Dr. J. J. Magdum Trust's
Dr. J. J. Magdum College of Engineering, Jaysingpur

DEPARTMENT : CIVIL ENGINEERING

CLASS :- SY CIVIL

SUBJECT :- FLUID MECHANICS II

TOPIC NO:-1

Open Channel Flow

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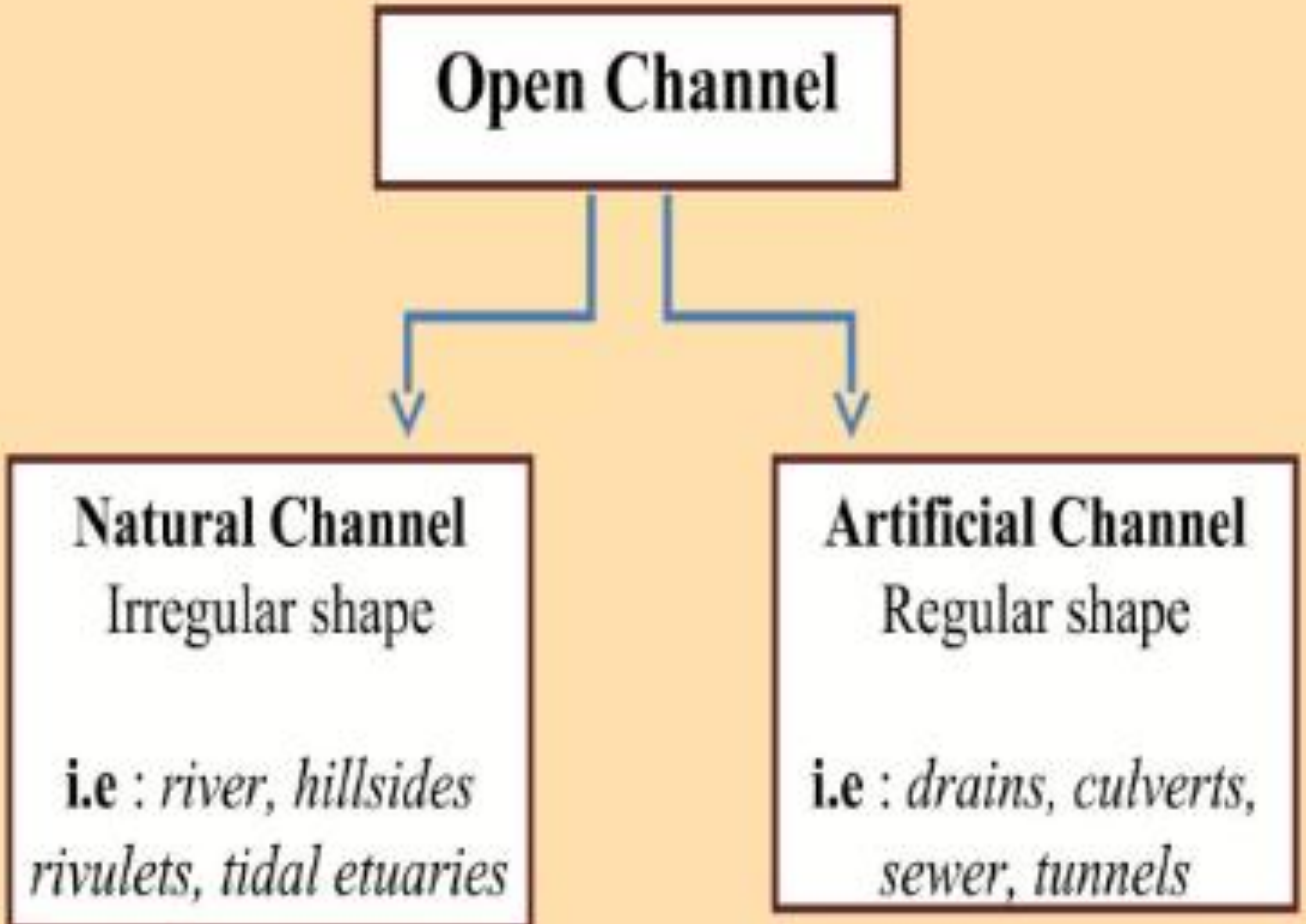
Open Channel Flow

- Open channel flow means flow through a channel that is open to atmosphere and have a free surface.
- Common examples of open channel flow include rivers, streams, spillways, flow over weirs and culverts that are not full etc.

Open channel flow.

- The flow of a liquid through a passage under atmospheric pressure is called an open channel flow.
- Chezy's and Manning's equations are two important formulas used to determine the velocity and discharge of an open channel flow.

