute the flow properties in the three following cases:

	Case 1	Case 2	Case 3	SI Units
Flow depth :	0.8	1.15	3.9	m
Cross-section area :				
Wetted perimeter :				
Mean flow velocity :				
Froude number :				
Specific energy :				

Notes :
- the wetted perimeter is the perimeter of contact between the fluid and the solid boundary, in a cross-section normal to the flow direction (see textbook page XXXVIII);
- the definition of the specific energy is given in textbook p. 29-30 : $E = H - z_o$.

2.5 During the January flood of the Brisbane River, what was the order of magnitude of the river discharge in Brisbane at the peak of the flood?

Note: this question requires a little bit of research and some basic calculation.

(a) 1 l/s; (b) 10 l/s; (c) 100 l/s; (d) 1 m^3/s; (e) 10 m^3/s; (f) 100 m^3/s; (g); 1,000 m^3/s; (h) 10,000 m^3/s.

University of Queensland St Lucia campus on 12 January 2011 afternoon

Coronation Drive on 13 January 2011 early morning
Photographs of the January 2011 flood of the Brisbane River

3- Application of the continuity and Bernoulli equations to a broad-crested weir

A broad-crested weir is a flat-crested structure with a crest length large compared to the flow thickness. The ratio of crest length to upstream head over crest must be typically greater than 1.5 to 3. Critical flow conditions occur at the weir crest. If the crest is "broad" enough for the flow streamlines to be parallel to the crest, the pressure distribution above the crest is hydrostatic and critical depth is recorded on the weir.

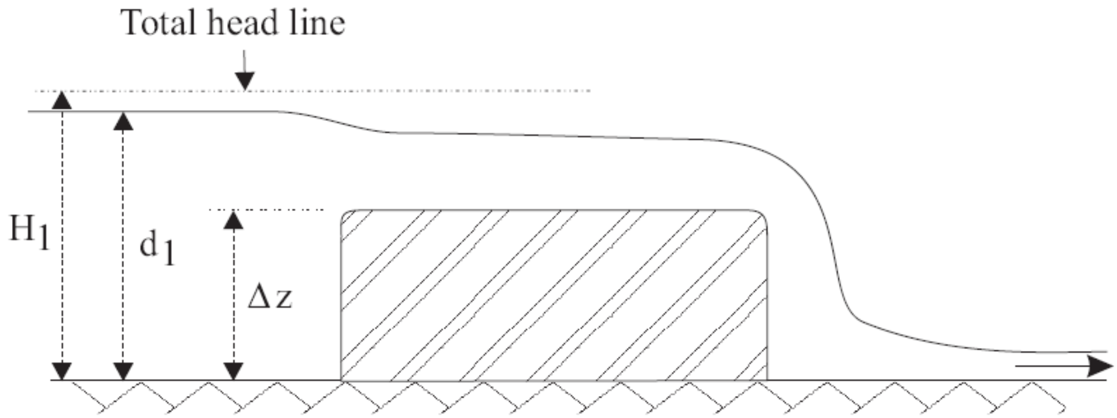
Considering a horizontal rectangular channel (B = 15 m), the crest of the weir is 1.2 m above the channel bed. Investigate the following two upstream flow conditions and calculate the flow properties missing the following table. Assume a supercritical downstream flow.

	Case 1	Case 2
Upstream flow depth	1.45 m	2.1 m
Upstream Froude number		
Flow depth above the weir crest		
Upstream specific energy :		
Velocity above the crest :		
Specific energy above the crest :		
Downstream flow depth :		
Downstream Froude number :		
Downstream specific energy		
Volume discharge :	3.195 m^3/s	

Notes:
- For more information on broad-crested weirs, see textbook pages 37-38 & 396-397.
- For a horizontal rectangular channel, the Froude number is defined as: $Fr = V/\sqrt{g \times d}$.
- The solution of case 2 requires the solution of a cubic equation. See textbook pp. 138-140.

Solution: The solution of case 1 is trivial. Case 2 is solved by combining the continuity equation and the Bernoulli principle for a short and smooth transition. Since the upstream flow is subcritical (check it), and since the downstream flow is supercritical, critical flow conditions must take place above the weir crest. That is, $d_2 = d_c = \sqrt[3]{Q^2 /(g \times B^2)}$.

Numerical solution:
Case 1: d_2 = 0.167 m, d_3 = 0.0405 m
Case 2: d_1 = 2.1 m, Δz = 1.2 m, Q = 22.8 m^3/s, d_3 = 0.25 m (d/s depth)



