Lecture # 4 (A)

Water Flow In Open Channels

In this lecture you will learn about:

- Introduction.
- Types of Flows In Open Channels.
- Flows Formulas In Open Channels.
- Most Economical Sections of Channels.

Course Name

"Irrigation And Hydraulic Structures"

Course Code: CT-351

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Prepared By: Engr. Jebran Khan

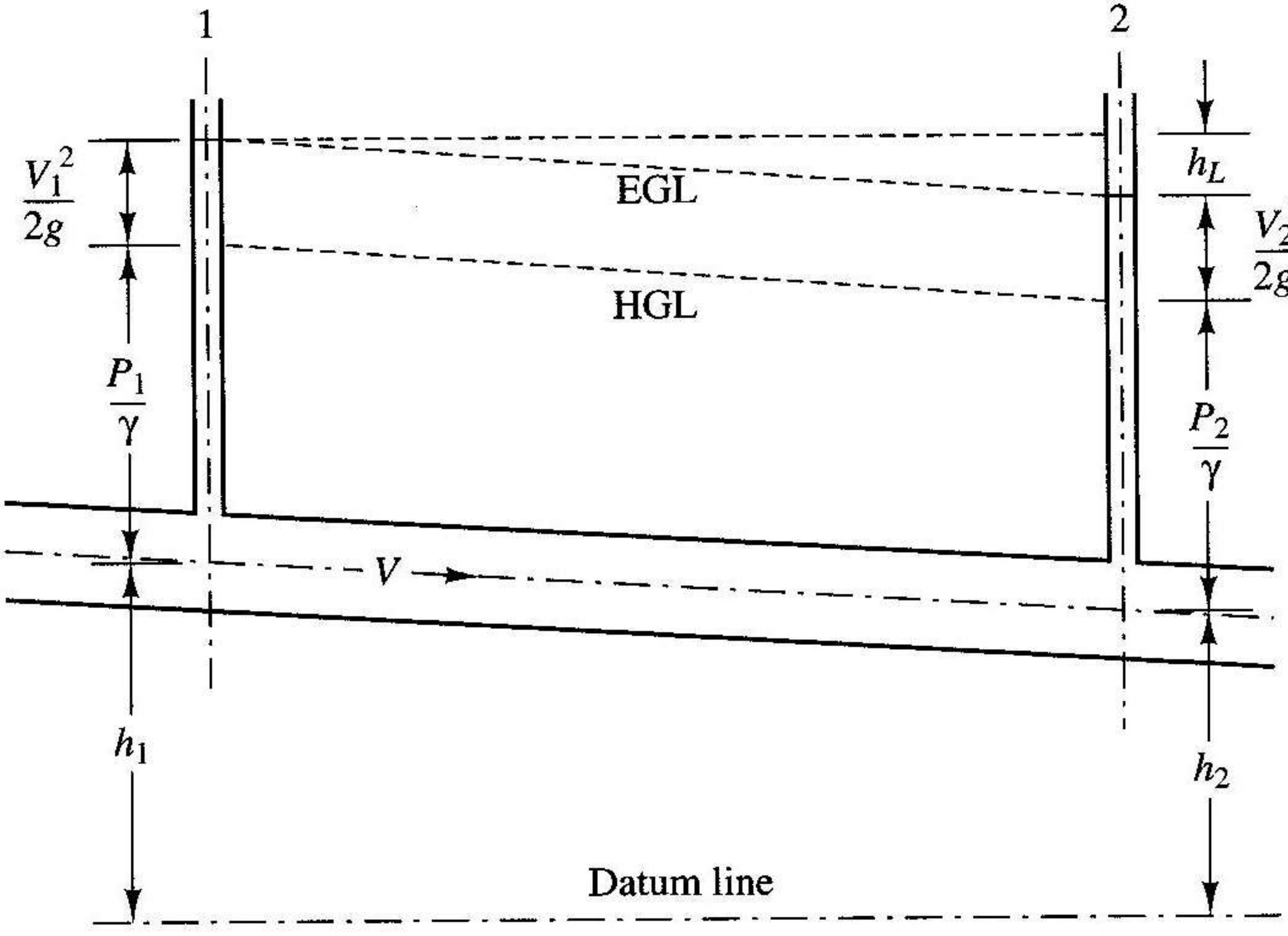
Introduction

- Open channel hydraulics, a subject of great importance to civil engineers, deals with flows having a free surface in channels constructed for water supply, irrigation, drainage, and hydroelectric power generation; in sewers, culverts, and tunnels flowing partially full; and in natural streams and rivers.
- An open channel is a duct in which the liquid flows with a free surface.
- This is in contrast with pipe flow in which the liquid completely fills the pipe and flow under pressure.
- The flow in a pipe takes place due to difference of pressure (pressure gradient), whereas in open channel it is due to the slope of the channel bed (i.e.; due to gravity).