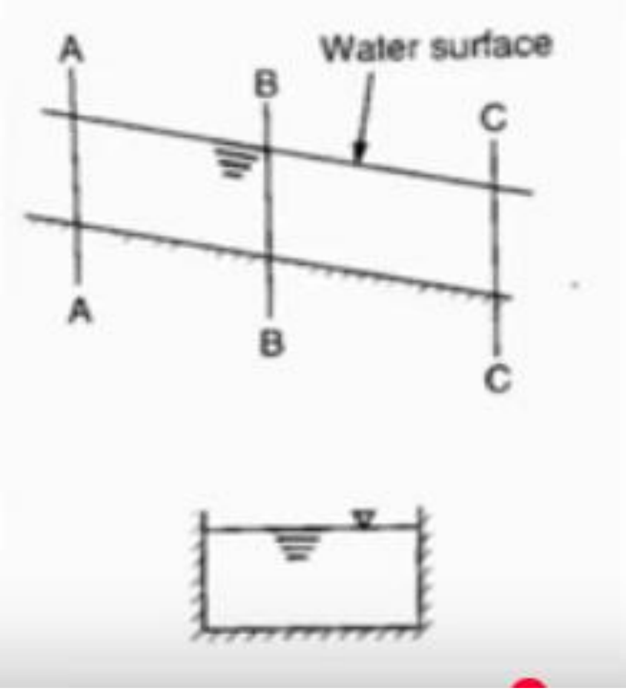
TYPES OF OPEN CHANNEL



Types of Channel

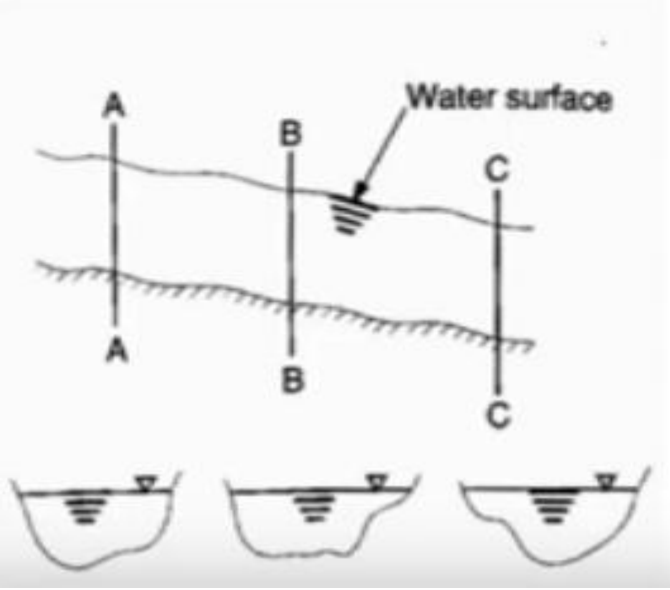
Prismatic channel

- A channel is defined as a Prismatic if it is in the prism.
- i.e. the cross section & bottom slope remain constant along the channel length.
- Most of the manmade channels are Prismatic channel.



Non-Prismatic channel

- If the cross section and or bottom slope of the channel changes along the channel length, it is said to be non-prismatic channel.
- Rivers are non-prismatic channel.



Rigid and Mobile Boundary Channels

On the basis of the nature of the boundary open channels can be broadly classified into two types:

(i) Rigid channels and

(ii) Mobile boundary channels.

On the basis of the nature of the boundary, open channel can also be classified as,

(A) Mobile boundary channel:

- The channel which consists of erodible bed and sides is known as mobile boundary channel. The shape of this type of channel undergoes deformation due to continuous erosion and deposition due to the flow. Unlined canals, natural streams are the examples of this type of channel

Mobile boundary channel

(B) Rigid boundary channel:

- If the materials on the bed and sides of channel is not movable, the channel is said to be rigid boundary channel. Lined canals, sewers are the examples of this type of channel.

Rigid boundary channel

Types of Open Channel Flow

The flow in an open channel is classified into the following types.

- Steady and unsteady flow
- Uniform and non-uniform flow
- Laminar and turbulent flow
- Sub-critical, critical, and super-critical flow

Types of Flow in Open Channel

1. **Steady and unsteady flow:**

- A flow is said to be steady if the flow characteristics i.e. depth, discharge or velocity at a section do not change with time.

$$\frac{\partial V}{\partial t} = 0 \; or \; \frac{\partial Q}{\partial t} = 0 \; or \; \frac{\partial y}{\partial t} = 0$$

On the contrary, if flow depth, discharge and velocity change with time, the flow is termed as unsteady flow.

$$\frac{\partial V}{\partial t} \neq 0 \; or \; \frac{\partial Q}{\partial t} \neq 0 \; or \; \frac{\partial y}{\partial t} \neq 0$$

2. **Uniform and non-uniform flow:**

- If the flow characteristics i.e. depth, velocity remain constant along the length of channel, the flow is termed as uniform flow.

$$\frac{\partial y}{\partial S} = 0, \frac{\partial V}{\partial S} = 0 \; for\ uniform\ flow$$

On the Contrary, the depth of flow varies along the length of channel at various sections, the flow is termed as non-uniform flow.

$$\frac{\partial y}{\partial L} \neq 0, \frac{\partial V}{\partial L} \neq 0 \; for\ non-uniform\ flow$$

Non-uniform flow is also called a **varying flow** and is further classified as,

- **Gradually varied flow-** If the depth of flow in a channel changes gradually over a long length of the channel then it is called a gradually varied flow.
- **Rapidly varied flow-** If the depth of the channel changes abruptly over a very small length of the channel, then it is called a rapidly varied flow.

