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Hydraulic Machines	المادة باللغة الانجليزية
المكانن هيدروليكية	المادة باللغة العربية
الثالثة	المرحلة الدراسية
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UNIT 2

UNIFORM FLOW IN OPEN CHANNEL

Introduction

An open channel is a passage in which liquid flows with a free surface, open channel flow has uniform atmospheric pressure exerted on its surface and is produced under the action of fluid weight. It is more difficult to analyze open channel flow due to its free surface. Flow in an open channel is essentially governed by Gravity force apart from inertia and viscous forces.

Comparison between Pipe Flow and Channel Flow

Pipe Flow	Channel Flow
<ol style="list-style-type: none"> Flow occurs due to difference of pressure. Free surface is absent in a pipe flow Line joining piezometric surface ($Z+p/\gamma$) indicates the hydraulic Grade line There is no relation b/w the drop of the energy gradient line and slope of the pipe axis. The total energy line lies at a distance of $(V^2/2g)$ above the H.G.L at every section. Pressure difference can be built between two sections. If Reynolds number is less than 2000 the flow is Laminar. If it is between 2000-4000 the flow is known as transition flow. If it is less than 4000 the flow is known as turbulent flow. 	<ol style="list-style-type: none"> Flow occurs due to the slope of the channel Free surface is present in an open channel flow. Liquid surface itself represents the hydraulic grade line (HGL) For uniform flow in an open channel, the drop in the energy gradient line is equal to the drop in the bed. The total energy line lies at a distance of $(V^2/2g)$ above the H.G.L at every section. Pressure difference between two sections cannot be built up. If Reynolds number is less than 500 the flow is Laminar. If it is between 500-600 the flow is known as transition flow. If it is less than 2000 the flow is known as turbulent flow.

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CLASSIFICATION OF CHANNELS

There are two types of channels

- i) Natural Channel
- ii) Artificial Channel

Natural channels: The irregular sections of varying shapes are the natural channels.

Ex. Rivers, streams and drains etc.

Artificial Channels: Artificial open channels are built for some specific purpose, such as irrigation, water supply, water power development etc. Such channels are regular in shape and alignment. Surface roughness is also uniform.

Depending upon the shape, a channel is either prismatic or non-prismatic.

A channel is said to be prismatic when the cross section is uniform and the bed slope is constant. Ex. Rectangular, trapezoidal, circular, parabolic.

A channel is said to be non-prismatic when its cross section and for slope change.

Ex: River, Streams & Estuary.

Open Channels and Closed Channels: A channel without any cover at the top are known as open channel. A channel having cover at the top is known as closed channel.

Types of flow in open channel

Flow in an open channel can be classified into different types based on different criteria.

- a) Steady Flow and Unsteady Flow: Flow in an open channel is said to be steady when the flow characteristics like depth, discharge, mean velocity at any point do not change with time i.e. $\frac{\partial v}{\partial t} = 0$, $\frac{\partial y}{\partial t} = 0$ is called steady flow.

If any of these characteristics change with time then the flow is called as unsteady flow $\frac{\partial v}{\partial t} \neq 0$, $\frac{\partial y}{\partial t} \neq 0$.

- b) Uniform and Non uniform flow: Uniform flow is defined as that type of flow in which the velocity at any given time does not change with respect to space

(length of direction of flow). Mathematically $\left(\frac{\partial v}{\partial s}\right)_{t=constant} = 0$

Non uniform flow is that type of flow in which the velocity at any given time changes

with respect to space. Thus mathematically $\left(\frac{\partial v}{\partial s}\right)_{t=\text{constant}} \neq 0$

Non uniform flow in open channel is also called as varied flow, which is classified into following two types.

- i) Rapidly varied Flow (R.V.F)
- ii) Gradually varied Flow (G.V.F)

Rapidly varied flow: rapidly varied flow is defined as that type of flow in which depth of flow changes abruptly over a small length of the channel. When there is any obstruction in the path of flow of water, the level of water rises above the obstruction and then falls and again rises over a small length of channel. Thus the depth of flow changes rapidly over a short length of the channel. For this short length of the channel the flow is called rapidly varied flow.

