TOPIC 2 - UNIFORM FLOW IN OPEN CHANNELS

2.1 OPEN CHANNEL FLOW BASICS

Open Channel Flow Characteristics

- Open channel flow is characterized by a flow not completely enclosed by solid boundaries.
  - Free surface is subject to atmospheric pressure.
  - Flow is not caused by external head but by the gravity component along the slope of the channel.
- Types of open channels:
  - Streams and rivers
  - Canals
  - Sewers, tunnels and pipelines that are not completely filled
- Solutions will be much more difficult than for pipes:
  - Much wider range of shapes and variability in shape
  - Wider range of roughness
  - Wider range of b.c.'s
  - Surface can rise and fall

- We will assume that streamlines are always parallel to the channel bottom so that the pressure distribution in the direction normal to the streamlines is ***hydrostatic***.
- Except for flow of very thin films of water, open channel flow is ***turbulent***. We will assume this to always be the case.
- We will always assume that the turbulent time averaged scale is the minimum scale of averaging.
- We typically apply cross sectional or depth averaging as well and thus the velocities variables will be depth averaged.

Hydraulic Radius and Hydraulic Diameter

- Hydraulic radius is defined as:

$$R_H = \frac{A}{P_w} \tag{2.1.1}$$

$$\text{where } R_H = \text{hydraulic radius} \tag{2.1.2}$$

$$A = \text{wetted area} \tag{2.1.3}$$

$$P_w = \text{wetted perimeter} \tag{2.1.4}$$

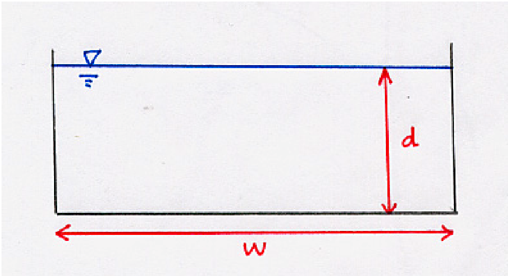
  - The hydraulic radius is often used as a mean flow depth.

- Hydraulic diameter is defined as:

$$D_H = \frac{4A}{P_w} \tag{2.1.5}$$

  - The hydraulic diameter is also called the equivalent pipe diameter.
  - Many engineers prefer the hydraulic diameter since friction laws are written with hydraulic diameter and not radius (in applying pipe formulae to open channels).

- For a rectangular open channel of width W and depth d:



$$R_H = \frac{dW}{W + 2d} \tag{2.1.6}$$

$$D_H = \frac{4dW}{W + 2d} \tag{2.1.7}$$

- For wide rectangular open channels $W \gg d$:

$$R_H = d \tag{2.1.8}$$

$$D_H = 4d \tag{2.1.9}$$

Reynold's Number for Open Channels

- Reynold's number is defined as:

$$R_e = \frac{UD\rho}{\mu} \tag{2.1.10}$$

- Since $D_H = 4R_H$, we have:

$$R_e = \frac{4UR_H\rho}{\mu} \tag{2.1.11}$$

- In pipes the critical Reynold's number where laminar flow becomes turbulent is $R_{e_{critical}} = 2000$.

- Reynold's number expressed in terms of R_H:

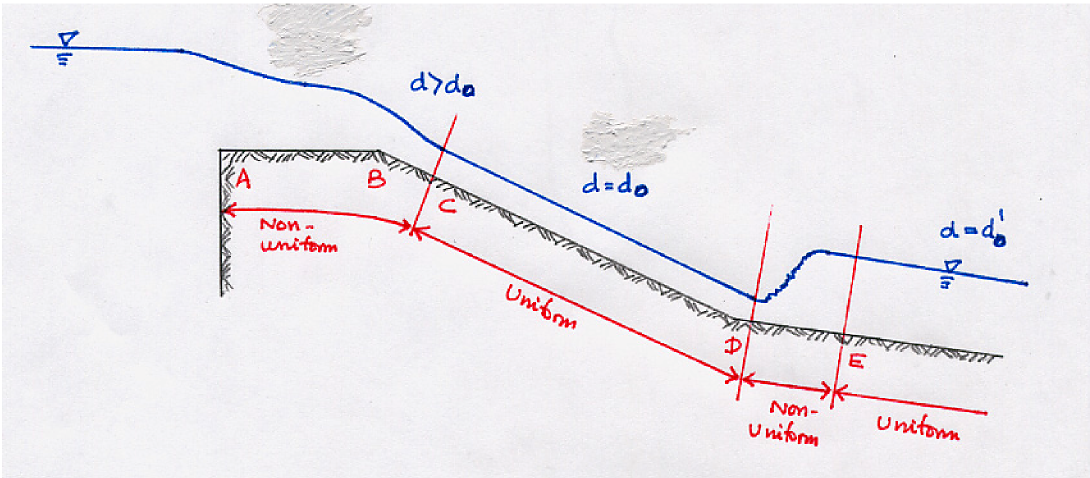
$$\frac{4UR_H\rho}{\mu} = 2000 \tag{2.1.12}$$

$$\frac{UR_H\rho}{\mu} = 500 \tag{2.1.13}$$

- Since the pertinent length scale in an open channel is better described by R_H, the transition from laminar to turbulent flow occurs at $R_{e_{critical}} = 500$.