Laminar and Turbulent Flow

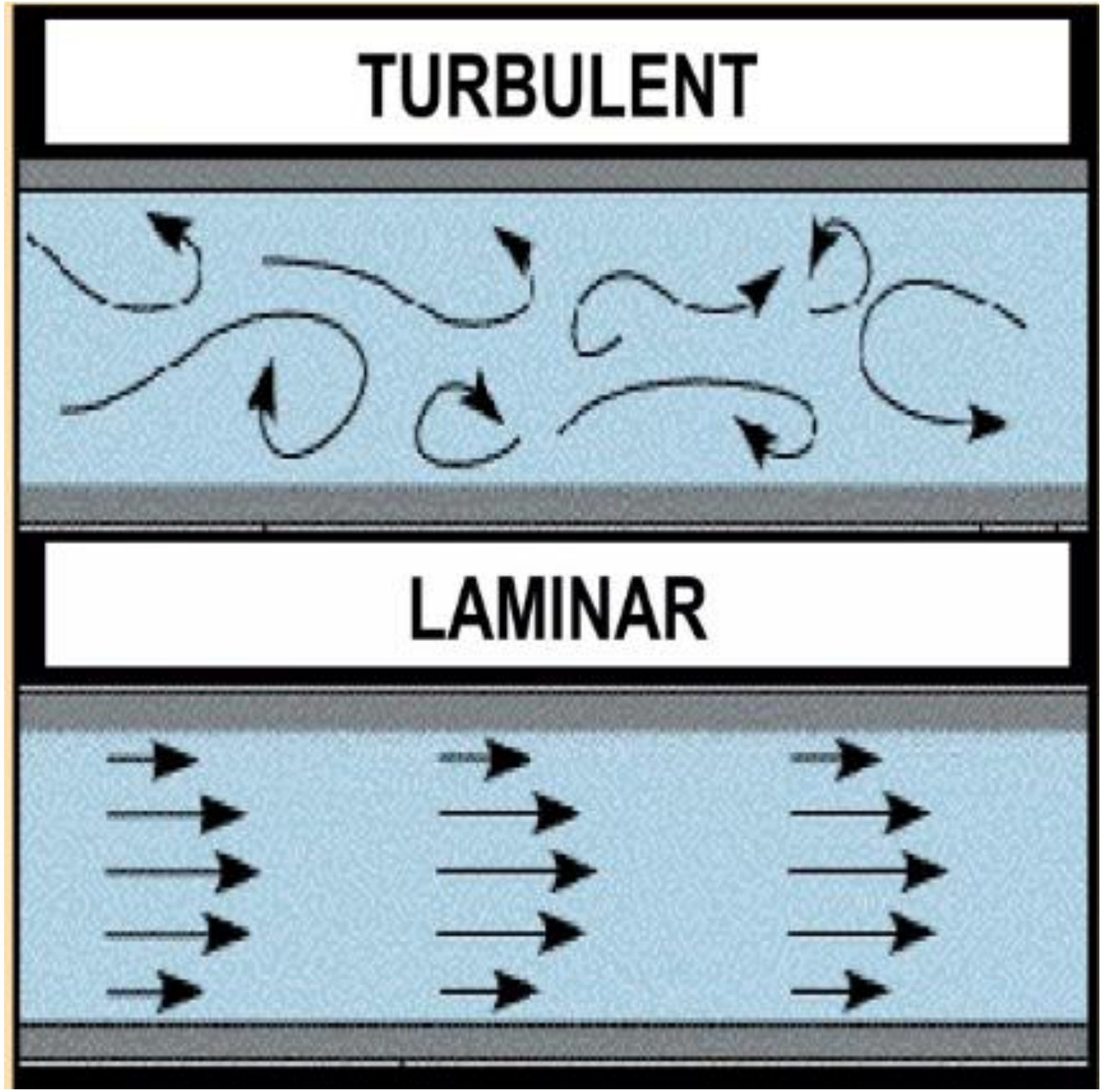
- The flow in an open channel flow is said to be laminar if Reynold's number is less than 500 to 600. Reynold's number is given as,

$$Re = \rho VR/\mu,$$

where,

- V - mean velocity of flow
- R - Hydraulic radius or hydraulic mean depth = cross-section of flow/wetted perimeter, ρ - density of the liquid, μ - viscosity of the liquid

- If Reynold's number is greater than 2000, then it is called a turbulent flow.
- If Reynold's number remains between 500 to 2000 then the flow is said to be in a transition state.


TURBULENT
LAMINAR

Sub-Critical, Critical, and Super Critical Flow

This classification is based on the Froude number. The Froude number is expressed as,

