CHPATER 1:

Basic Concepts

Basic Concepts

- An open channel is one that has its **top surface open** and so, water having pressure equal to the atmospheric pressure.

- Open-channel flows are not entirely included within *rigid boundaries*; a part of the flow is in contract with nothing at all, just empty space.

- Because the flow boundary is freely deformable, in contrast to the solid boundaries, the flow surface is called a **free surface**.

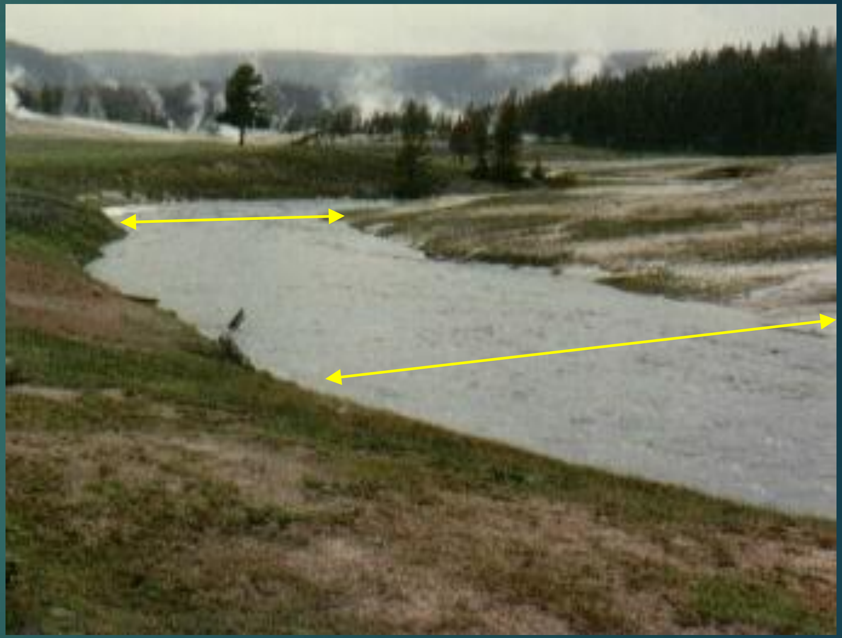
Channel vs. Pipe

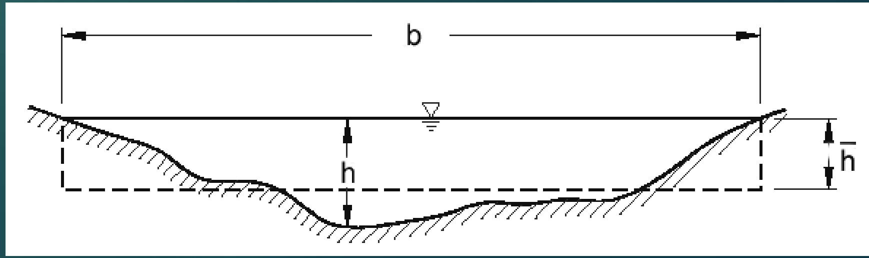
- In the pipe flow, there is no direct atmospheric flow and there would be **hydraulic pressure** only.

- The flow in open channel is due to gravity while in pipe flow pressure works (e.g., pumping water)

- In open channels, flow conditions are greatly influenced by slope of the channel.

- In pipes the flow cross section is known and fixed while it is unknown in open channel.





Types of Open-Channels

Examples of open channels flow are river, streams, flumes, sewers, ditches and lakes.




Types of Open-Channels




Classification of Open-Channel

Natural Channels: Very irregular in shape.

Rivers, tidal estuaries.

Artificial Channels: Developed by men and usually designed with regular geometric shapes.

Irrigation canals, laboratory flumes.

Prismatic Channels: unvarying cross-section and constant bottom slope.

Artificial channels like Rectangular, Trapezoid

Non-Prismatic Channels varying cross-section and bottom slope.

The natural channels are usually prismatic

Classification of Open-Channel

Rigid Boundary Channels: Non-changeable boundaries (bed and sides).