Introduction

- It may be noted that the flow in a closed conduit is not necessarily a pipe flow. It must be classified as open channel flow if the liquid has a free surface.
- for a pipe flow:
  - The hydraulic gradient line (HGL) is the sum of the elevation and the pressure head (connecting the water surfaces in piezometers).
  - The energy gradient line (EGL) is the sum of the HGL and velocity head.
  - The amount of energy loss when the liquid flows from section 1 to section 2 is indicated by hL.

Introduction



(a)

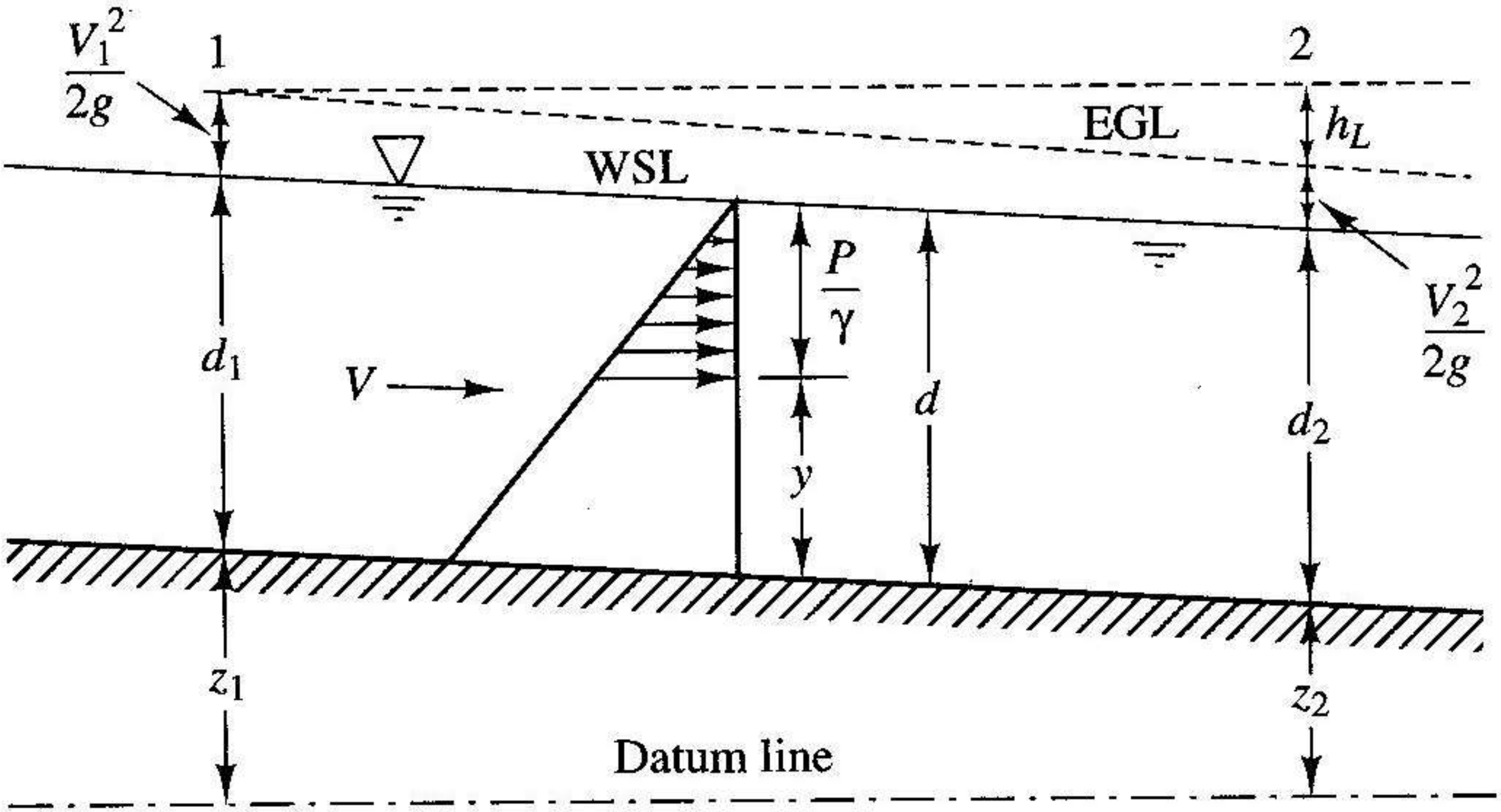
Pipe system

Introduction

➢ For open channel flow :

- ❖ The hydraulic gradient line (HGL) corresponds to the water surface line (WSL); the free water surface is subjected to only atmospheric pressure which is commonly referred to as the zero pressure reference in hydraulic engineering practice.
- ❖ The energy gradient line (EGL) is the sum of the HGL and velocity head.
- ❖ The amount of energy loss when the liquid flows from section 1 to section 2 is indicated by hL. For uniform flow in an open channel, this drop in the EGL is equal to the drop in the channel bed.

Introduction



(b)

Open Channel

Type of Open Channels

- Based on their existence, an open channel can be natural or artificial :
  - Natural channels such as streams, rivers, valleys , etc. These are generally irregular in shape, alignment and roughness of the surface.
  - Artificial channels are built for some specific purpose, such as irrigation, water supply, wastewater, water power development, and rain collection channels. These are regular in shape and alignment with uniform roughness of the boundary surface.