$$Fe = V/(gD)^{(1/2)}$$

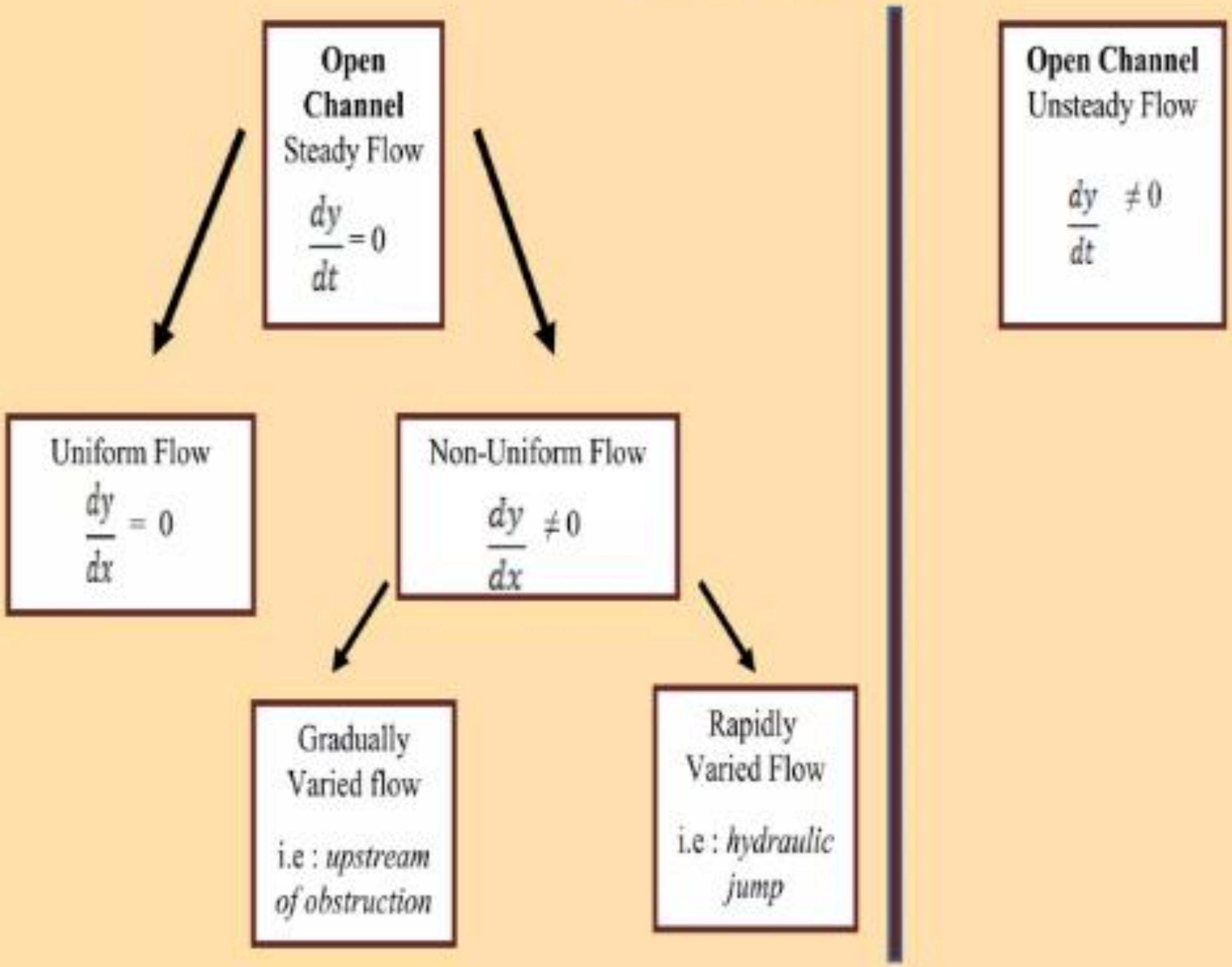
where,

V - mean velocity of flow

D - hydraulic depth = wetted area/top width of the channel.

- If the **Fe < 1** then it is called a sub-critical flow. It is also called a **tranquil or streaming flow.**
- The flow is **critical** if the **Fe = 1**.
- If the **Fe > 1** then the flow is **super-critical /shooting / rapid / torrential flow.**

TYPES OF FLOWING WATER AND ITS CONTROL



Open channel flow.

- The flow of a liquid through a passage under atmospheric pressure is called an open channel flow.
- Chezy's and Manning's equations are two important formulas used to determine the velocity and discharge of an open channel flow.

- **Determination of Discharge through Open Channel Flow**
- Chezy’s formula was derived in the 1760s. Due to its drawbacks in giving practical results, Manning’s formula was derived in1889 as an improvement to Chezy’s formula.

1. Chezy's Formula

- French engineer Antoine Chezy derived Chezy's formula in the 1760s to study the flow behavior. The formula is given by:

$$V = C.\sqrt{RS}$$

Where

C= Chezy's constant;

R= hydraulic radius;

S= slope of the channel bottom

2. Manning’s Formula

- Irish engineer Robert Manning derived manning’s formula in 1889. It is derived from Chezy's formula.
- Manning derived an average empirical relation for Chezy’s coefficient as:

Manning's Formula

Which gives the average velocity of flow as,

$$V = (1/n)\, R^{2/3}\, S^{1/2}$$

Where,

V= velocity of flow

n= Manning's Roughness coefficient

R= Hydraulic radius/hydraulic depth

S= bed slope or slope of the channel bottom

Factors affecting manning's roughness coefficient:

- When channel applies friction to a certain flow, then the manning roughness Coefficient comes into action.
- The roughness coefficient given by manning depends on various factors like the roughness of the bed Material, variations in channel, Density and type of vegetation involved, Cross section geometry, One channel is meandered to the degree to which it is done and last but most important is Open channel flow area surface changes.
- These are all the factors that can affect the friction coefficient.

- Factors like suspended load, sediment grain size, presence of bedrock or boulders in the stream channel, variations in channel width and depth, and overall sinuosity of the stream channel can all affect Manning's n value.

Many factors affect the Manning's roughness coefficient, including:

- **Surface roughness**: The size and shape of the channel, floodplain, and surface material that creates friction on flow
- **Vegetation**: The type, density, height, and distribution of vegetation
- **Obstructions**: Objects like bridge piers or buildings in the channel or overbanks can increase the n value
- **Irregularities**: Variations in the cross-section size and shape along the floodplain
- **Channel alignment**: Sharp curvature with severe meandering increases roughness, while smooth curvature with a large radius does not
- **Silting, scouring, and debris**: Silting can decrease the n value, while scouring can increase it
- **Seasonal change**: Vegetation in the summer typically has a higher n value
- **Stage and discharge**: In most streams, the n value decreases with an increase in stage and discharge

Numerical

Chezy's Formula

Numerical 4: A channel has two sides vertical and semi circular bottom of 2m wide diameter. Calculate the discharge of water through the channel, when the depth of flow is 2m. Take C=70 and slope of bed as 1 in 1000.

- Find the discharge through a rectangular channel of width 2 m, having a bed slope of 4 in 8000.The depth of flow is 1.5m.

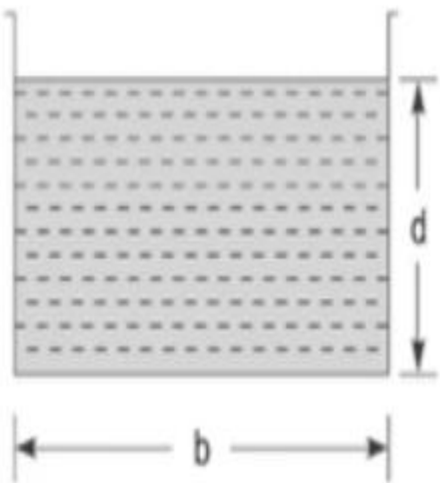
Take N = 0.15.

