# CE 15008
# Fluid Mechanics

**LECTURE NOTES**

**Module-IV**


**Prepared By**

**Dr. Prakash Chandra Swain**

**Professor in Civil Engineering**

**Veer Surendra Sai University of Technology, Burla**


***Branch - Civil Engineering in***
***B Tech***
***Semester – 4th Semester***

**Department Of Civil Engineering**

**VSSUT, Burla**

# Disclaimer

This document does not claim any originality and cannot be used as a substitute for prescribed textbooks. The information presented here is merely a collection by Prof. P. C. Swain with the inputs of Post Graduate students for their respective teaching assignments as an additional tool for the teaching-learning process. Various sources as mentioned at the reference of the document as well as freely available materials from internet were consulted for preparing this document. Further, this document is not intended to be used for commercial purpose and the authors are not accountable for any issues, legal or otherwise, arising out of use of this document. The authors make no representations or warranties with respect to the accuracy or completeness of the contents of this document and specifically disclaim any implied warranties of merchantability or fitness for a particular purpose.

# COURSE CONTENT

**CE 15008:**

**FLUID MECHANICS (3-1-0)**

**CR-04**

**Module-IV** **(8 Hours)**

**Open channel flow**

Definition; Uniform flow; Chezy's, Kutter's and Manning's equations; Channels of efficient cross section.

Flow in Open Channels: Specific energy, Critical flow, Discharge curve, Application of specific energy, Specific force, Classification of Surface profiles, Back water & draw down curves, Flow transition in open channels.

Measurements: Hook gauge; Point gauge; Pitot tube; Current meter; Venturi meter; Orifice meter; Orifices and mouthpieces; Notches and weirs.

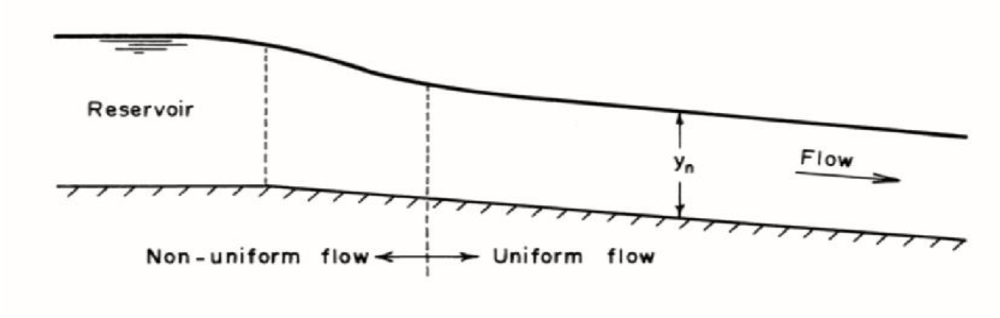
# Lecture Notes

## Module 4

### Open channel flow: Uniform flow, best hydraulic sections, energy principles, Froude number

Open channel flow must have a free surface. Normally free water surface is subjected to atmospheric pressure, which remains relatively constant throughout the entire length of the channel. In free-surface flow, the component of the weight of water in the downstream direction causes acceleration of flow (it causes deceleration if the bottom slope is negative), whereas the shear stress at the channel bottom and sides offers resistance to flow. Depending upon the relative magnitude of these accelerating and decelerating forces, the flow may accelerate or decelerate. For example, if the resistive force is more than the component of the weight, then the flow velocity decreases and, to satisfy the continuity equation, the flow depth increases.

The converse is true if the component of the weight is more than the resistive force. However, if the channel is long and prismatic(i.e., channel cross section and bottom slope do not change with distance), then the flow accelerates or decelerates for a distance until the accelerating and resistive forces are equal. From that point on, the flow velocity and flow depth remain constant  Such a flow, in which the flow depth does not change with distance, is called uniform flow, and the corresponding flow depth is called the normal depth.
Uniform flow is discussed in this chapter. An equation relating the bottom shear stress to different flow variables is first derived. Various empirical resistance formulas used for the free-surface flows are then presented. A procedure for computing the normal depth for a specified discharge in a channel of known properties is outlined.