Type of Open Channels

Type of Open Channels

Type of Open Channels

- Based on their shape, an open channel can be prismatic or non-prismatic:
  - Prismatic channels: a channel is said to be prismatic when the cross section is uniform and the bed slop is constant.
  -)Non-prismatic channels: when either the cross section or the slope (or both) change, the channel is referred to as non-prismatic. It is obvious that only artificial channel can be prismatic.
- The most common shapes of prismatic channels are rectangular, parabolic, triangular, trapezoidal and circular.

Type of Open Channels

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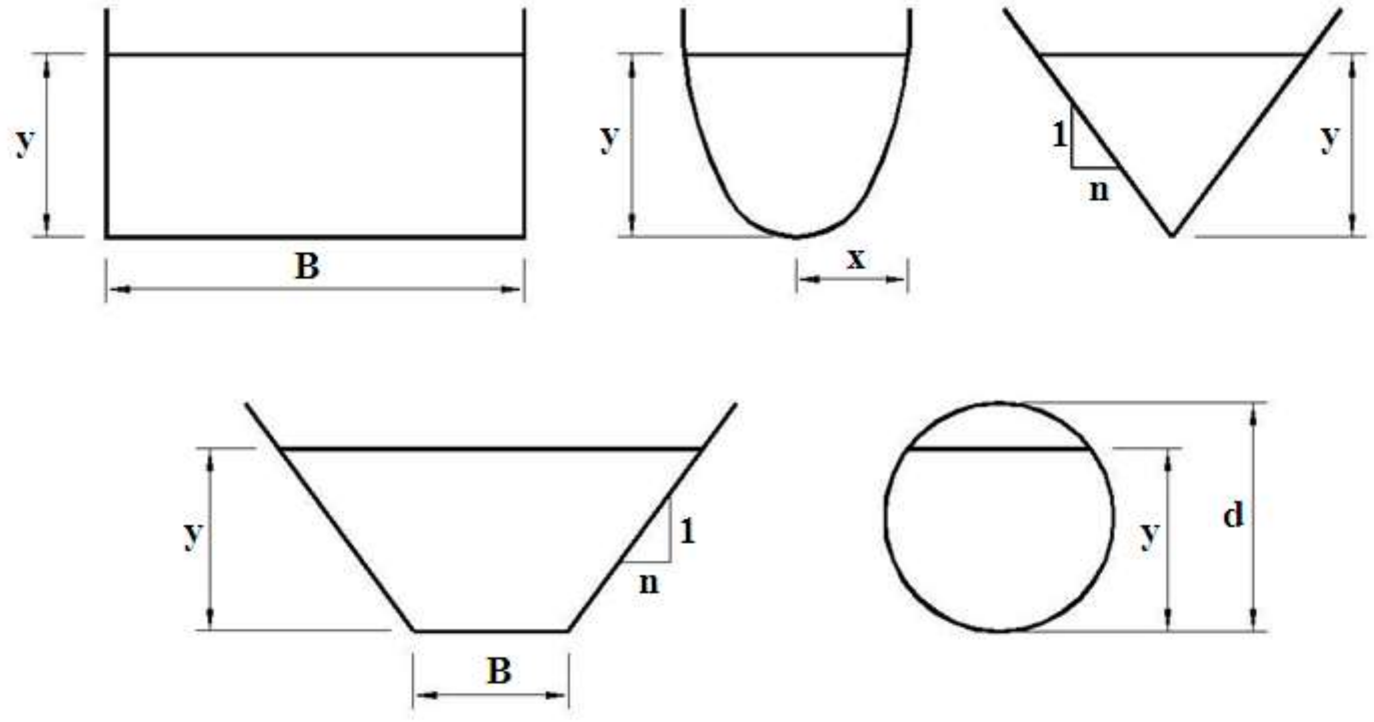