Lined canals, sewers and non-erodible unlined canals

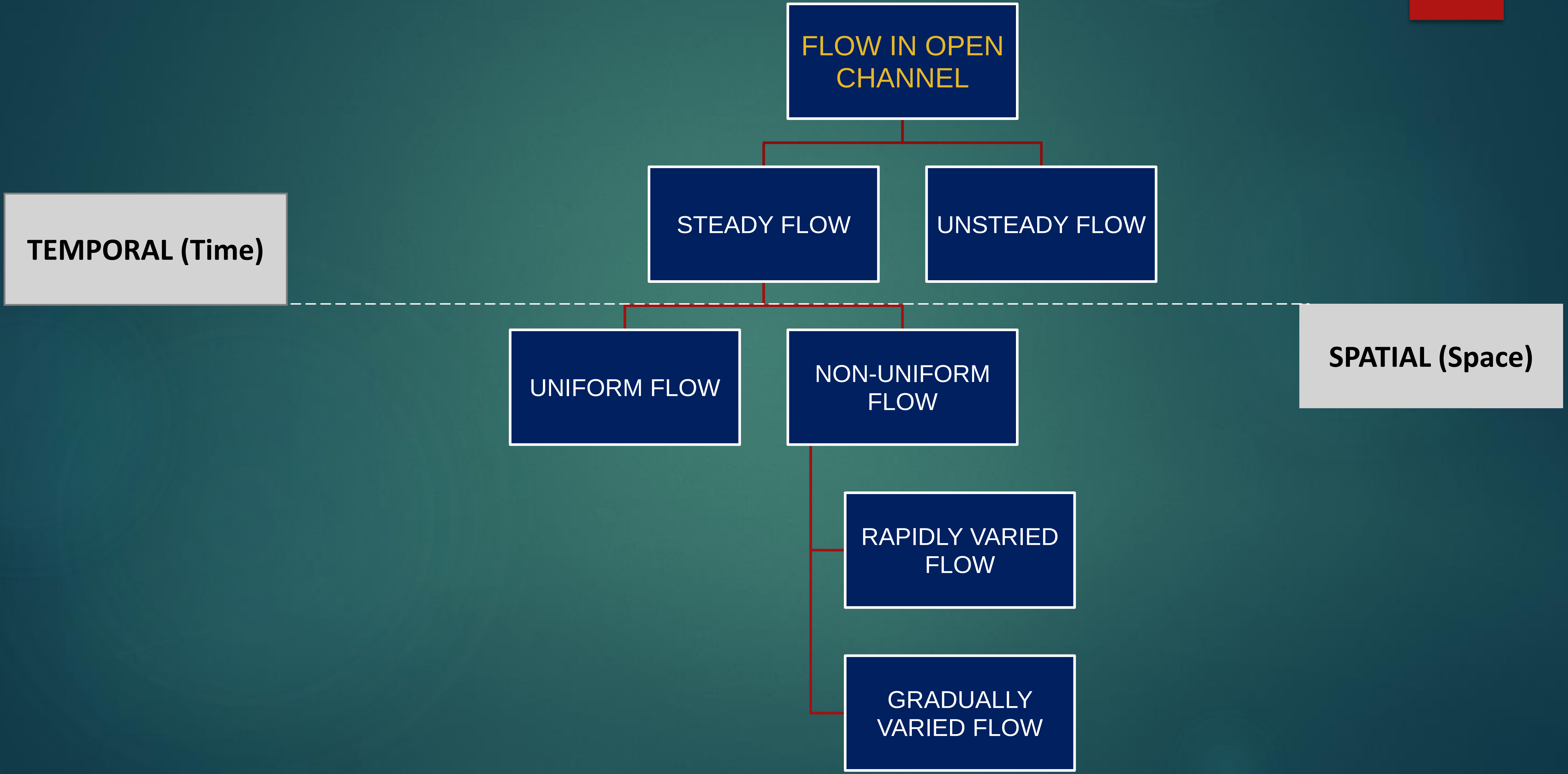
Mobile Boundary Channels: Boundary is composed of loose sedimentary particles moving under the action of flowing water.

An alluvial channel

Small Slope Channels: having a bottom slope less than 1 in 10 (10%).

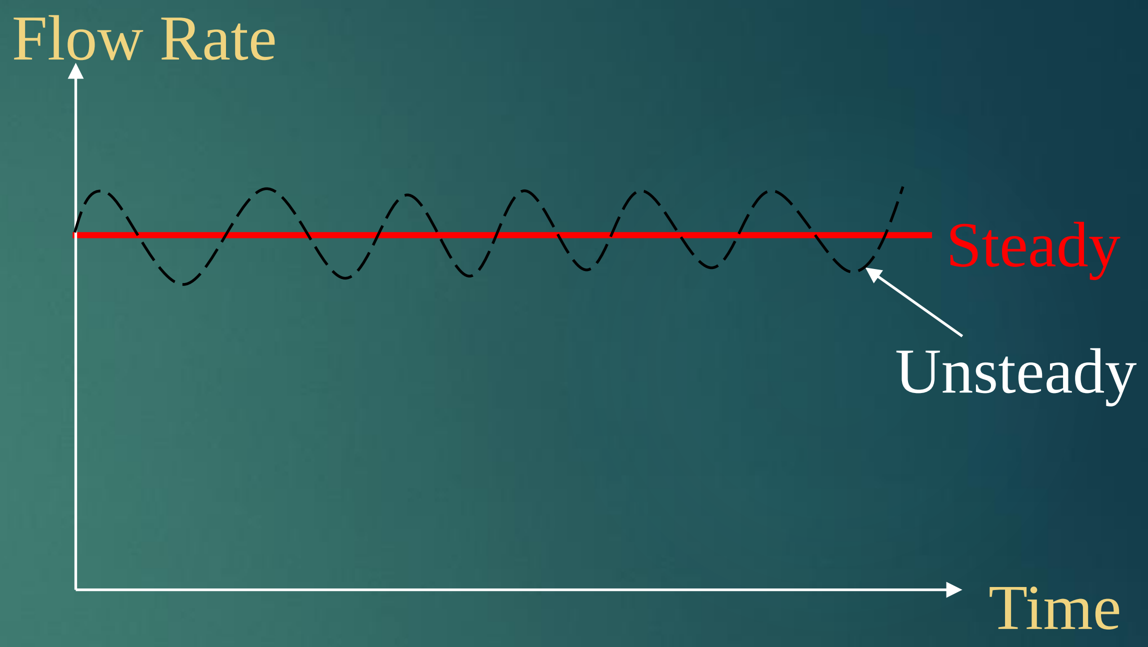
Large Slope Channels: having a bottom slope greater than 1 in 10 (10%).