Gradually varied flow: If the depth of flow in a channel changes gradually over a long length of the channel, the flow is said to be gradually varied flow.

c) Laminar and Turbulent flow: Laminar flow is defined as that type of flow in which the fluid particles move along well defined paths or stream line and all the stream lines are straight and type of flow is also called stream line flow or viscous flow.

Turbulent flow is that type of flow in which the fluid particles move in a zigzag way.

The flow in open channel is said to be laminar if the Reynolds number Re is less than 500 or 600. If the Reynolds number is more than 2000, the flow is said to be turbulent. If Re lies between 500-2000, the flow is said to be in transition state.

d) Sub critical, critical and Super critical flow: The flow in open channel is said to be sub critical if the Froude's number (F_e) is less than 1.0. Sub critical flow is also called tranquil or streaming flow.

The flow is said to be critical flow if $F_e = 1.0$ and if the flow is said to be super critical or shooting or rapid or torrential if F_e is greater than 1.0.

Geometric properties of open channels

Depth of flow (y): It is the vertical distance between the lowest points of the channel sections from the free liquid surface. It is expressed in meters.

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Area of cross section or Wetted area (A) It is the area of the liquid surface when a cross section is taken normal to the direction of flow. It is expressed in m^2 .

Wetted perimeter (P): It is the length of the channel boundary in contact with the flowing liquid at any section. It is expressed in meters.

Hydraulics radius or Hydraulic mean depth (R): It is the ratio of area of cross section (A) to the wetted perimeter (P). It is expressed in meters.

$$R = \frac{A}{P}$$

Top width (T): It is the width of the channel at the free surface as measured perpendicular to the direction of flow at any given section. It is expressed in meters.

Hydraulic depth (D): It is the ratio of area of cross section (A) to the top width (T).

$$D = \frac{A}{T}$$

Section factors (Z): It is the product of the area of cross section (A) to the square root of the hydraulic depth (D).

$$Z = A\sqrt{D}$$

Hydraulic Slope (S): Hydraulic slope of the total energy line is defined as the ratio of drop in total energy line (h_f) to the channel length (L).

$$S = \frac{h_f}{L}$$

Geometric properties for different types of prismatic channels

Rectangular Channel:

Consider a rectangular channel whose width is **B** and depth of flow is **y** therefore the area of cross section

$$A = B \times y$$

Then wetted perimeter

$$P = B + 2y$$

Top width $T=B$

$$\text{Hydraulic depth } D = \frac{A}{T} = \frac{By}{B} = y$$

Trapezoidal channel: Consider a trapezoidal channel, let n be the side slope, **B** be the

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bottom width, y be the depth of flow and T top width. Therefore the area of the cross section

Area of flow $A = (\text{Area of rectangular} + 2 \times \text{Area of the half triangle})$

$$= By + (2 \times (1/2) \times ny \times y)$$

$$A = (By + ny^2)$$

$$\text{Wetted perimeter } P = B + 2\sqrt{n^2y^2 + y^2}$$

$$P = B + 2y\sqrt{n^2 + 1}$$

$$\text{Top Width } T = B + 2ny$$

$$\text{Hydraulic radius, } R = \frac{A}{P}$$

$$R = \frac{By + ny^2}{B + 2y\sqrt{1 + n^2}}$$

$$\text{Hydraulic Depth, } D = \frac{A}{T}$$

$$D = \frac{By + ny^2}{B + 2ny}$$

Triangular channel: Consider a triangular channel, let the top width be T and depth of flow be y and slope $1:n$ then

