Hydraulic Engineering and Infrastructures

Civil Engineering Department

Uniform Flow

1 Flow in a straight channel †

In a straight channel reach, with width $B = 8\,\mathrm{m}$ and slope $S_0 = 1\,\%$, a discharge $Q = 5\,\mathrm{m}^3/\mathrm{s}$ flows under steady conditions (the discharge per unit width is therefore $q = 0.625\,\mathrm{m}^2/\mathrm{s}$). The roughness coefficient, expressed according to the Gauckler–Strickler[1] formula, is $n = \frac{1}{K_s} = 0.02\,\mathrm{s}/\mathrm{m}^{1/3}$.

Determine:

1. the characteristics of the uniform flow y_0, v_0, Fr_0, E_0;
2. the critical depth y_{CR} and the corresponding specific energy E_{CR}.

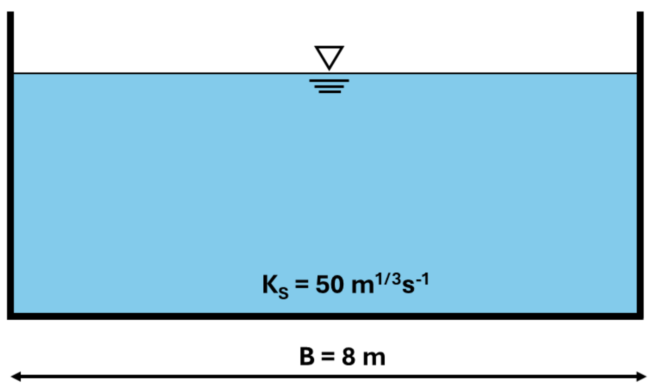

Figure 1: Sketch of a straight rectangular channel.

[1]The Gauckler-Manning-Strickler (GMS) formula is also known as the Gauckler-Strickler formula, the Manning formula and the Manning-Strickler formula.

Objectives and guidance

The goal of this exercise is to understand how to determine the main hydraulic characteristics of a steady, uniform open-channel flow. This exercise helps to relate discharge, channel geometry, slope, and roughness to flow depth and velocity, and to distinguish between uniform and critical flow conditions.

Recommended procedure

1. Start by estimating the uniform flow depth using the given discharge, slope, and roughness, typically through an iterative approach.
2. Once the uniform depth is found, compute the corresponding flow velocity and identify the flow regime by evaluating the Froude number.
3. Determine the specific energy and specific force associated with the uniform flow conditions.
4. Calculate the critical depth and the corresponding specific energy based solely on the discharge per unit width.
5. Compare the uniform and critical conditions to assess whether the flow is subcritical or supercritical.

2 Trapezoidal channel †

A trapezoidal channel has a base width $b = 5\,\mathrm{m}$, side slopes with an angle of 45°, a Manning roughness $n = 0.025\,\mathrm{s/m^{1/3}}$ and a slope $S = 0.17\,\%$. Its cross section is drawn in Figure 2.

1. Express $A(y)$, $P(y)$ and $R_H(y)$.
2. Compute the discharge if the normal depth is $y_n = 2\,\mathrm{m}$
3. Compute the normal depth if the discharge is $Q = 100\,\mathrm{m^3/s}$
4. Express the specific energy and find the depth for which it is minimized. What is this water depth, how is it called ? What is its value for $Q = 100\,\mathrm{m^3/s}$?
5. An engineer informs you that the flow speed should be above $2\,\mathrm{m/s}$ to ensure sediment transport, what is the minimal required water depth?.