Flow classification



Flow classification (Time Criteria)

- If the flow parameters, such as velocity, pressure, density and flow rate do not vary with time then the flow is **steady**.



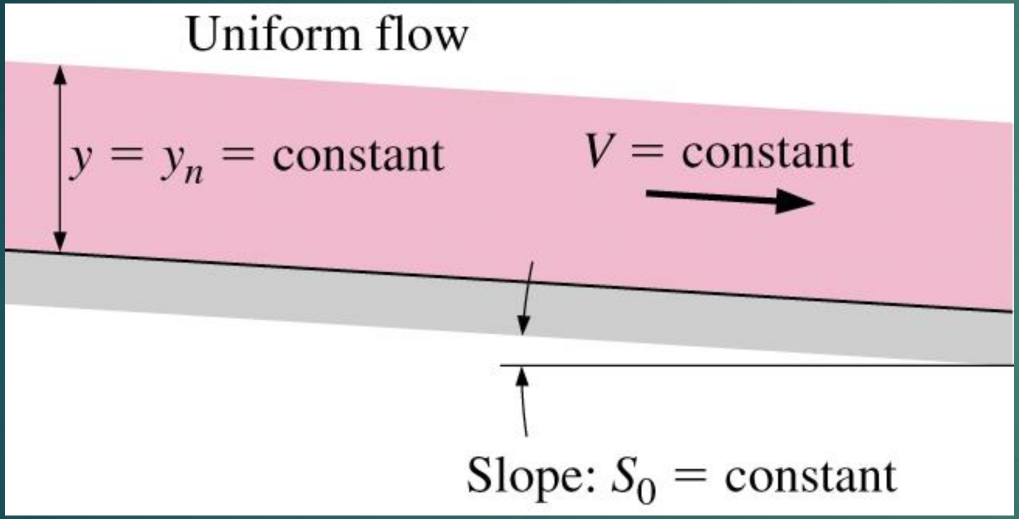
- **Steady flow** (dy/dt = 0). Water depth at one point is same all the time. (Flow constant with time)

- If the flow parameters vary with time then the flow is categorized as **unsteady**.

- **Unsteady flow** (dy/dt ≠ 0) Water depth changes all the time. (Flow variation with time)

Flow classification (Space Criteria - Uniform Flow)

- If the flow parameters do not vary with distance along the flow path, then the flow is **uniform**.

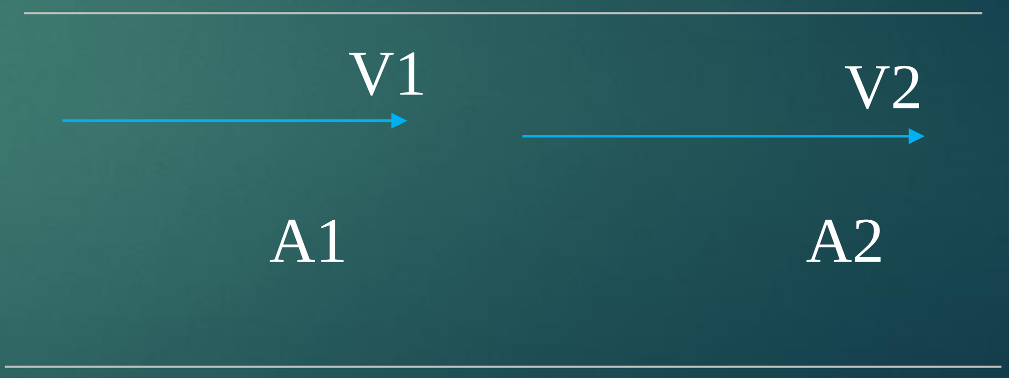


- Depth of water in a uniform flow is called normal depth or y_n

- **Uniform flow** (dy/dx = 0) Water depth same along the whole length of flow.