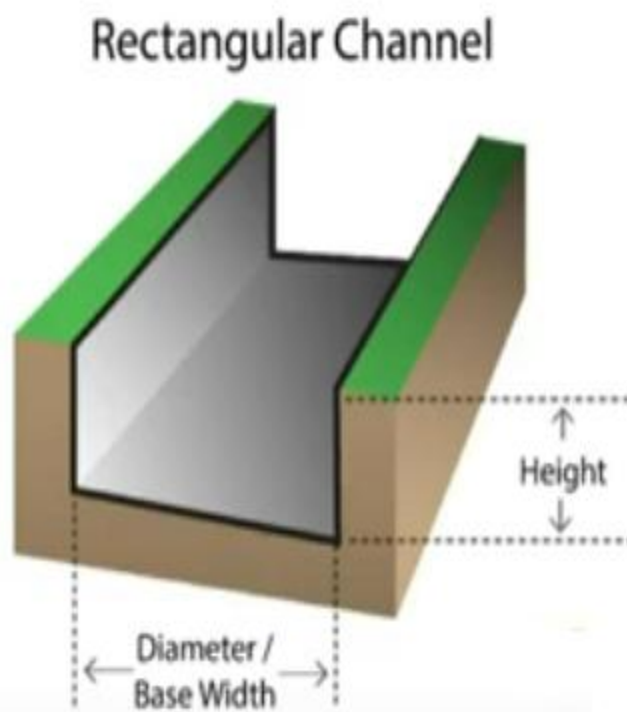
Most economical section of channel/ Hydraulically Efficient Section (Rectangular, Triangular, Trapezoidal)

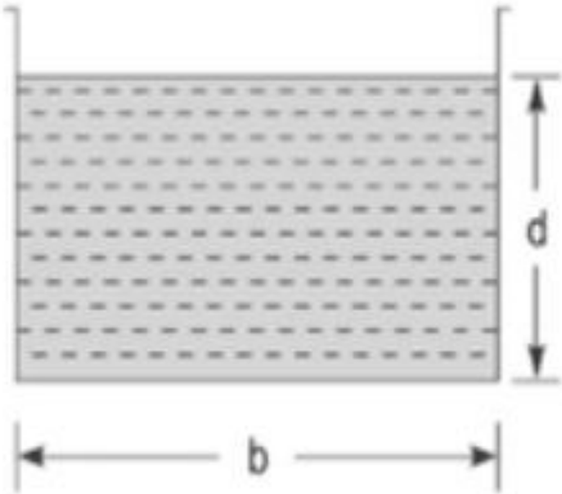
- A section of a channel is said to be most economical when the cost of construction of the channel is minimum.
- But the cost of construction of channel depends on excavation and the lining, to keep the cost minimum the wetted perimeter should be minimum for a given discharge.

Most Economical Rectangular Channel

The condition for most economical section, is that for a given area, the perimeter should be minimum. Consider a rectangular channel as shown in Fig.







Let b = width of channel

d = depth of the flow

Area of flow $A = b \times d$

Perimeter $P = b + d + d = b + 2d$

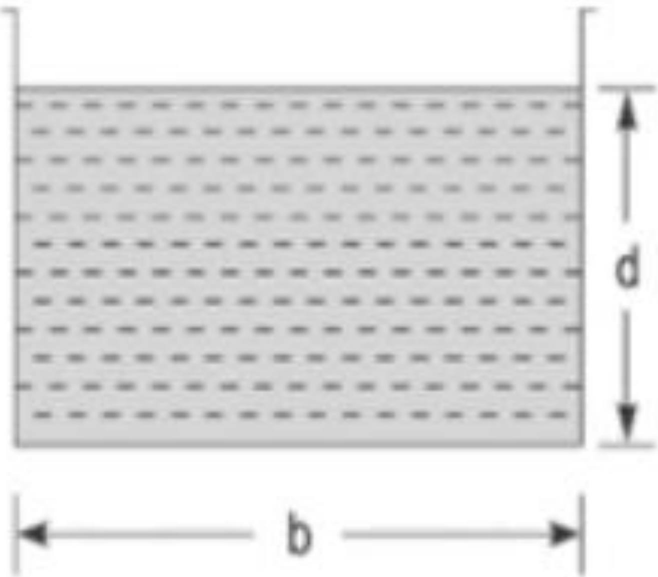
$$\therefore b = \frac{A}{d}$$

Substitute value of b,

$$P = \frac{A}{d} + 2d$$

For most economical channel, P should be minimum,

$$\frac{dP}{dd} = 0$$



$$\frac{\quad}{dd} = 0$$

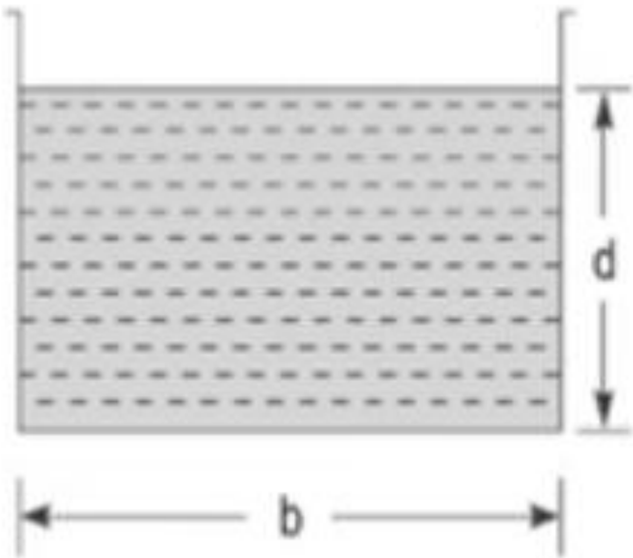
$$\frac{d}{dd}\left[\frac{A}{d} + 2d\right] = 0$$