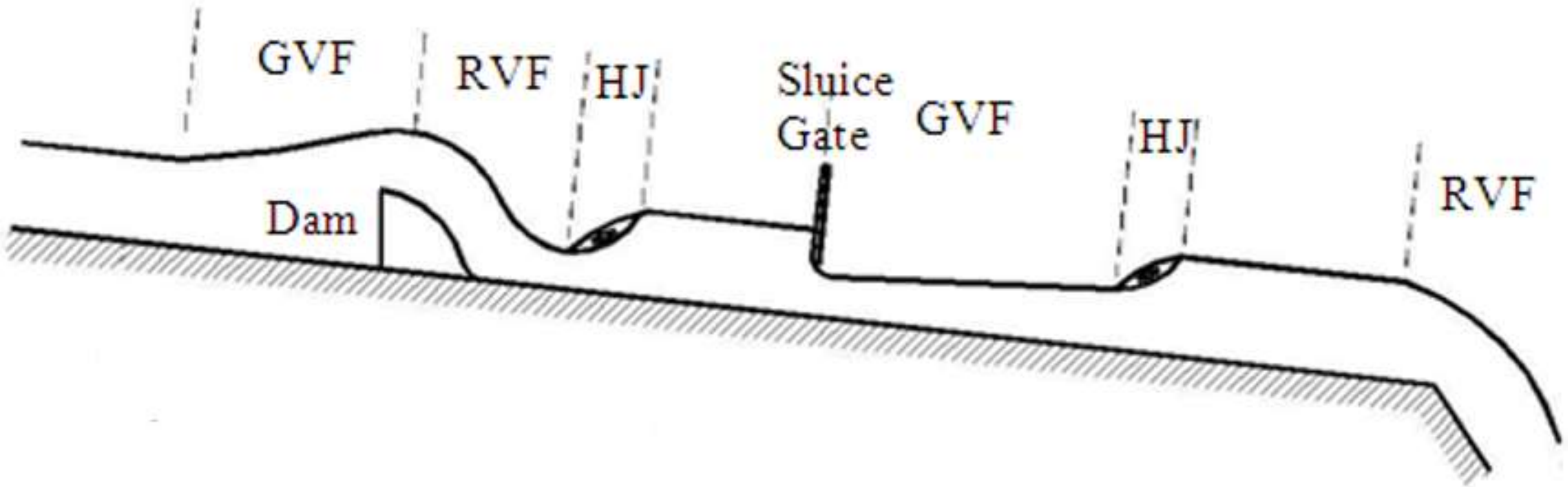
Types of Flow in Open Channels

The flow in an open channel can be classified into the following types :

A).Uniform and non-uniform flow:

- If for a given length of the channel, the velocity of flow, depth of flow, slope of the channel and cross-section remain constant, the flow is said to be **uniform**.
- Otherwise it is said to be **non-uniform**.
- Non-uniform flow is also called **varied flow** which can be further classified as:
  - Gradually varied flow (GVF) where the depth of the flow changes gradually along the length of the channel.
  - Rapidly varied flow (RVF) where the depth of flow changes suddenly over a small length of the channel. For example, when water flows over an overflow dam, there is a sudden rise (depth) of water at the toe of the dam, and a hydraulic jump forms.

Types of Flow in Open Channels



Types of Flow in Open Channels

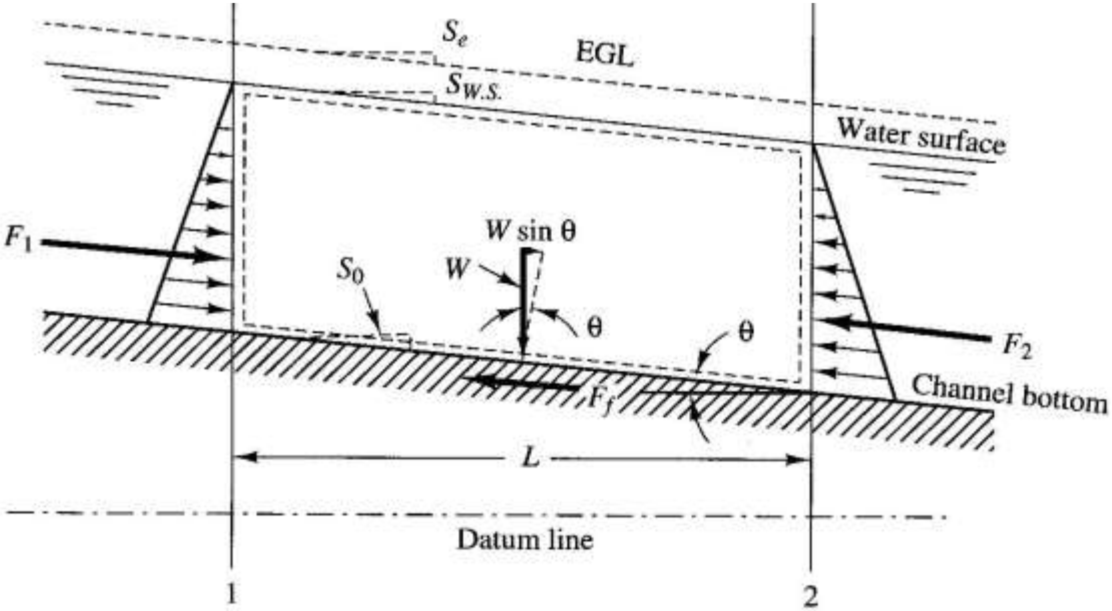
Uniform Flow

Uniform flow in an open channel must satisfy the following conditions.

1. The water depth, flow area, discharge, and the velocity distribution at all sections throughout the entire channel reach must remain unchanged.
2. The energy gradient line, the water surface line, and the channel bottom line must be parallel to each other.

The slopes of these parallel lines are the same

$$S_e = S_{W.S.} = S_0$$



Types of Flow in Open Channels

B). Steady and unsteady flow: :

- The flow is steady when, at a particular section, the depth of the liquid and other parameters (such as velocity, area of cross section, discharge) do not change with time. In an unsteady flow, the depth of flow and other parameters change with time.