$$V_1 = V_2$$

$$A_1 = A_2$$

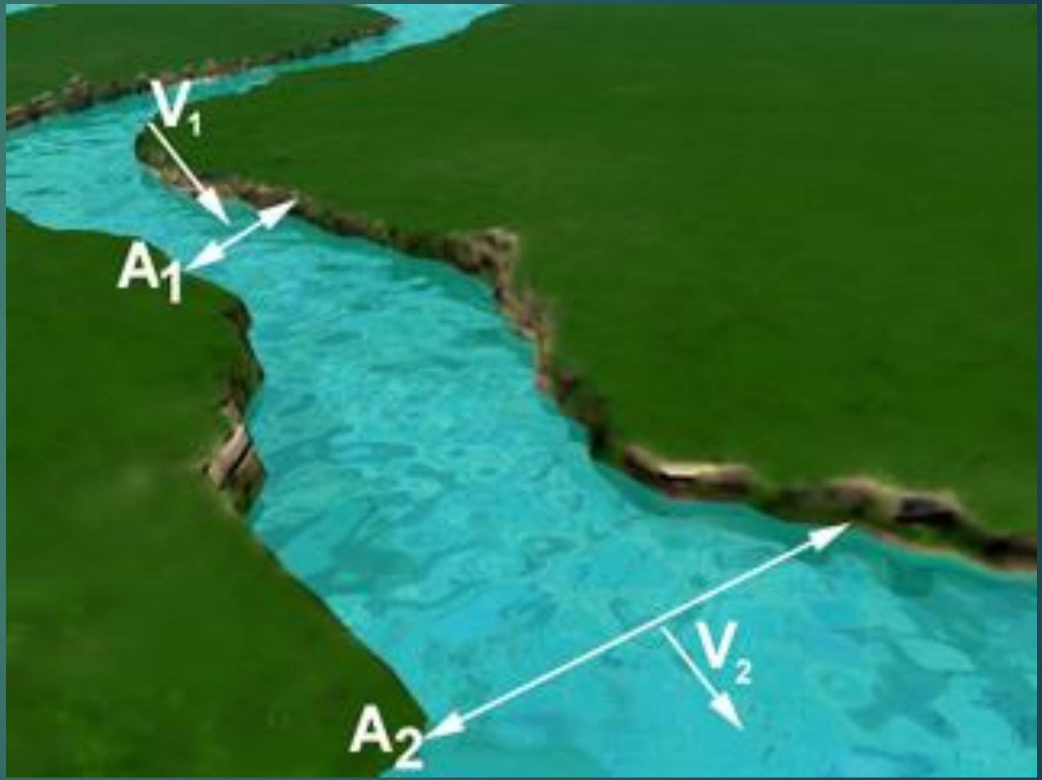


Uniform Flow

Flow classification (Space Criteria - Non uniform Flow)

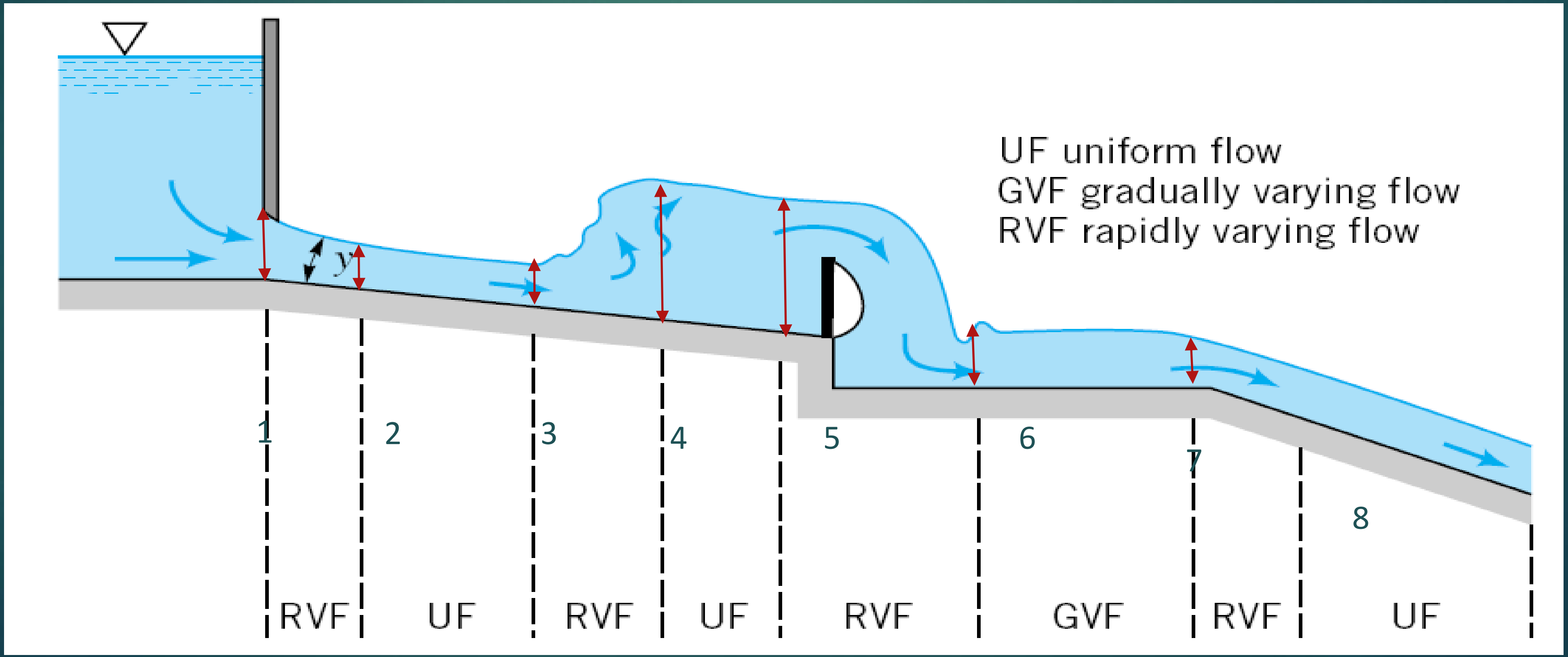
- If the flow parameters vary with distance along the flow path, then the flow is **non-uniform**.