$$-\frac{A}{d^2} + 2 = 0$$

$$A = 2d^2$$

$$b \times d = 2d^2$$

$$\boxed{\therefore b = 2d}$$



Now hydraulic mean depth,

$$\boxed{m = \frac{A}{P}}$$

$$= \frac{b \times d}{b + 2d}$$

$$= \frac{2d \times d}{2d + 2d}$$

$$= \frac{2d^2}{4d} = \frac{d}{2}$$

$$\boxed{\therefore m = \frac{d}{2}}$$

▪ Manning's Formula

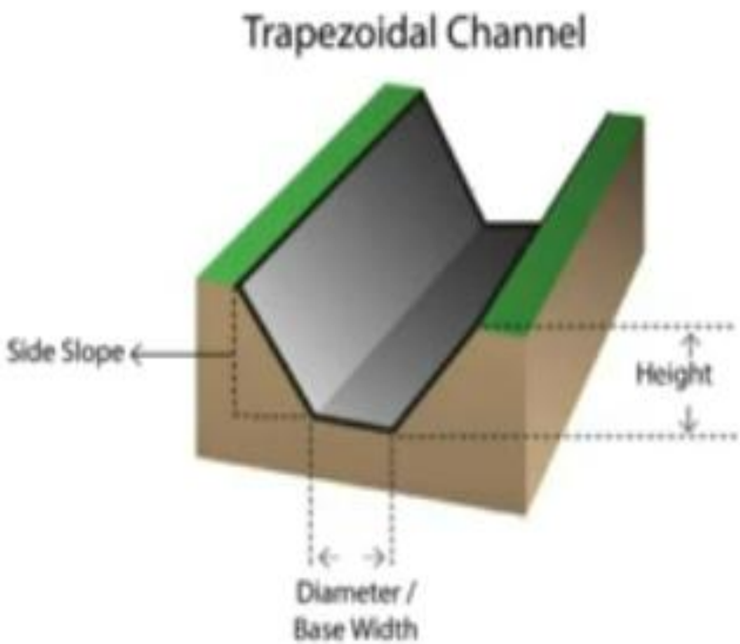
– According to this formula the value of Chezy's constant

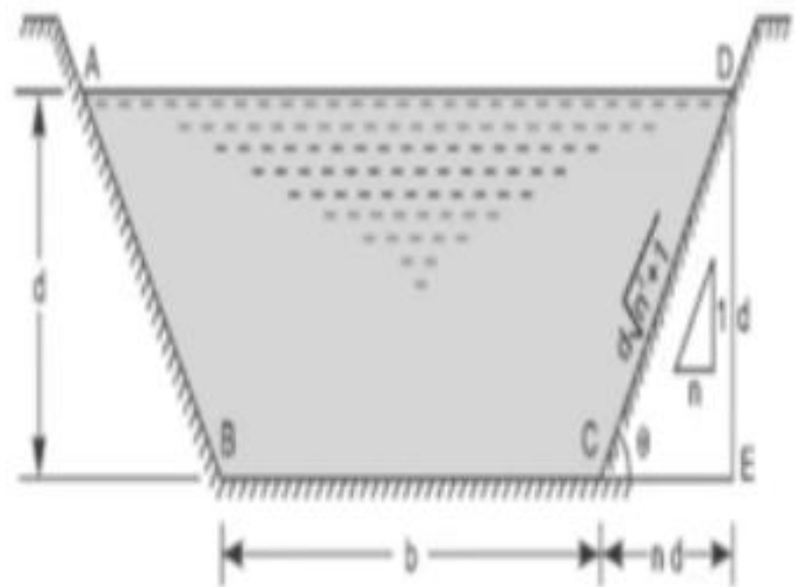
$$C = \frac{1}{N} m^{1/6}$$

Where m = Hydraulic mean depth

N = Manning's roughness coefficient. It depends on nature of boundary surface of channel. Its value varies from 0.01 for glass and PVC boundary to 0.04 and more for natural boulder streams.

2. Most Economical Trapezoidal Channel.





– Let b = width of channel

d = depth of the flow

θ = angle made by the sides with horizontal

(i) The side slope is given as 1 vertical to n horizontal.

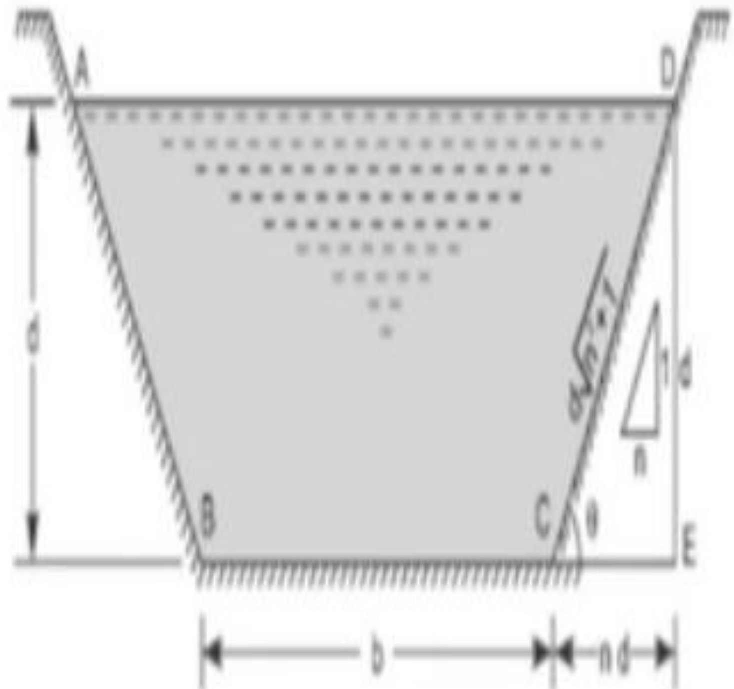
Area of flow,

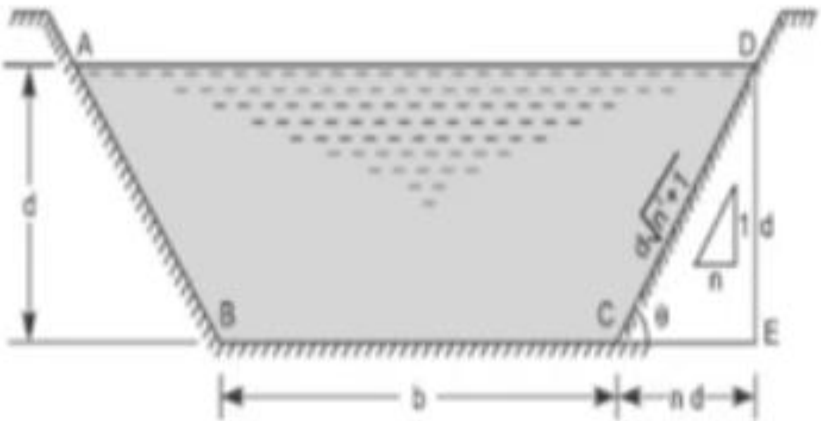
$$A = b \times d + 2 \times \frac{1}{2} \times nd \times d$$