## Manning Equation

Since the derivation of the Chezy equation in 1768, several researchers have tried to develop a rational procedure for estimating the value of Chezy constant, *C*. However, unlike the Darcy-Weisbach friction factor for the closed conduits, these attempts have not been very successful, because *C* depends upon several parameters in addition to the channel roughness.

$C \propto R^{1/6}$

French engineer named A. Flamant incorrectly attributed the above equation to an Irishman, R. Manning, and expressed it in the following form in 1891
$V = 1/n R^{2/3} S^{1/2}$

**CHEZY'S EQUATION**

$V = C\sqrt{RSo}$

## Pitot Tube

A pitot tube is a pressure measurement instrument used to measure fluid flow velocity. The pitot tube was invented by the French engineer Henri Pitot in the early 18th century and was modified to its modern form in the mid-19th century by French scientist Henry Darcy.

- It is widely used to determine the airspeed of an aircraft, water speed of a boat, and to measure liquid, air and gas flow velocities in industrial applications.
- The pitot tube is used to measure the local flow velocity at a given point in the flow stream and not the average flow velocity in the pipe or conduit.
- The basic pitot tube consists of a tube pointing directly into the fluid flow. As this tube contains fluid, a pressure can be measured; the moving fluid is brought to rest (stagnates) as there is no outlet to allow flow to continue.
- This pressure is the stagnation pressure of the fluid, also known as the total pressure or (particularly in aviation) the pitot pressure.
- The measured stagnation pressure cannot itself be used to determine the fluid flow velocity (airspeed in aviation). However, Bernoulli's states:

- Stagnation pressure = static pressure + dynamic pressure

Which can also be written

$$p_t = p_s + \left(\frac{\rho u^2}{2}\right)$$

Solving that for flow velocity:

$$u = \sqrt{\frac{2(p_t - p_s)}{\rho}}$$

Weather instruments at Mount Washington Observatory. Pitot tube static anemometer is on the right.

*CURRENT METER*

A current meter is oceanographic device for flow measurement by mechanical (rotor current meter), tilt (Tilt Current Meter), acoustical (ADCP) or electrical means.

MEASUREMENT PRINCIPLES

**a. Mechanical**

Mechanical current meters are mostly based on counting the rotations of a propeller and are thus rotor current meters.

A mid-20th-century realization is the Ekman current meter which drops balls into a container to count the number of rotations.

**b. Acoustic**

There are two basic types of acoustic current meters: Doppler and Travel Time. Both methods use a ceramic transducer to emit a sound into the water.

Doppler instruments are more common.

An instrument of this type is the Acoustic Doppler Current Profiler (ADCP**)** which measures the water current velocities over a depth range using the Doppler effect of sound waves scattered back from particles within the water column.

The ADCPs use the traveling time of the sound to determine the position of the moving particles. Single-point devices use again the Doppler shift, but ignoring the traveling times. Such a single-point Doppler Current Sensor (DCS) has a typical velocity range of 0 to 300 cm/s.

Travel time instruments determine water velocity by at least two acoustic signals, one up stream and one down stream.

**c. Electromagnetic Induction**

This novel approach is for instance employed in the Florida Strait where electromagnetic induction in submerged telephone cable is used to estimate the through-flow through the gateway and the complete setup can be seen as one huge current meter.

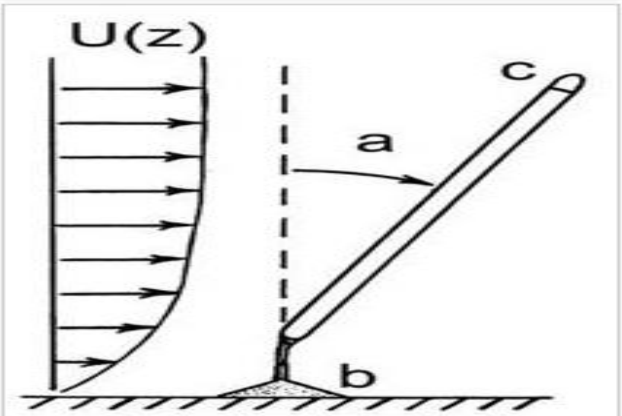
it is possible to evaluate the variability of the averaged horizontal flow by measuring the induced electric currents. The method has a minor vertical weighting effect due to small conductivity changes at different depths.