- **Non-uniform** flow ($dy/dx \neq 0$) Water depth changes either rapidly or gradually.



Flow classification (Space Criteria – Non Uniform Flow)

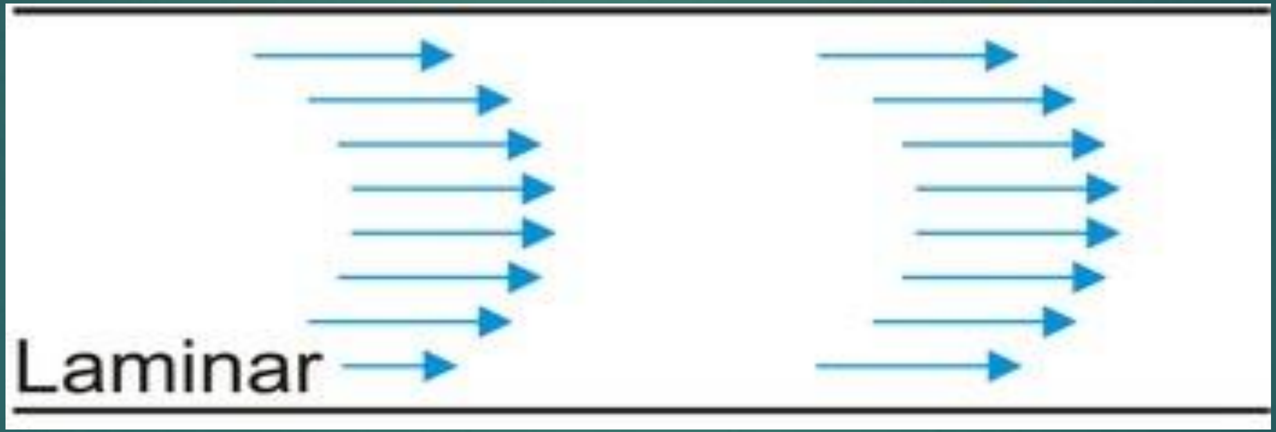
- Rapidly varying flows (RVF): flow depths that vary considerably over a short distance
- Gradually varying flow (GVF): flow depths that vary slowly with distance.



Flow classification (flow particles motion)

Laminar

- Type of fluid flow in which the fluid travels smoothly or in regular paths.

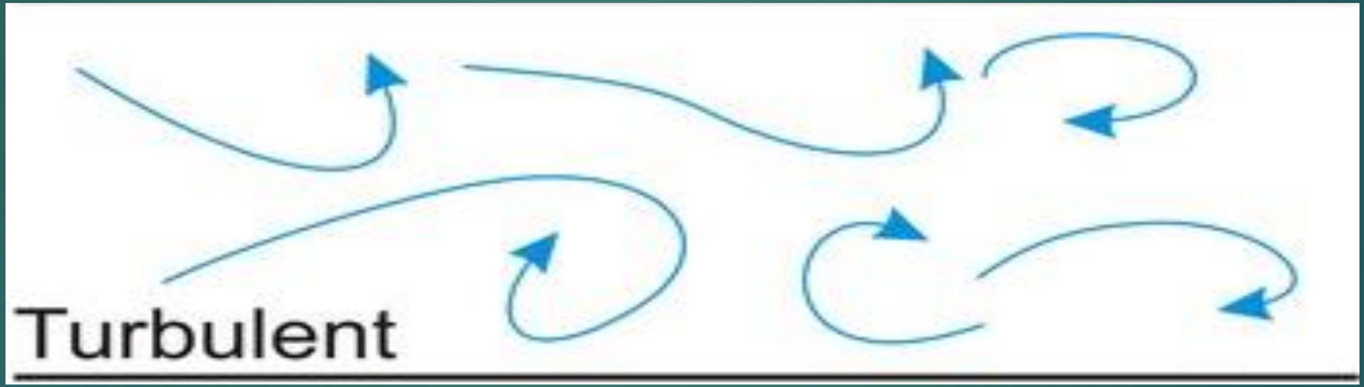


- The flow channel is relatively small, the fluid is **moving slowly**, and its viscosity is relatively high.