$$= d(b + nd) \qquad \ldots\ldots (i)$$

$$\frac{A}{d} = (b + nd)$$

$$\boxed{b = \frac{A}{d} - nd}$$





Now wetted perimeter,

$$P = AB + BC + CD$$

$$= BC + 2CD$$

$$P = b + 2\sqrt{CE^2 + DE^2}$$

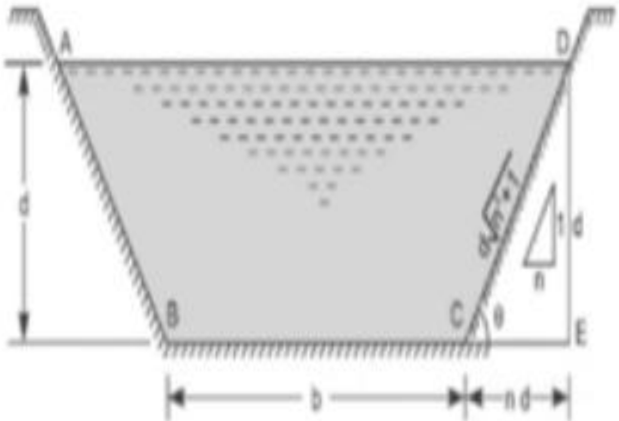
$$= b + 2\sqrt{n^2d^2 + d^2}$$

$$\boxed{= b + 2d\sqrt{n^2 + 1}} \quad \ldots \ldots \text{(iii)}$$

Substituting value of b from equation (ii), $b = \frac{A}{d} - nd$

$$\boxed{P = \frac{A}{d} - nd + 2d\sqrt{n^2 + 1}}$$

For most economical channel, P should be minimum,



$$\frac{dP}{dd} = 0$$

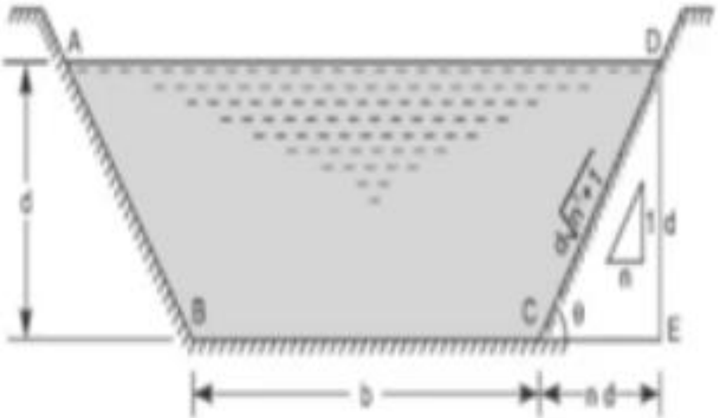
$$P = \frac{A}{d} - nd + 2d\sqrt{n^2 + 1}$$

$$\frac{d}{dd}\left[\frac{A}{d} - nd + 2d\sqrt{n^2 + 1}\right] = 0$$

$$-\frac{A}{d^2} - n + 2\sqrt{n^2 + 1} = 0$$

$$\frac{A}{d^2} + n = 2\sqrt{n^2 + 1}$$

Substituting value of A from equation (i),



$$A = d(b + nd)$$

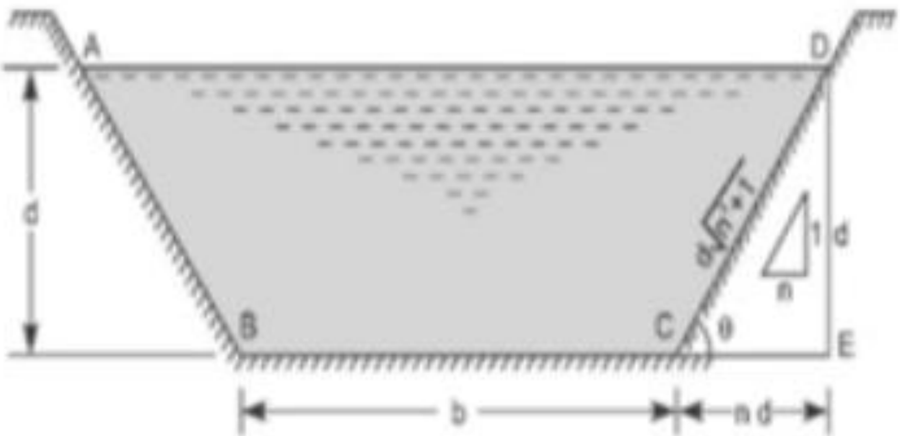
$$\frac{d(b + nd)}{d^2} + n = 2\sqrt{n^2 + 1}$$

$$\frac{(b + nd)}{d} + n = 2\sqrt{n^2 + 1}$$

$$\frac{b + nd + nd}{d} = \frac{b + 2nd}{d} = 2\sqrt{n^2 + 1}$$

$$\therefore \frac{b + 2nd}{2} = d\sqrt{n^2 + 1}$$

$\therefore$ *half of top width = one of the sloping side*



$$A = d \times (b + nd)$$

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

$$= b + (b + 2nd)$$

$$P = 2b + 2nd = 2(b + nd)$$

$$m = \frac{A}{P} = \frac{d \times (b + nd)}{2(b + nd)}$$

$$\therefore m = \frac{d}{2}$$

Numerical

A rectangular channel carries water at the rate of 400 litres/s when bed slope is 1 in 2000. Find the most economical dimensions of the channel if C = 50.