**d.Tilt**

Tilt current meters operate under the drag-tilt principle. They consist of a sub-surface buoy that is anchored to the sea floor with a flexible line or tether.

The float tilts as a function of its shape, buoyancy and the water velocity. Once the characteristics of a given buoy are known, the velocity can be determined by measuring the angle of the buoy.

A Tilt Current Meter is typically deployed on the bottom with an anchor but may be deployed on lobster traps or other convenient anchors of opportunity.



Tilt Current Meter Operating Principle

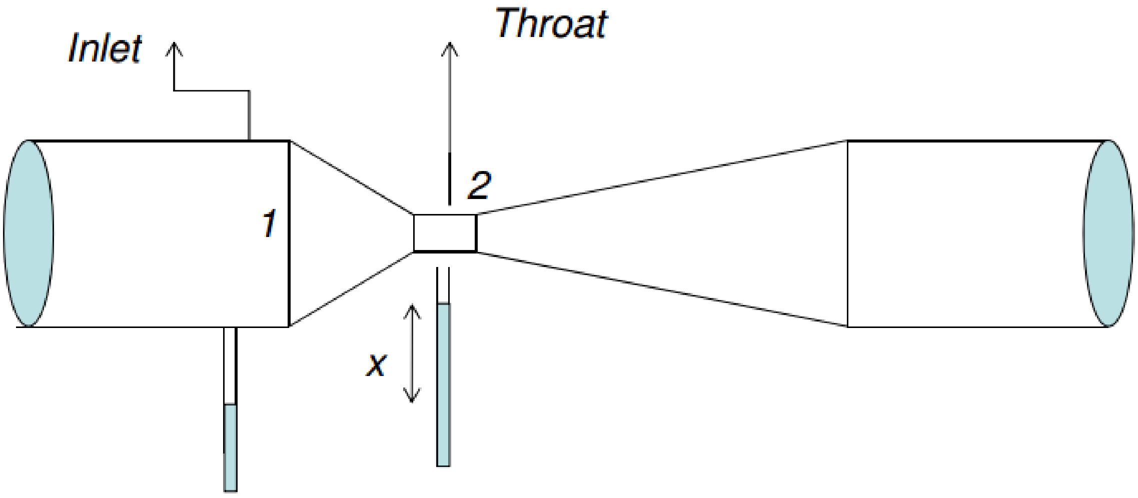
**VENTURIMETER**

Venturimeter is a device used for measuring the rate of flow of a fluid flowing through a pipe. It consists of three parts:

• A short converging part

• Throat

• Diverging part




Let d1 = diameter at the inlet (section 1)

p1 = pressure at section 1

v1 = velocity at section 1

A1= area at section1

d2, p2, v2, A2 are the corresponding values at the throat (section 2)

Applying Bernoulli's equations at sections 1 and 2, we get

$$\frac{p_1}{\rho g}+\frac{w_1^2}{2g}+z_1=\frac{p_2}{\rho g}+\frac{w_2^2}{2g}+z_2.$$