C). Laminar and turbulent flow:

- The flow in open channel can be either laminar or turbulent. In practice, however, the laminar flow occurs very rarely. The engineer is concerned mainly with turbulent flow. In the case of open channel Reynold's number is defined as:

$$\mathrm{Re} = \frac{\rho V R}{\mu}$$

Types of Flow in Open Channels

$$\text{Re} = \frac{\rho V R}{\mu}$$

where,

V = mean velocity of flow of water,

R = hydraulic radius or hydraulic mean depth

$$= \frac{area\ of\ \ flow\ (wetted\ area)}{wetted\ \ perimeter} = \frac{A}{P}$$

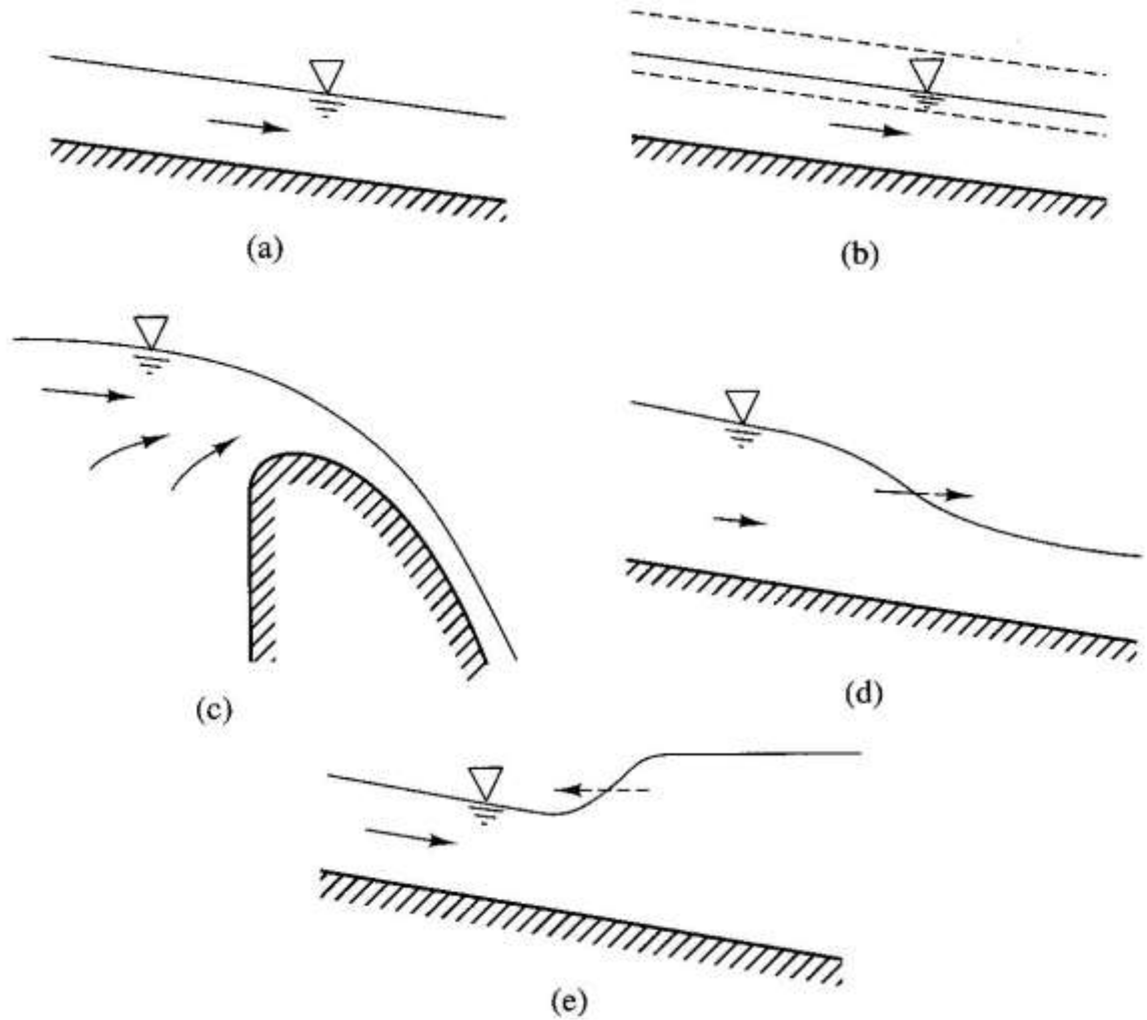
ρ and μ = density and viscosity of water.

For open channel flow:

$Re < 500$	Laminar flow
$Re > 2000$	Turbulent flow
& $500 < Re < 2000$	Transitional flow

Recall that Reynold's number is the measure of relative effects of the inertia forces to viscous forces.

