FLOW PROFILES AND DIRECT STEP METHOD
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1. Outcomes

T2: Select and conduct civil engineering experiments to meet a need, and analyze and evaluate the resulting data.
P2: Organize and deliver effective written, verbal, graphical and virtual communications.

2. Objectives

- Explain the different types of flow profile that may occur in open channels.
- Reproduce and observe the characteristics of an M3 profile.
- Use the Direct Step Method to compute a flow profile.
- Compare the experimental profile and the computed profile.
- Analyze and discuss about the results.

3. Theory

Flow profiles describe the shape of the water surface in relation to the bottom for a steady-gradually varied flow condition. In this case, the flowrate is constant and the depth of water varies gradually along the length of a channel. In order to plot a profile it is necessary to measure or determine the elevation of the bottom of the channel and the water surface at different locations along the length of the channel.

Flow profiles are classified according to two major characteristics: the type of channel slope ($S_o$), and the location of the depth of water ($y$) with respect to the normal depth ($y_n$) and the critical depth ($y_c$).

<table>
<thead>
<tr>
<th>Table 1: Type of Channel Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of channel slope</td>
</tr>
<tr>
<td>------------------------</td>
</tr>
<tr>
<td>Horizontal</td>
</tr>
<tr>
<td>Mild</td>
</tr>
<tr>
<td>Critical</td>
</tr>
<tr>
<td>Steep</td>
</tr>
<tr>
<td>Adverse</td>
</tr>
</tbody>
</table>

Figure 1: Zone classification according to the zone at which the depth of water is located
Therefore, depending upon the channel slope and the zone at which the depth of water \( y \) is located, the thirteen possible types of profiles are: H2, H3, M1, M2, M3, C1, C2, C3, S1, S2, S3, A2, and A3.

![Flow Profiles Diagram](image)

**Figure 1: Flow Profiles [5]**

**Flow Profile Computation: Direct Step Method**

There are different computational methods to determine a flow profile, such as graphical-integration methods, direct-integration methods, and step methods. In this lab, the direct step method will be used to determine the computational profile. The direct step method consists of the step-by-step calculation of the length of short reaches along the channel, \( \Delta x \), that satisfy the energy equation for a given set of depth of water downstream and upstream of each reach.

Figure 3 illustrates a typical channel reach to which \( \Delta x \) will be calculated.
In Figure 3, the energy equation between the points 1 and 2 is given by

\[ z_1 + y_1 + \frac{V_1^2}{2g} = z_2 + y_2 + \frac{V_2^2}{2g} + h_f + h_L \]  

(1)

Considering no local energy losses by contraction or expansion of the channel, the equation can be expressed as

\[ S_o \Delta x + E_1 = E_2 + S_f \Delta x \]  

(2)

where,

\[ y_1 + \frac{V_1^2}{2g}, \text{ and } y_2 + \frac{V_2^2}{2g} \] are \( E_1 \) and \( E_2 \) respectively

\[ S_o \Delta x \]

\[ h_f = S_f \Delta x \]

By solving \( \Delta x \), the equation 2 can be expressed as

\[ \Delta x = \frac{E_2 - E_1}{S_o - S_f} \]  

(3)

In addition, \( S_f \) can be determined using Manning’s equation

\[ S_f = \frac{n^2 V_{avg}^2}{R_{avg}^{4/3}} \]  

(4)

where,

\[ n = \text{Manning’s roughness coefficient} \]

\[ V_{avg} = \text{average velocity between downstream and upstream sections (1 and 2) of each channel reach (\( \Delta x \)); m/s.} \]

\[ R_{avg} = \text{average hydraulic radius between downstream and upstream sections (1 and 2) of each channel reach (\( \Delta x \)); m.} \]
4. Experimental Procedure

- The flume has to be set up to the following conditions: Flowrate $Q=1.0$ L/s and Channel slope ($S_o$) greater than 0.0 and smaller than 0.45% to ensure a Mild slope condition ($S_o > 0$ and $y_n > y_c$).
- An M3 profile will be generated by using a sluice gate. The sluice gate is located at the mark 4.0 m (which will be the station 4+00) and an opening height of 15 mm is set up. Stop blocks are also installed at the flume outlet to ensure the presence of a hydraulic jump.
- The station 4+00 will have a depth of water equivalent to 15 mm which is equivalent to the opening gate.
- Locate the vernier at the station 3+90 and measure the depth of water.
- Move the vernier downstream to the following stations by increments of 0.10 m and record the depth of water at each station until the hydraulic jump is reached.

Use the following tables as guide to record the experimental data.

<table>
<thead>
<tr>
<th>Station</th>
<th>$y$ (mm)</th>
<th>Cumulative $\Delta x$, m</th>
</tr>
</thead>
<tbody>
<tr>
<td>4  +00</td>
<td>15.0</td>
<td>0.00</td>
</tr>
<tr>
<td>3  +90</td>
<td></td>
<td>0.10</td>
</tr>
<tr>
<td>3  +80</td>
<td></td>
<td>0.20</td>
</tr>
<tr>
<td>3  +70</td>
<td></td>
<td>0.30</td>
</tr>
<tr>
<td>3  +60</td>
<td></td>
<td>0.40</td>
</tr>
<tr>
<td>3  +50</td>
<td></td>
<td>0.50</td>
</tr>
<tr>
<td>3  +40</td>
<td></td>
<td>0.60</td>
</tr>
</tbody>
</table>

5. Calculations

The experimental M3 profile reproduced in the Lab will be compared with the computed M3 profile by using the Direct Step Method.

- Determine the computed profile by using the following method:

  Considering constant the following parameters: Flowrate ($Q$), Manning’s coefficient ($n = 0.008$), Channel slope ($S_o$), and the width of the channel ($b = 0.076$ m), create an Excel spreadsheet by using the following columns:
Column 1: Depth of water, m. Start with the initial depth of water recorded at the station 3+90, and increase the depth of water by \( \Delta y = 0.002 \) m.
- Column 2: Cross-sectional area of flow, m\(^2\).
- Column 3: Velocity of flow at the section, m/s.
- Column 4: Specific energy at the section, m.
- Column 5: Wetted Perimeter of the section, m.
- Column 6: Hydraulic Radius at the section, m.
- Column 7: Average velocity between consecutive sections, m/s.
- Column 8: Average hydraulic radius between consecutive sections, m.
- Column 9: Friction slope calculated with Manning’s equation (4).
- Column 10: Length of the channel reach, \( \Delta x \), using the equation (3), m.
- Column 11: Cumulative distance along the channel, m.
- Indicate in the table where the hydraulic jump occurs.

- Plot the experimental and the computed profile together. Include the bottom profile in the graph.
- Compare and analyze the results.

6. **Analysis and discussion of the results**

- Compare the experimental and the computed profiles. Are they similar? If not, explain Why?
- What is the effect of increasing or decreasing Manning’s coefficient on the computed profile?
  To respond this question it is necessary to use the Excel spreadsheet to plot a profile with a Manning’s coefficient greater and smaller than 0.008. Include the graph in the answer.

7. **Content of the report**

It is required to submit a formal report by next class. The report should cover the following:

- Introduction and objectives
- Theory
- Experimental procedure
- Experimental data
- Calculations: Explain in detail the procedure and include the Excel tables.
- Analysis and discussion of results
- References

8. **References used for this guide**


