

Hydraulics and Hydraulic Machines

1. Open channel hydraulics

1.2 Uniform flow

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Learning objectives

At the end of the class you will be able to

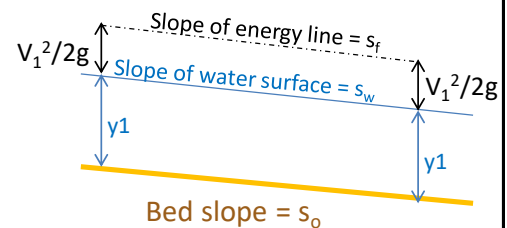
- Explain the characteristics of uniform flow in open channels
- Estimate the discharge in open channels under uniform flow condition

Uniform flow

- Flow properties remain uniform throughout the reach
- Flow properties \rightarrow depth of flow, velocity, discharge, bed slope
- Depth of a uniform flow is called uniform depth (y_n)
- Gravitational force is balanced by the frictional resistance

Uniform Flow

- When water flows in a channel, some amount of resistance is offered. This resistance increases with velocity of flow
- When water enters the sloping channel,
 - Initially velocity is low, frictional resistance is low
 - Further, the flow accelerates under gravity \rightarrow velocity increases
 - At some point, gravitational force is balanced by the frictional resistance \rightarrow This point onwards the flow is uniform



Salient features of uniform flow

- Depth of flow, wetted area, velocity and discharge are constant at every section along the channel

$$y_1 = y_2, v_1 = v_2, Q_1 = Q_2$$

- Total energy line, water surface and the channel bottom are parallel

$$S_o = S_f = S_w$$

$$TE_1 = z_1 + y_1 + \frac{v_1^2}{2g} \quad TE_2 = z_2 + y_2 + \frac{v_2^2}{2g}$$

$$S_f = \frac{TE_1 - TE_2}{L}$$

$$y_1 = y_2 \quad v_1 = v_2 \quad \frac{z_1 - z_2}{L} = S_o$$

$$S_f = \frac{TE_1 - TE_2}{L} = \frac{z_1 - z_2}{L} = S_o$$

S_o = Bed slope

S_w = Slope of the water surface

S_f = Slope of the total energy line

Equations for uniform flow

- Manning's equation

$$v = \frac{1}{n} R^{2/3} S_o^{1/2}$$

n = Manning's roughness coefficient

R = Hydraulic radius (A/P)

- Chezy's equation

$$v = C \sqrt{RS_o}$$

S_o = Channel bed slope

C = Chezy's constant

$$= (1/n) R^{1/6}$$

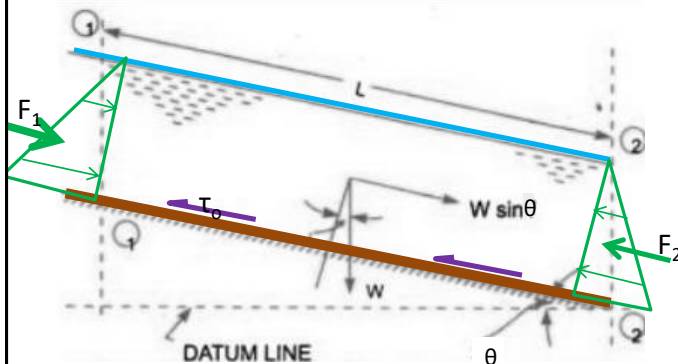
Discharge $Q = AC \sqrt{RS_o}$

$$Q = A \frac{1}{n} R^{2/3} S_o^{1/2}$$

Manning's n for Channels (Chow, 1959).

Type of Channel and Description	Minimum	Normal	Maximum
Natural streams - minor streams (top width at floodstage < 100 ft)			
1. Main Channels			
a. clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
b. same as above, but more stones and weeds	0.030	0.035	0.040
c. clean, winding, some pools and shoals	0.033	0.040	0.045
d. same as above, but some weeds and stones	0.035	0.045	0.050
2. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
a. bottom: gravels, cobbles, and few boulders	0.030	0.040	0.050
b. bottom: cobbles with large boulders	0.040	0.050	0.070
3. Floodplains			
a. Pasture, no brush			
1. short grass	0.025	0.030	0.035

Chezy's formula



$$y_1 = y_2, A_1 = A_2$$

Forces acting

1. Component of weight along the direction of flow
($W \sin\theta = \gamma A L \sin\theta$)
2. Force due to hydrostatic pressure (F_1 and F_2)
3. Resistance to flow exerted by the wetted surface of the channel
= wetted perimeter $\times L \times \tau_o = PL \tau_o$

Net force = $F_1 - F_2 + \gamma AL \sin\theta - PL\tau_o = 0$ (for uniform flow)

- $F = \frac{1}{2} \gamma y^2$ since $y_1 = y_2 \rightarrow F_1 = F_2$

$$\rightarrow \gamma AL \sin\theta = PL\tau_o$$

$$\rightarrow \tau_o = \gamma RS_o$$

From studies, $\tau_o = (f/8)\rho v^2$

Equating both \rightarrow

$$v = C\sqrt{RS_o} \quad C = \sqrt{\frac{8g}{f}}$$

V = Average velocity

S_o = bed slope = $z_1 - z_2 / L$

f = friction factor

R = Hydraulic radius = A/P

τ_o = Average shear stress at the channel boundary

Summary

- Open channel flow: without a closed periphery
- HGL and water surface are same, gravitational force controls the flow
- Characteristics : A, P, R
- Uniform flow: Flow properties remain same along the length, Friction is balanced by gravitational force
- Uniform discharge: Manning's equation or Chezy's equation

$$Q = AC\sqrt{RS_o} \quad Q = A\frac{1}{n}R^{2/3}S_o^{1/2}$$

Problem-1

An earthen channel with a base width 2 m and side slope 1H : 2V carries water with a depth of 1m.

The bed slope is 1 in 625,

Calculate the discharge if Manning's $n = 0.03$

Also calculate the average shear stress at the channel boundary

Solution:

Trapezoidal channel

Discharge = 2.35 m³/s

Shear stress = 9.26 N/m²



Problem-2

A circular sewer pipe is to be laid on a slope of 1 in 2500 and is required to carry a discharge of 1.5 m³/s.

Calculate the diameter of the pipe required, if the pipe has to flow half full.

Assume Manning's roughness coefficient for the pipe = 0.015.

$$P = r\theta$$

$$A = \frac{r^2}{2}(\theta - \sin\theta)$$

Ans

$r = 1.05$ m

$d = 2.1$ m