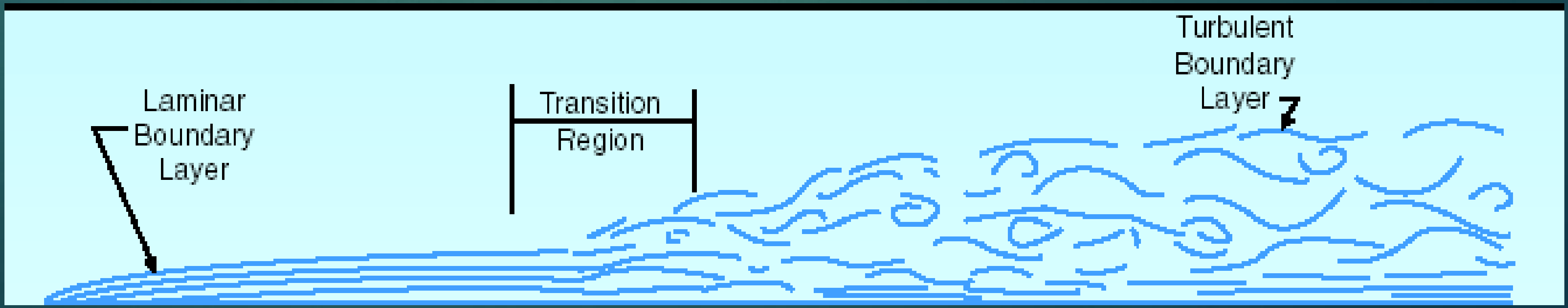
Flow classification (flow particles motion)

Turbulent

- The fluid undergoes irregular fluctuations and mixing.
- Most kinds of fluid flow are turbulent except near solid boundaries



Transitional



Effective Forces In Flow Analysis (Reynolds number)

- Viscous
- Inertia
- Gravity

A non-dimensional number →

$$\text{Reynolds number} = \frac{Inetria\ Forces}{Viscous\ \ Forces}$$

$$R_e = \frac{V \times D}{\upsilon}$$

where V = Average velocity of flow, D = pipe diameter, and υ = Kinematic viscosity of the fluid.

$$R_e = \frac{V \times R_h}{\upsilon}$$

where V = Average velocity of flow, R_h = is hydraulic radius, and υ = Kinematic viscosity of the fluid.

Laminar flow : **Re < 500** (viscous > inertia)

Transitional flow: **500 < Re < 1300**

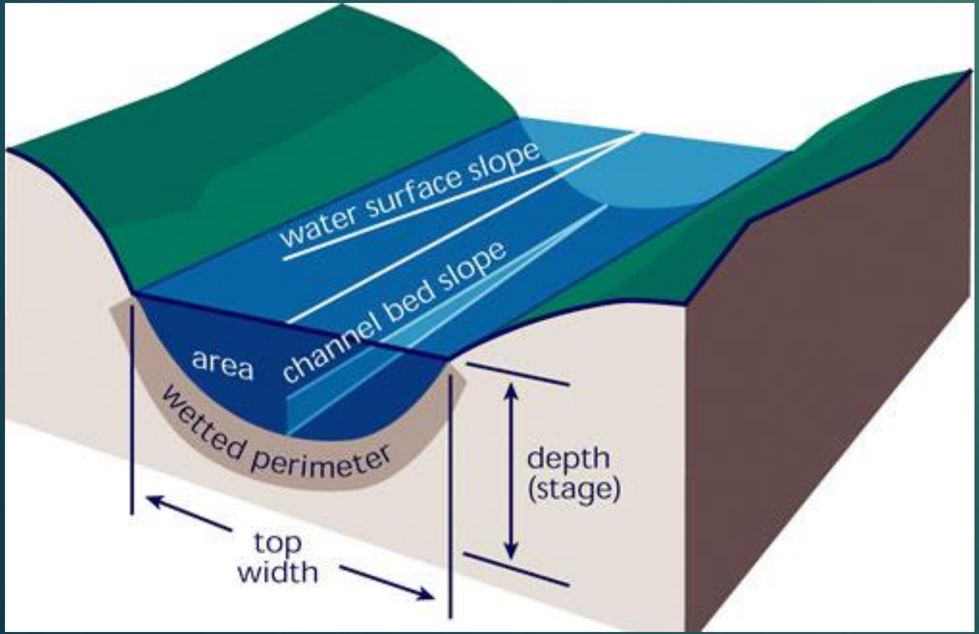
Turbulent flow: **Re > 1300** (inertia > viscous)