Sketch of the flow pattern above a broad crested weir

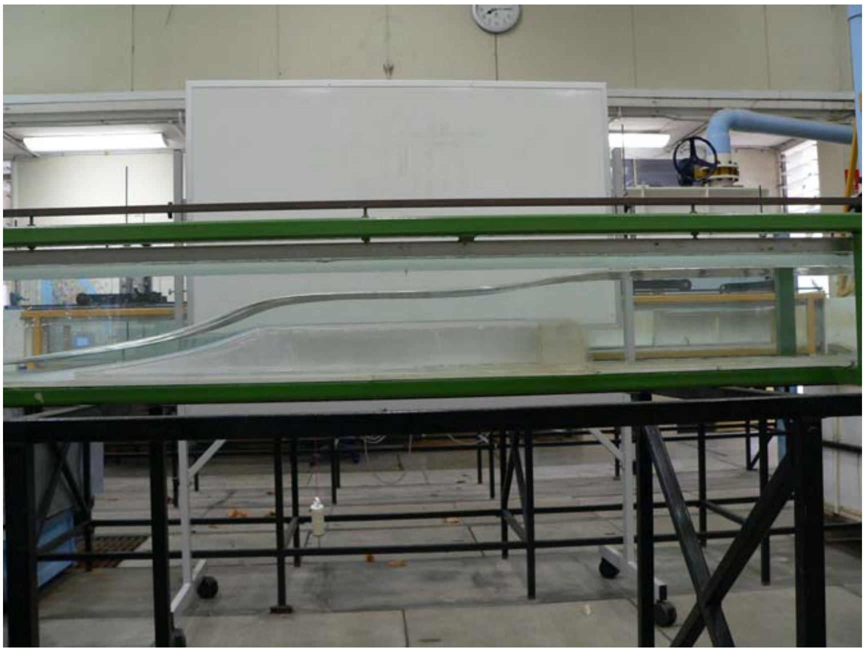
4- Application of the continuity, momentum and Bernoulli principles to a broad-crested weir

Considering a broad-crested weir, draw a sketch of the weir in a rectangular horizontal channel.
(4.1) What is the main purpose of a broad-crest weir?

A broad-crested weir is installed in a horizontal and smooth channel of rectangular cross-section. The channel width is 10 m. The bottom of the weir is 1.5 m above the channel bed. The water discharge is 11 m^3/s and the upstream water depth is 2.235 m.
(4.2) Compute the depth of flow downstream of the weir in absence of downstream control, assuming that critical flow conditions take place at the weir crest.
(4.3) Calculated the horizontal, sliding force acting on the weir. Give the direction of the force exerted by the flow onto the sill.

Solution
(4.1) For more information on broad-crested weirs, see textbook pages 37-38 & 396-397.
(4.2) Question (4.2) is based upon the application of the continuity and Bernoulli principles.
(4.3) Question (4.3) is based upon the application of the momentum principle.

Numerical solution:
d_2 = 0.173 m,
$F_{sliding}$ = +178 kN (The force exerted by the fluid onto the weir sill acts in the downstream direction.)



Photograph of a broad-crested weir - Flow from right to left

5- Application of the basic principles to a sluice gate

An undershot sluice gate is in a channel 5 m wide and the discharge Q is 4 m^3/s. The upstream flow depth is 1.2 m. The bed of the channel is horizontal and smooth.

(5.1) Sketch the sluice gate flow.

(5.2) Draw on your sketch the variation of the pressure with depth at sections 1 and 2, and on the upstream face of the sluice gate. Sections 1 and 2 are located far enough from the sluice gate for the velocity to be essentially horizontal and uniform.

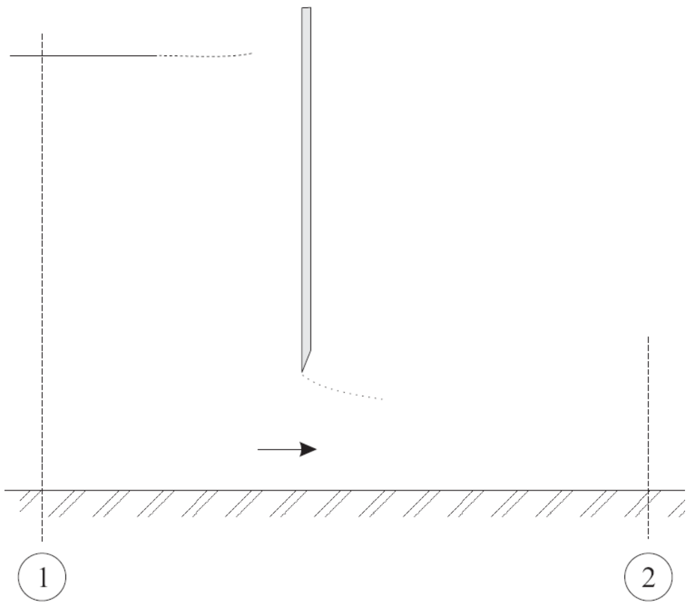
(5.3) Show on your figure the forces acting on the control volume contained between sections 1 and 2. Show also your choice for the positive direction of distance and of force.

(5.4) Write the Momentum equation as applied to the control volume between sections 1 and 2, using the sign convention you have chosen. Show on your figure the forces and velocities used in the Momentum equation.

(5.5) Compute and give the values (and units) of the specified quantities in the following list:

(a) Velocity of flow at section 1. (b) Specific energy at section 1. (c) Specific energy at section 2. (d) Assumption used in answer (c). (e) Depth of flow at section 2. (f) Velocity of flow at section 2. (g) The force acting on the sluice gate. (h) The direction of the force in (g): i.e. upstream or downstream. (i) The critical depth for the flow in figure 1. (j) What is maximum possible discharge per unit width for a flow with Specific Energy entered at (b)? *(This question is a general question, not related to the sluice gate.)*

Numerical solution:
$Q = 4\ m^3/s$,
$d_1 = 1.2$ m,
$d_2 = 0.18$ m,
$F_G = +1.9$ E+4 N (The force exerted by the fluid onto the gate acts in the downstream direction.)



Sketch (incomplete) of a vertical sluice gate