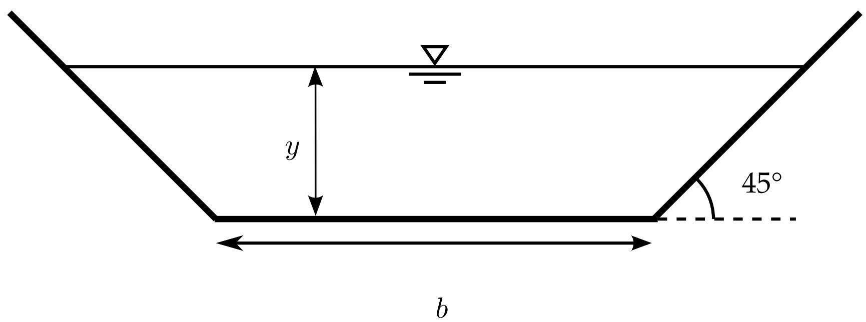

Figure 2: Cross-section of a trapezoidal channel

Objectives and guidance

This exercise focuses on expressing the normal depth and deriving the Froude number for a simple cross-section (and can easily be extended to any cross-section). It relies on a prismatic channel and a flow in normal conditions, showing that the computation of the discharge under such conditions is straight-forward while looking for flow depths is more challenging.

Recommended procedure

1. Express the geometric properties of the trapezoidal section: top width, wetted perimeter, cross-sectional area, and hydraulic radius as functions of the water depth.
2. For a known normal depth, compute the discharge using Manning's equation.

3. If the discharge is given, solve Manning's equation numerically (or iteratively) to find the normal depth.
4. Express the specific energy as a function of depth and discharge, then find the depth at which it is minimized. This defines the critical depth.
5. For a specified minimum flow velocity, set up the velocity–depth relation and solve numerically to determine the minimum water depth that satisfies the condition.

3 Simple step ††

A channel with a width of 1 m has a singularity, as shown in Figure 3. Draw an E vs y diagram with the different flow depths corresponding to the singularity in Figure 3. Assume that $Q = 5\ \mathrm{m}^3/\mathrm{s}$, that the step height is $a = 30\ \mathrm{cm}$, and that there is only one local energy loss of $h_s = 0.15\ \mathrm{m}$ between sections (2) and (3).

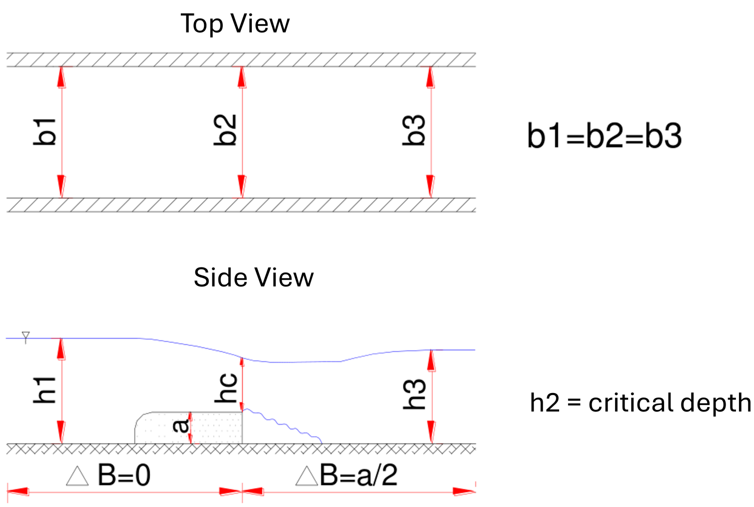

Figure 3: Step installed in a rectangular channel of constant width.

Objectives and guidance

This exercise focuses on understanding specific energy in open-channel flow, how a bed step modifies the flow regime, and how the energy equation with bed elevation changes and local energy losses can be used to determine the flow depths at different sections. Students should use the specific energy relationship to calculate the critical, upstream, and downstream flow depths, and represent the results on an E–y diagram.

Recommended procedure

1. Determine the critical depth from the discharge and channel geometry.
2. Apply the specific energy balance between sections (1) and (2), accounting for the step height, to find the upstream flow depth(s).
3. Apply the energy balance between sections (2) and (3), including the specified local loss h_s, to determine the downstream depth(s).

4. Plot the E–y diagram, the line $E = y$, and indicate the relevant points for each section.