Area of cross section is $A = ((1/2) \times b \times h)$

$$A = ny^2$$

$$\text{Wetted perimeter } P = 2\sqrt{n^2y^2 + y^2}$$

$$P = 2y\sqrt{n^2 + 1}$$

$$\text{Top width } T = 2ny$$

$$\text{Hydraulic Radius, } R = \frac{A}{P}$$

$$R = \frac{ny^2}{2y\sqrt{1 + n^2}}$$

$$R = \frac{ny}{2\sqrt{1 + n^2}}$$

$$\text{Hydraulic Depth, } D = \frac{A}{T}$$

$$D = \frac{ny^2}{2ny}$$

$$D = \frac{y}{2}$$

Uniform Flow in open channels

Flow in an open channel is said to be uniform when the parameters such as depth area of cross section, velocity discharge etc., remain constant throughout the entire length of the channel.

Features of Uniform flow

- a] Depth of flow, area of cross section, velocity and discharge are constant at every section along the channel reach.
- b] Total energy line, water surface and channel bottom are parallel to each other, also their slopes are equal or $S_o = S_w = S_f$
 $S_f = \text{energy line slope}$ $S_o = \text{channel bed slope}$ $S_w = \text{water surface slope}$

CHEZY'S FORMULA

Consider uniform flow between two sections 1 and 2, L distant apart as shown
 Various forces acting on the control volume are:

- i] Hydrostatic forces
- ii] Component of weight $w \sin \theta$ along the flow.
- iii] Shear or resistance to flow acting along the wetted perimeter and opposite to the direction of motion

From second law of Newton

Force = Mass x acceleration

As the flow is uniform, acceleration = Zero (0) $\therefore \sum \text{forces} = 0$

$$\text{forces} = +F_1 - F_2 + w \sin \theta - \tau_0 \times \text{contact area} = 0$$

Again $F_1 = F_2 \therefore \text{Flow is uniform}$

$$\therefore w \sin \theta - \tau_0 \times \text{contact area} = 0$$

$$\therefore w \sin \theta = \tau_0 \times \text{contact area} \quad \text{--- (1)}$$

From the definition of specific weight $\gamma = \frac{\text{weight}}{\text{volume}}$

Weight $w = \gamma \times \text{volume}$

$$= \gamma \times A \times L$$

Contact area = wetted perimeter x length = $P \times L$

Also, for small values of θ , $\sin \theta \approx \tan \theta = 0$

Substituting all values in eq 1 and simplifying

$$AL S_0 = \tau_0 PL \quad \tau_0 = \frac{A}{P} S_0$$

But, $\frac{A}{P} = R$ (Hydraulic radius)

$$\therefore \tau_0 = \gamma R S_0 \quad (2)$$

From experiment it is established that shear stress $\tau_0 = \frac{f}{8} \rho V^2$

$$\therefore \frac{f}{8} \rho V^2 = \gamma R S_0 \quad V = \sqrt{\frac{8\gamma}{\rho f}} \sqrt{R S_0} \quad \text{or}$$

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

Where, $C = \sqrt{\frac{8\gamma}{\rho f}}$ C= Chezy's constant

From continuity equation $Q=AV$

$$\therefore Q = AC \sqrt{R S_0} \quad (3)$$

It should be noted that chezy's C is not just a non – dimensional number and it has a

dimension of $\left[L^{\frac{1}{2}} T^{-1} \right]$

Chezy's equation is used in pipe flow also. The value of Chezy's C is different for Different types of channels.

MANNING'S FORMULA

Robert Manning in 1889, proposed the formula $V = \frac{1}{N} R^{\frac{2}{3}} S_0^{\frac{1}{2}}$

The above formula is known as Manning's formula where N is Manning's roughness or rugosity coefficient. Similar to Chezy's C Table 1 gives the range of value of the

Manning's constant N

Sl.no	Surface	Recommended Value of N
1	Glass, Plastic, Brass	0.010
2	Timber	0.011 – 0.014
3	Cement plaster	0.011
4	Cast iron	0.013
5	Concrete	0.012 – 0.017
6	Drainage tile	0.013
7	Brickwork	0.014
8	Rubble masonry	0.017 – 0.025
9	Rock cut	0.035 – 0.040