Types of Flow in Open Channels



Classifications of open channel flow: (a) uniform flow, (b) unsteady, uniform flow, (c) steady, varied flow, (d) unsteady, varied flow, (e) unsteady, varied

Types of Flow in Open Channels

D). Sub-critical, critical, and supercritical flow:

- The criterion used in this classification is what is known by Froude number, Fr, which is the measure of the relative effects of inertia forces to gravity force:

$$Fr = \frac{V}{\sqrt{g D_h}}$$

where,

V = mean velocity of flow of water,

D_h = hydraulic depth of the channel

$$= \frac{area\ of\ \ flow\ (wetted\ area)}{water\ surface\ width} = \frac{A}{T}$$

For open channel flow:

$Fr < 1$	Sub-critical flow
$Fr = 1$	Critical flow
& $Fr > 1$	Supercritical flow

Types of Flow in Open Channels

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For open channel flow:

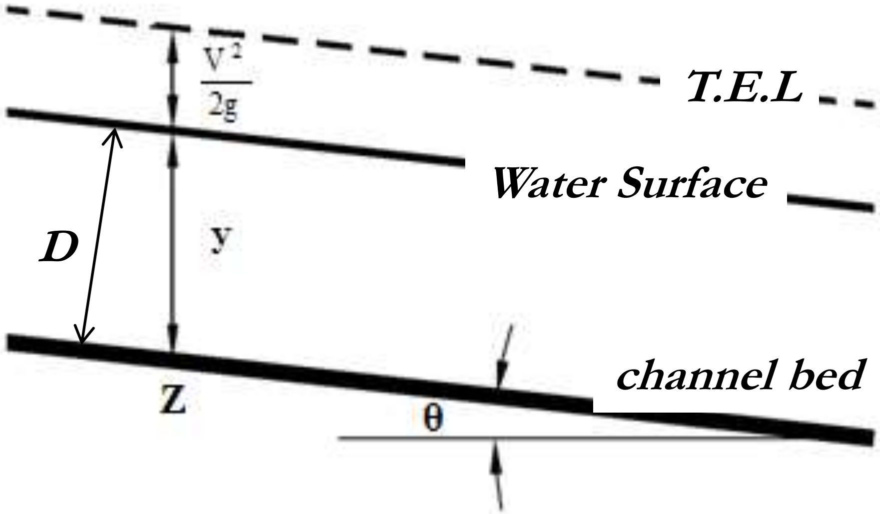
$Fr < 1$	Sub-critical flow
$Fr = 1$	Critical flow
& $Fr > 1$	Supercritical flow

Flow Formulas in Open Channels

In the case of steady-uniform flow in an open channel, the following main features must be satisfied:

- The water depth, water area, discharge, and the velocity distribution at all sections throughout the entire channel length must remain constant, i.e.; Q , A , y , V remain constant through the channel length.
- The slope of the energy gradient line (S), the water surface slope (S_{ws}), and the channel bed slope (S_o) are equal.

$S = S_{ws} = S_o$



Flow Formulas in Open Channels

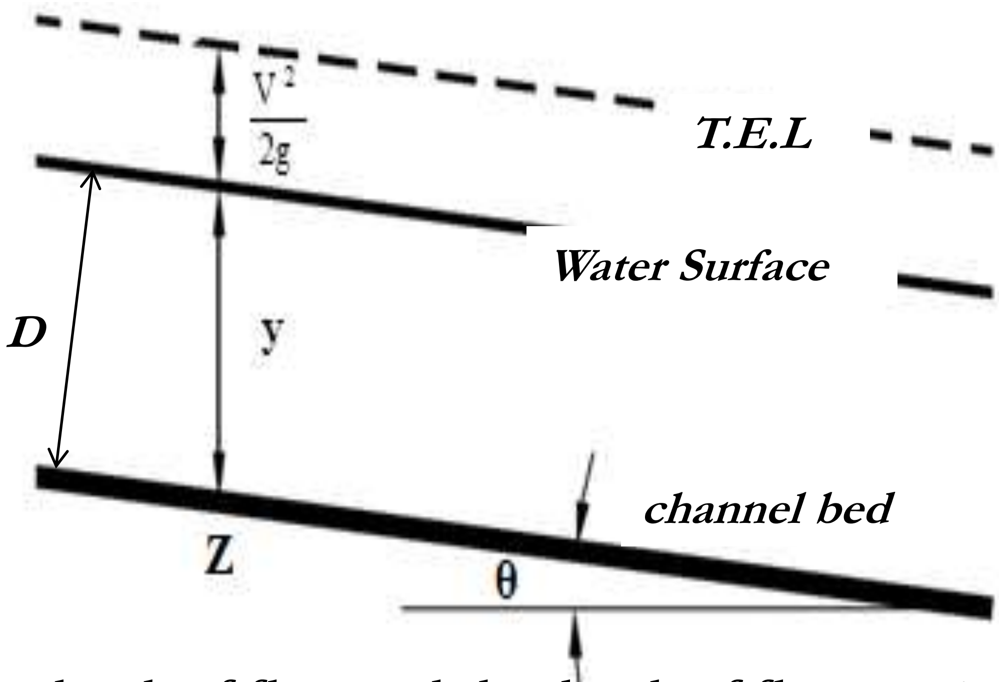
- The depth of flow, y , is defined as the vertical distance between the lowest point of the channel bed and the free surface.
- The depth of flow section, D , is defined as the depth of liquid at the section, measured normal to the direction of flow.