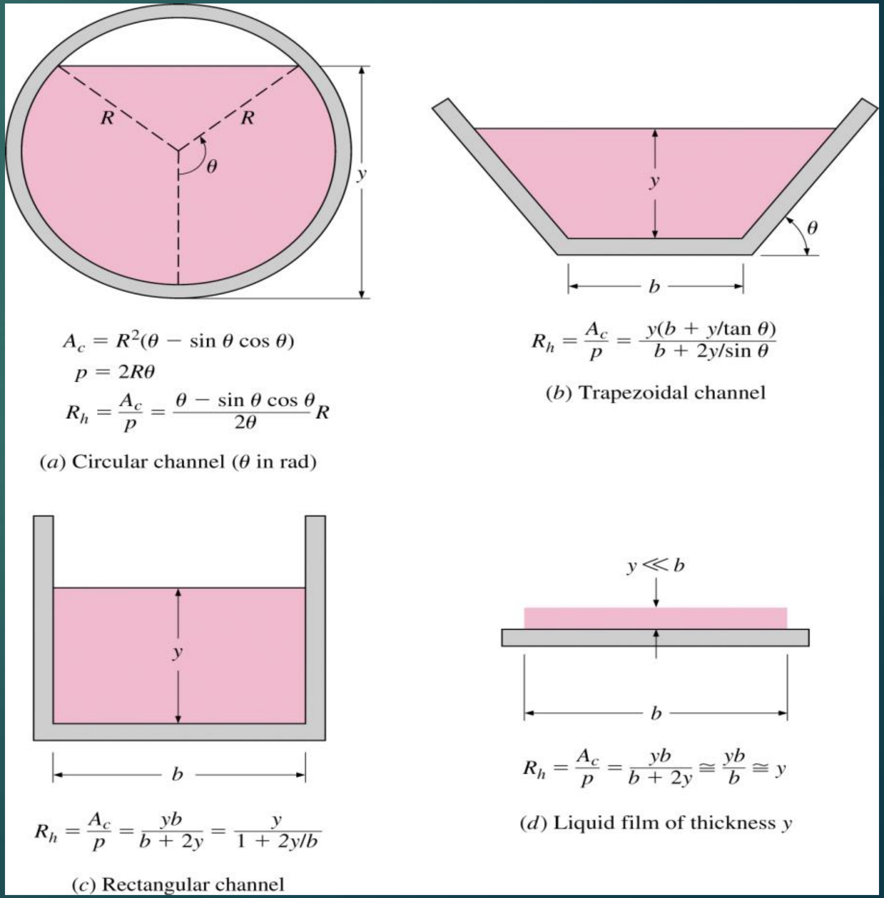
Effective Forces In Flow Analysis (hydraulic radius)

- The **hydraulic radius** is the term used to describe the shape of a channel.

$$R_h = \frac{\text{Cross sectional area}}{\text{wetted perimeter}} = \frac{A}{P}$$

- The wetted perimeter ***does not*** include the free surface.

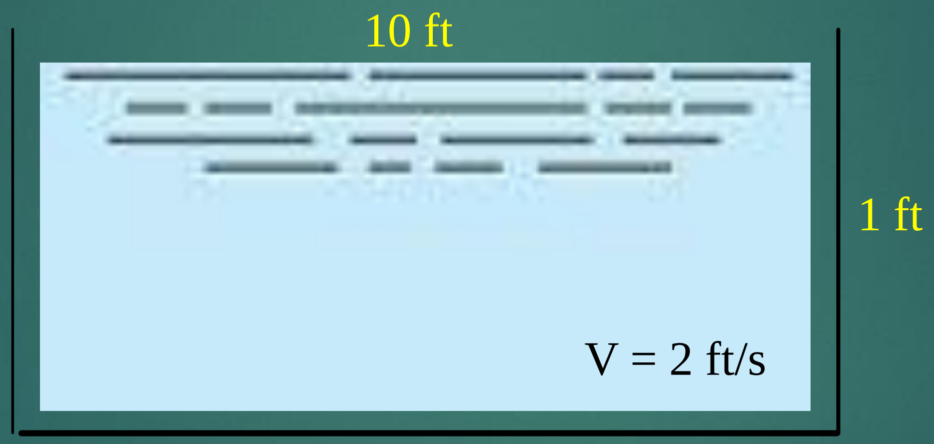


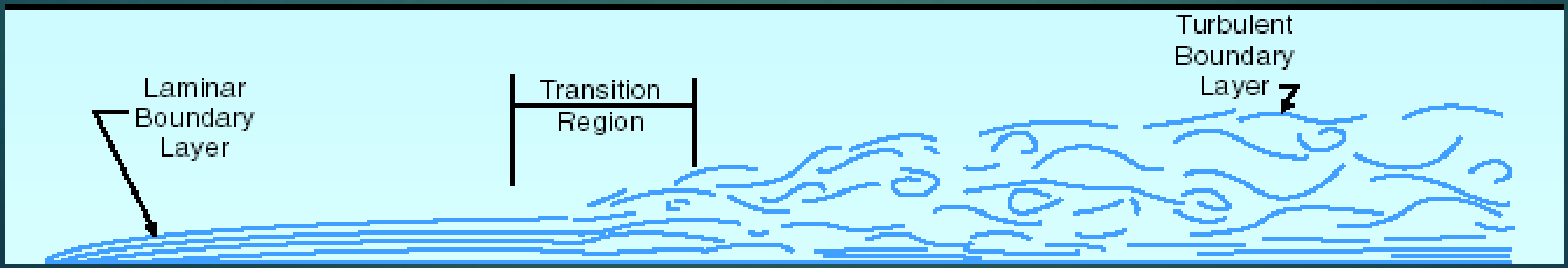


Effective Forces In Flow Analysis

Example 1-1

Determine the type of flow (laminar or turbulent) for the following rectangular channel.

