Civil Hydraulics – Module 1: Channel Hydraulics

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1. Introduction

How is channel hydraulics used by engineers

- Predict flow behaviour in channels to guide design
- Estimate effects of flooding

Key concepts of open channel flow

Flow in **pipes** is **driven** by **pressure difference** whereas flow in an **open-channel** is **driven** naturally by **gravity**

- **The free surface:** the pressure is known along the open channel (pressure at surface is atmospheric)
- → the level of the free surface can vary in open channel flow
- **Critical points:** points where the relationship between flow rate and depth is precisely known
- **Alternate depths:** different depths that a flow can exist at for a given specific energy
- **Conjugate depths:** depths before and after a hydraulic jump (there will be energy loss)

Flow classification

- **Steady uniform flow:** depth is constant with time and distance with the gravity forces in equilibrium with the resistance forces.
  → when the forces acting on the body of water are equal, the normal depth will occur
  → this generally occurs when the water flows down a long, straight and gently sloping channel
  → if flow is at a depth greater (smaller) than the normal depth, the flow will accelerate (decelerate) which increases (decreases) flow resistance and the flow depth will decrease (increase) until the forces are equal and the depth is reduced (increased) to its normal level
  → non-uniform flow is more likely but the assumption of uniform flow serves as a good approximation in most cases (except for very steep sloping channels)
  → forces acting on the body of water include
  - Downstream component of gravity
  - Flow resistance (shear between the water body and the channel boundary – acting in opposite direction to the flow)
- **Steady non-uniform flow:** the depth varies with distance but not with time
  - *Gradually varied*
  - *Rapidly varied*
- **Unsteady flow:** the depth varies with both time and distance (e.g. floods)

- **Critical Flow:** wave speed is equal to flow velocity
  - *Subcritical flow:* waves can propagate upstream
  - *Supercritical flow:* waves cannot propagate upstream

Non-uniform flow

- **Rapidly varied flow:** transition from subcritical to supercritical flow (or vice-versa) can occur
  - *Hydraulic jump:* highly turbulent reason in which the flow depth will increase and transition from supercritical to subcritical flow
- **Gradually varied flow:** flow depth and velocity vary gradually over the channel

Slopes and flow depth

- **Steep slope:** normal depth < critical depth
- **Critical slope:** normal depth = critical depth
- **Mild slope:** normal depth > critical depth

Principles of conservation

- **Conservation of Mass (Continuity):** discharge at section 1 = discharge at section 2
- **Conservation of Energy:** energy at section 1 = energy at section 2
- **Conservation of Momentum:**
  → the in-balance in pressure downstream and upstream which produces a force and subsequent rapid deceleration through the hydraulic jump

State of Flow – Laminar & Turbulent Flow

The **state of flow** may be **turbulent** or **laminar** and is determined using the **Reynolds Number**

$$Re_{channel} = \frac{\rho R V}{\mu}$$

- **Laminar flow:** Re < 500
- **Turbulent flow:** Re > 1000
  (the upper limit of Re is not well defined for channels and is normally taken to be 2000)
- **Transitional flow:** the Reynolds number is between the lower and upper limits

2. When Resistance Controls Flow

Friction formulae in open channels

- Chezy equation
- Manning's roughness coefficient
- Friction factor

Flow velocity in a Pipe

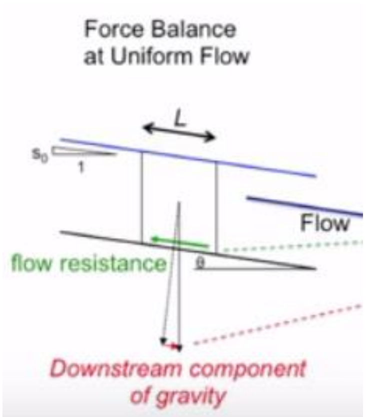
The **Darcy-Weisbach equation** can also be applied to open channels and is given by:

$$U = \left(\frac{2gDs_f}{f}\right)^{\frac{1}{2}} = flow\ velocity\ in\ pipe$$

- $D = Pipe\ diameter$
- $s_f = energy\ gradient$
- $f = friction\ factor$

Chezy Equation

Derived using a **force balance** at **uniform flow**
→ assuming force resistance is equal to the downstream component of gravity



$$\boldsymbol{Flow\ resistance} = \tau_0 P L$$

- $\tau_0 = Mean\ shear\ stress\ at\ channel\ boundary$
- $P = Wetted\ perimeter\ of\ channel$

$$\boldsymbol{Downstream\ component\ of\ gravity} = \rho A L g \sin(\theta)$$

- $\rho A L = mass\ of\ water$
- $g \sin(\theta) = downstream\ component\ of\ gravitation\ acceleration$
- $\sin\theta \approx S_0\ where\ S_0 = stream\ gradient < 0.01\ \left(\frac{1}{100}\right)$

$$\therefore \tau_0 = \frac{A}{P}\rho g S_0$$

$$\rightarrow \tau_0 = \rho g R s_0 \qquad , R = Hydrualic\ radius = \frac{A}{P}$$

It was **assumed that**:

$$\tau_0 = KU^2$$

$$\therefore U = \sqrt{\frac{\rho g}{K} R_{s_0}}$$

$$\rightarrow U = C\sqrt{Rs_0} \qquad , C = Chezy\ coefficient = \sqrt{\frac{\rho g}{K}}$$