$$D = y\cos\theta$$

but for small θ , $\cos\theta = 1$,

and therefore $D \approx y$

$$y = vertical\ distance = \frac{p}{\gamma}.$$



Unless mentioned otherwise, the depth of flow and the depth of flow section will be assumed equal. For uniform flow the depth attains a constant value known as the normal depth, yn

Flow Formulas in Open Channels

Many empirical formulas are used to describe the flow in open channels

1. The Chezy Formula(1769)

The Chezy formula is probably the first formula derived for uniform flow. It may be expressed in the following form

$$V = C\sqrt{R_h S}$$

C is the *Chezy coefficient (Chezy's resistance factor), $m^{1/2}/s$*, a dimensional factor which characterizes the resistance to flow .

$$R_h \rightarrow \text{hydraulic Radius} = \frac{\text{wetted A}}{\text{wetted P}}$$

$$S = bed\ \ slope$$

Flow Formulas in Open Channels

2. The Manning Formula: (1895)

$$C = \frac{1}{n} R_h^{1/6}$$

where n = Manning's coefficient for the channel roughness, $m^{-1/3}/s$.

Substituting manning Eq. into Chezy Eq, we obtain the *Manning's formula for uniform* flow:

$$V = \frac{1}{n} R_h^{2/3} S^{1/2}$$

$$R_h \rightarrow \text{hydraulic Radius} = \frac{\text{wetted A}}{\text{wetted P}}$$

$$S = \textit{bed slope}$$

$$n \rightarrow \text{Manning Coefficien t}$$

Flow Formulas in Open Channels

Typical Values of Manning's n

Channel Surface	n
Smooth steel surface	0.012
Corrugated metal	0.024
Smooth concrete	0.011
Concrete	0.013
Glazed brick	0.013
Earth excavation, clean	0.022
Natural stream bed, clean, straight	0.030
Smooth rock cuts	0.035
Natural stream bed, weeds, rocks	0.04-0.06
Channels not maintained	0.05-0.10

$$C = \frac{1}{n} R_h^{1/6}$$

Flow Formulas in Open Channels

3. The Strickler Formula:

$$V = k_{str} R_h^{2/3} \sqrt{S}$$

where kstr = Strickler coefficient, m1/3/s Comparing Manning formula and Strickler formulas, we can see that $\frac{1}{n} = k_{str}$

V = mean velocity (m/s)

R_h = hydraulic radius or hydraulic mean depth (m)

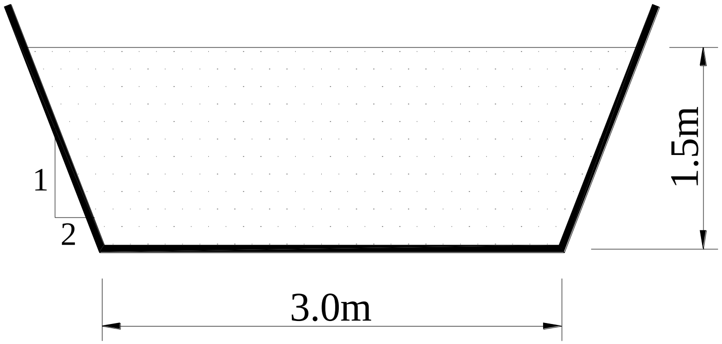
$$= \frac{area\ of\ flow\ (wetted\ area)}{wetted\ perimeter} = \frac{A}{P}$$

S = head loss per unit length $(m/m) = \frac{h_L}{L}$

= slope of E.G.L

Example 1

open channel of width = 3m as shown, bed slope = 1:5000, d=1.5m find the flow rate using Manning equation, n=0.025.



$$V = \frac{1}{n} R_h^{\frac{2}{3}} \sqrt{S}$$

$$A = 0.5 \times (3+9) \times 1.5 = 9 \text{ m}^2$$

$$P = 2\sqrt{(3^2 + 1.5^2)} + 3 = 9.708$$

$$R_h = \frac{A}{P} = \frac{9}{9.708} = 0.927$$

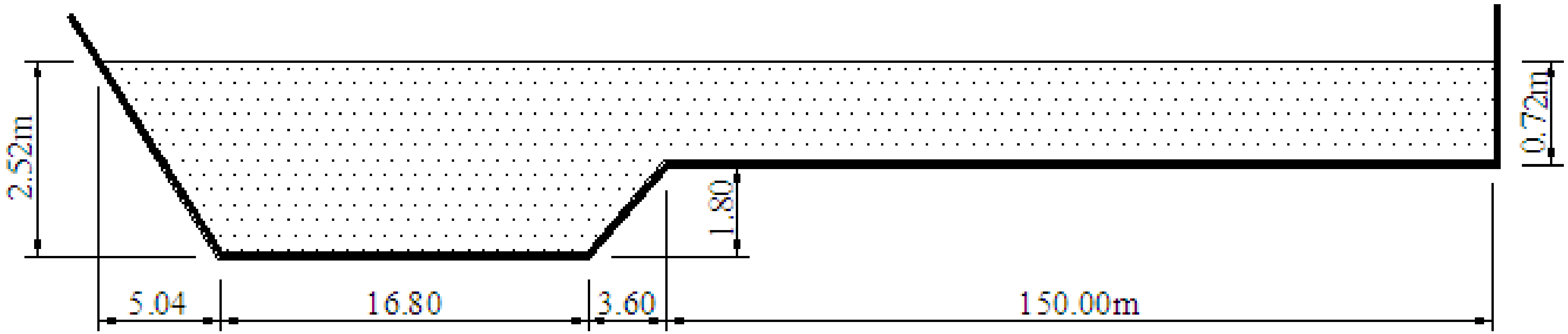
$$V = \frac{1}{0.025} \times 0.927^{\frac{2}{3}} \sqrt{1/5000} = 0.538 \text{ m/s}$$