As pipe is horizontal $z_1=z_2$

$$\Rightarrow \frac{p_1-p_2}{\rho g}=\frac{v_2^2-v_1^2}{2g}$$

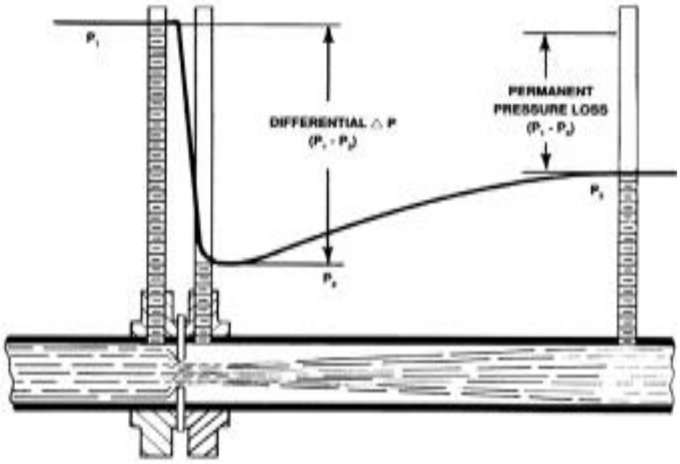
$$\Rightarrow h=\frac{v_2^2-v_1^2}{2g}$$

## ORIFICE METER

An orifice meter is a conduit and a restriction to create a pressure drop.

An hour glass is a form of orifice. A nozzle, venturi or thin sharp edged orifice can be used as the flow restriction. In order to use any of these devices for measurement it is necessary to empirically calibrate them.

That is, pass a known volume through the meter and note the reading in order to provide a standard for measuring other quantities. Due to the ease of duplicating and the simple construction, the thin sharp edged orifice has been adopted as a standard and extensive calibration work has been done so that it is widely accepted as a standard means of measuring fluids.




Typical Orifice Flow Pattern Flange Taps Shown

## *WEIRS:*

A weir is a barrier across a river designed to alter its flow characteristics. In most cases, weirs take the form of obstructions smaller than most conventional dams, pooling water behind them while also allowing it to flow steadily over their tops. Weirs are commonly used to alter the flow of rivers to prevent flooding, measure discharge, and help render rivers navigable.

### FUNCTIONS:

Weirs allow hydrologists and engineers a simple method of measuring the volumetric flow rate in small to medium-sized streams or in industrial discharge locations. Since the geometry of the top of the weir is known and all water flows over the weir, the depth of water behind the weir can be converted to a rate of flow.

The calculation relies on the fact that fluid will pass through the critical depth of the flow regime in the vicinity of the crest of the weir.

The discharge can be summarised as:

$$Q = CLH^n$$

Where

- $Q$ is flow rate of fluid
- $C$ is a constant for structure
- $L$ is the width of the crest
- $H$ is the height of head of water over the crest
- $n$ varies with structure (e.g. 3/2 for horizontal weir, 5/2 for v-notch weir)

**TYPES OF WEIRS:**

**Broad-crested weir**

A broad-crested weir is a flat-crested structure, with a long crest compared to the flow thickness. When the crest is "broad", the streamlines become parallel to the crest invert and the pressure distribution above the crest is hydrostatic.

## Broad Crested Weir

Applying Energy Equation ignoring $h_L$

$$H+Z+\frac{V^2}{2g}=Z+y_c+\frac{V_c^2}{2g}$$

For Critical flow $\frac{V_c^2}{2g}=\frac{y_c}{2}$

$$\therefore H+\frac{V^2}{2g}=\frac{2V_c^2}{2g}+\frac{V_c^2}{2g}$$

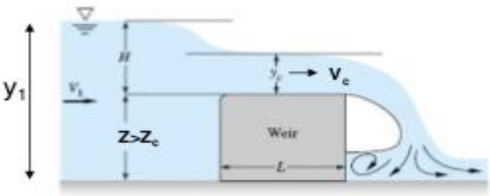
$$V_c=\sqrt{\frac{2}{3}g\left(H+\frac{V_1^2}{2g}\right)}$$

$$Since: Q=By_cV_c=B\frac{V_c^2}{g}V_c=\frac{BV_c^3}{g}$$

$$\therefore Q=\frac{B}{g}\left[\sqrt{\frac{2}{3}g\left(H+\frac{V^2}{2g}\right)}\right]^3$$