Given:

$Q = 400 \text{ litres/s} = 0.4 \text{ m}^3/\text{s}$

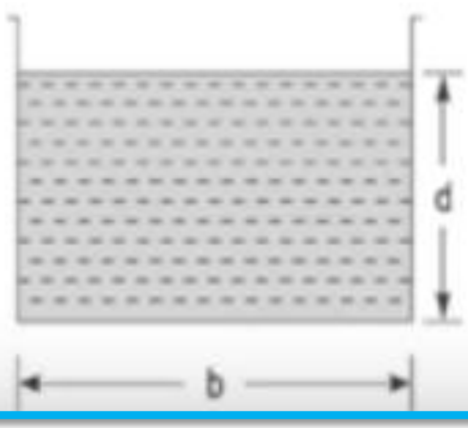
$i = 1/2000$

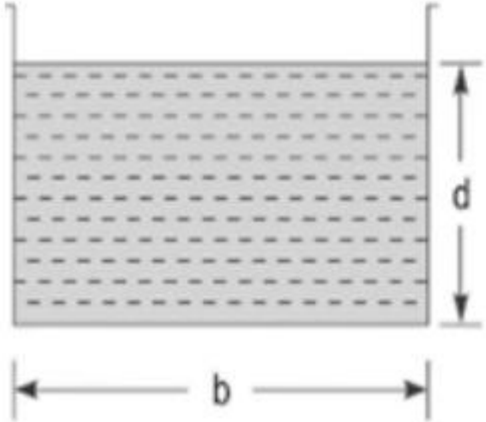
$C = 50$

Find:

$b = ?$

$d = ?$





For the most economical rectangular channel:

(i) $b = 2d$

(ii) $m = d/2$

Area of flow, $A = b \times d = 2d^2$

Discharge, $Q = CA\sqrt{mi}$

$$0.4 = 50 \times 2d^2 \sqrt{\frac{d}{2} \times \frac{1}{2000}}$$

$$\boxed{d = 0.577 \text{ m}}$$

$$\boxed{\therefore b = 2d = 1.154 \text{ m}}$$

Find the velocity of flow and rate of flow of water through a rectangular channel of 6 m wide and 3 m deep, when it is running full. The channel is having bed slope as 1 m in 2000. Take chezy's constant C = 55.

Given:

$b = 6$ m

$d = 3$ m

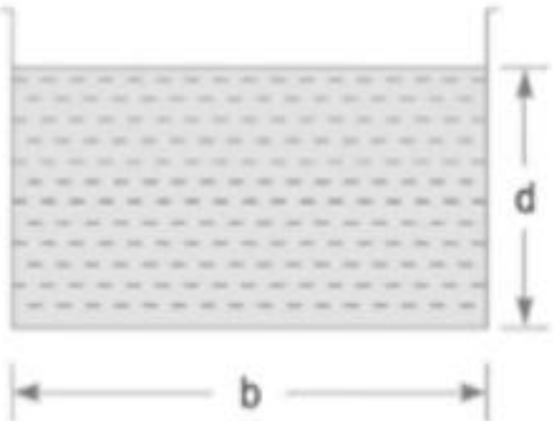
$i = 1/2000$

$C = 55$

Find:

$V = ?$

$Q = ?$



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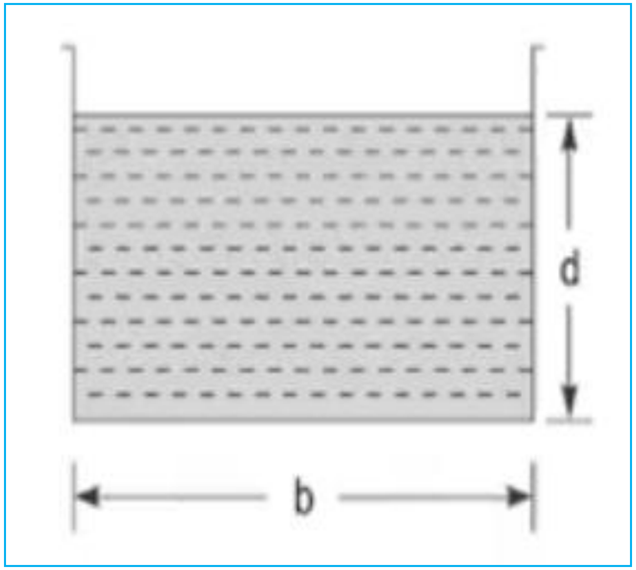

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$$d = 0.577 \text{ m}$$

$$\therefore b = 2d = 1.154 \text{ m}$$

A trapezoidal channel has side slopes of 1 horizontal to 2 vertical and the slope of the bed is 1 in 1500. The area of the section is 40 m^2. Find the dimensions of the section if it most economical. Determine the discharge of the most economical section if C = 50.

Given:	Find:
$n = 1/2$	$b = ?$
$i = 1/1500$	$d = ?$
$A = 40\ m^2$	
$C = 50$	

For the most economical trapezoidal channel:

(i) $\frac{b + 2nd}{2} = d\sqrt{n^2 + 1}$

(ii) $m = d/2$

$$\frac{b + 2nd}{2} = d\sqrt{n^2 + 1}$$

$$\frac{b + 2 \times \frac{1}{2} \times d}{2} = d\sqrt{\left(\frac{1}{2}\right)^2 + 1}$$

$$\boxed{b = 1.236\ d}$$

For most economical channel

$$\boxed{m = \frac{d}{2}}$$

$$= 2.4 \text{ m}$$

Discharge,

$$\boxed{Q = CA\sqrt{mi}}$$

$$= 80 \text{ m}^3/\text{s}$$