Steady and Uniform Flow in Open Channels

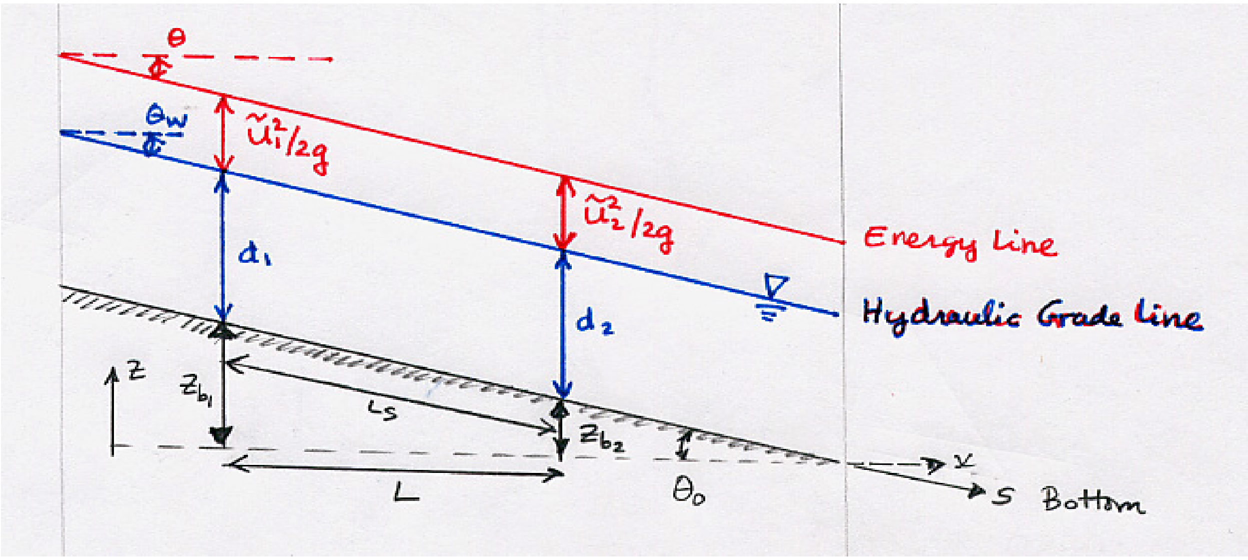
- Steady flow is characterized by no changes in time.
- Uniform flow is characterized by the water cross section and depth remaining constant over a certain ***reach*** of the channel.



- For any channel of given roughness, cross section and slope, there exists one and only one water depth, called the normal depth d_0, at which the flow will be uniform.
- Given steady flow conditions, uniform flow will eventually be established in any channel which continues sufficiently far with constant slope and cross section.

- For the flow in the figure, we have the following regimes:
    - A to C: Flow accelerates
    - C to D: Flow is established as uniform
    - D to E: Flow decelerates
    - E and beyond: Uniform flow is re-established
- For steady uniform channel flow, channel slope, depth and velocity all remain constant along the channel.

• Consider the following stretch of channel:



Channel Bed Slope

• ***Channel Bed Slope*** is defined as:

$$S_0 = \tan\theta_0 = \frac{z_{b_1} - z_{b_2}}{L} \qquad (2.1.14)$$

Water Surface Slope

- ***Water Surface Slope*** corresponds to the ***Hydraulic Grade Line (HGL)*** for open channel flows.

$$S_w = \tan\theta_w = \frac{d_1 + z_{b_1} - d_z - z_{b_2}}{L} \quad (2.1.15)$$

- Since $d_1 = d_2$ for steady uniform flow:

$$S_w = \frac{z_{b_1} - z_{b_2}}{L} \quad (2.1.16)$$

$$S_w = S_0 \quad (2.1.17)$$

- Thus, the channel bed slope and water surface slope are identical and these surfaces are parallel.

Total Energy Line

- ***Total Energy Line*** is defined as:

$$S = \sin\theta = \frac{\frac{\tilde{u}_1^2}{2g} + d_1 + z_{b_1} - \frac{\tilde{u}_2^2}{2g} - d_2 - z_{b_2}}{L_s} \quad (2.1.18)$$

- Since $\tilde{u}_1 = \tilde{u}_2$ and $d_1 = d_2$

$$S = \frac{z_{b_1} - z_{b_2}}{L_s} \quad (2.1.19)$$

$$S = \frac{z_{b_1} - z_{b_2}}{L} \cdot \frac{L}{L_s} \quad (2.1.20)$$

$$S = S_0 \frac{L}{L_s} \quad (2.1.21)$$

- We note that $\cos\theta_0 = \frac{L}{L_s}$

$$S = S_0 \cos\theta_0 \qquad (2.1.22)$$

- However for most open channels, the bed slope is small $\theta_0 < 5°$ in which case $0.9962 < \cos\theta_0 < 1.0000$.
- Thus, for most open channels

$$S_0 = S_w \cong S \qquad (2.1.23)$$