$$Q=1.7B\left(H+\frac{V^2}{2g}\right)^{3/2} \quad in\ SI$$

$$Q=3.09B\left(H+\frac{V^2}{2g}\right)^{3/2} \quad in\ FPS$$




$V$ = Velocity of approach $=Q/By_1$

H= Head over the crest

B= Width of Channel

Since $Q_{act}=C_dQ$

$$\therefore Q_{act}=1.7C_dB\left(H+\frac{V^2}{2g}\right)^{3/2} \quad in\ SI$$

$$Q_{act}=3.09C_dB\left(H+\frac{V^2}{2g}\right)^{3/2} \quad in\ FPS$$

**Sharp crested weir**

A sharp-crested weir allows the water to fall cleanly away from the weir. Sharp crested weirs are typically ¼ inch (6.4 mm) or thinner metal plates. Sharp crested weirs come in many different shapes and styles, such as rectangular (with and without end contractions),

**Compound weir**

The sharp crested weirs can be consolidated into three geometrical groups :

a) The rectangular weir

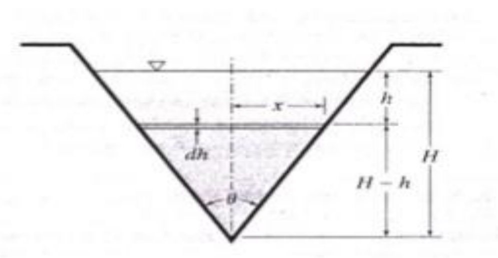
b) The V or triangular notch

c) Special notches, such as trapezoidal, circular or parabolic weirs.

For accurate flow measurement over a wider range of flow rates, a compound weir combines two or more types -typically a V-notch weir with a rectangular weir.

## Discharge over Triangular Notch (V-Notch)

- In order to obtain discharge over whole area we must integrate above equation from $h=0$ to $h=H$, therefore;




$$Q=\int_0^H dh(2(H-h)\tan(\theta/2))(\sqrt{2gh})$$

$$Q=2\sqrt{2g}\tan(\theta/2)\int_0^H (H-h)\sqrt{h}\,dh$$

$$Q=2\sqrt{2g}\tan(\theta/2)\int_0^H (Hh^{1/2}-h^{3/2})dh$$

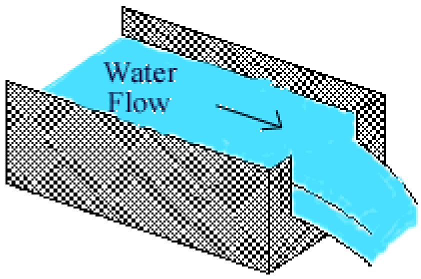
$$Q=2\sqrt{2g}\tan(\theta/2)\left[\frac{4}{15}H^{5/2}\right]$$

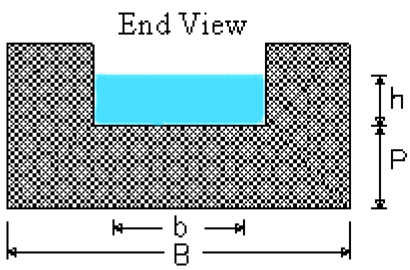
$$Q=\frac{8}{15}\sqrt{2g}\tan(\theta/2)[H^{5/2}]$$

$$Q_{act}=\frac{8}{15}C_d\sqrt{2g}\tan(\theta/2)[H^{5/2}]$$

44

## RECTANGULAR NOTCH



$$Q=C_e\frac{2}{3}\sqrt{2g}(b+K_b)(h+K_h)^{3/2}$$

Where Q= Discharge

$C_e$ =Discharge Coefficient

g= Acceleration due to gravity

b =Notch width

h=Head

$K_b$ and $K_h$ accounts for effects of viscosity and surface tension

## References

**Text Books:**
1. Fluid mechanics by A.K. Jain, Khanna Publishers.
**Reference Books:**
1. Hydraulics and Fluid Mechanics including Hydraulic Machines by P.N.Modi and S.M. Seth, Standard Book House.
2. Engineering Fluid Mechanics by K.L. Kumar, S. Chand & Co.
3. Fluid Mechanics by V.L. Streeter, MGH