$$Q = VA = 0.538 \times 9 = 4.84 \text{ m}^3 / s$$

Flow Formulas in Open Channels

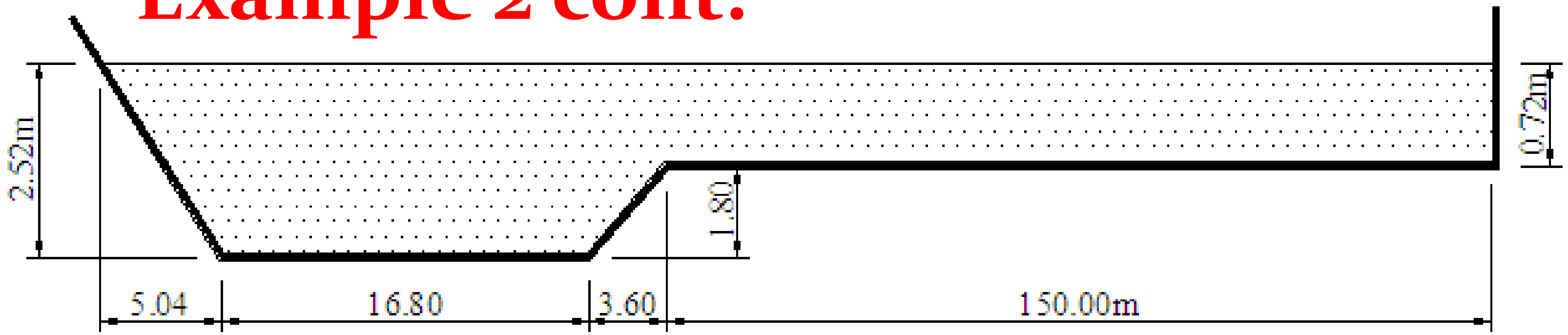
Example 2

open channel as shown, bed slope = 69:1584, find the flow rate using Chezy equation, C=35.



Flow Formulas in Open Channels

Example 2 cont.



$$V = C\sqrt{R_h S}$$

$$A = \frac{2.52 \times 5.04}{2} + 2.52 \times 16.8 + \frac{0.72 \times 2.52}{2} \times 3.6 + 0.72 \times 150 = 162.52\ \text{m}^2$$

$$P = 0.72 + 150 + \sqrt{\left(1.8^2 + 3.6^2\right)} + 16.8 + \sqrt{\left(2.52^2 + 5.04^2\right)} = 177.18\ \text{m}$$

$$R_h = \frac{A}{P} = \frac{162.52}{177.18} = 0.917$$

$$V = 35\sqrt{0.917 \times \frac{0.69}{1584}} = 0.7\ \text{m/s}$$

$$Q = VA = 0.7 \times 162.52 = 113.84\ \text{m}^3 / s$$

Most Economical Section of Channels

During the design stages of an open channel, the channel cross-section, roughness and bottom slope are given.

The objective is to determine the flow velocity, depth and flow rate, given any one of them. The design of channels involves selecting the channel shape and bed slope to convey a given flow rate with a given flow depth. For a given discharge, slope and roughness, the designer aims to **minimize the cross-sectional area A in order to reduce construction costs**

Most Economical Section of Channels

- A section of a channel is said to be most economical when the cost of construction of the channel is minimum.
- But the cost of construction of a channel depends on excavation and the lining. To keep the cost down or minimum, the wetted perimeter, for a given discharge, should be minimum.
- This condition is utilized for determining the dimensions of economical sections of different forms of channels.

Most Economical Section of Channels

- Most economical section is also called the best section or most efficient section as the discharge, passing through a most economical section of channel for a given cross sectional area A, slope of the bed So and a resistance coefficient, is maximum.

$$Q = AV = AC\sqrt{R_h S} = AC\sqrt{\frac{A}{P}S} = const.^* \frac{1}{\sqrt{P}}$$

Hence the discharge *Q will be maximum when the wetted perimeter P is minimum.*

Most Economical Section of Channels

The most 'efficient' cross-sectional shape is determined for uniform flow conditions. Considering a given discharge Q, the velocity V is maximum for the minimum cross-section A. According to the Manning equation the hydraulic diameter is then maximum.

It can be shown that:

1. the wetted perimeter is also minimum,
2. the semi-circle section (semi-circle having its centre in the surface) is the best hydraulic section

Thank You