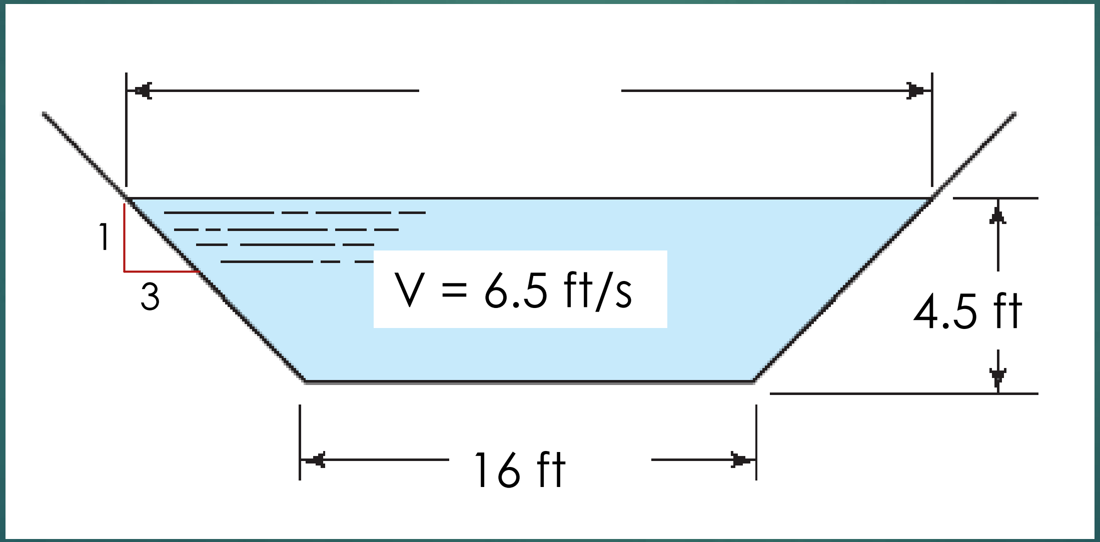




Effective Forces In Flow Analysis

Example 1-2

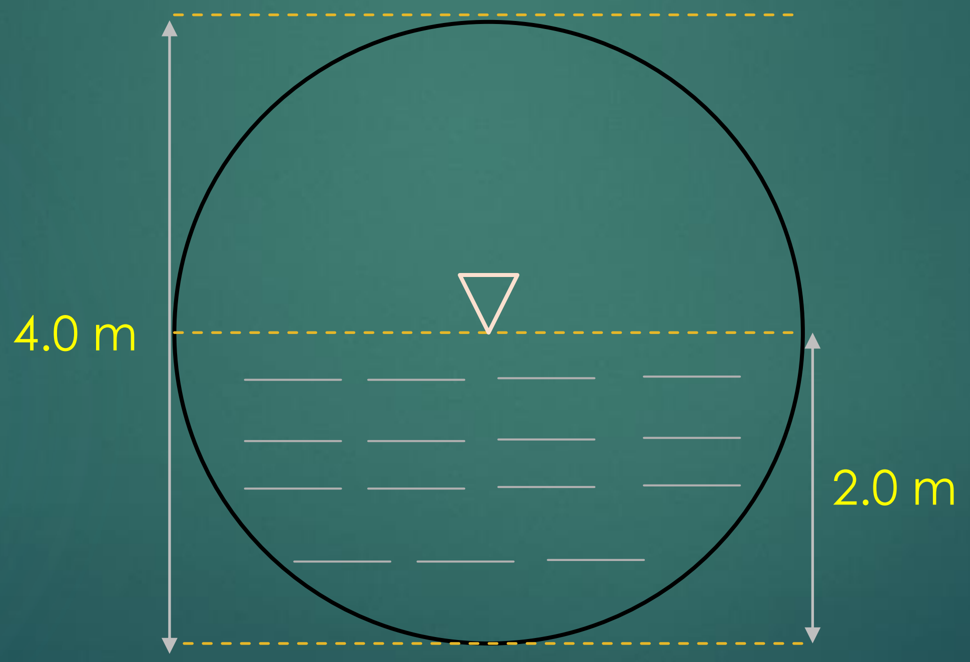
Determine the type of flow (laminar or turbulent) for the following trapezoidal channel.



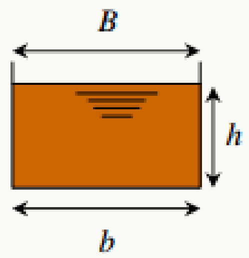
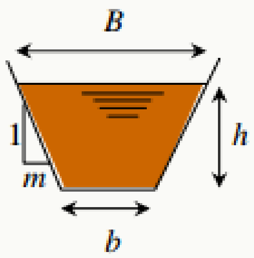
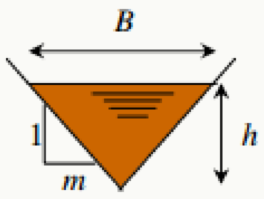
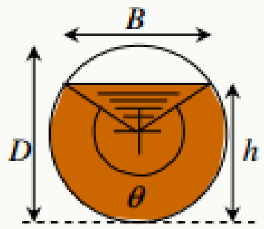
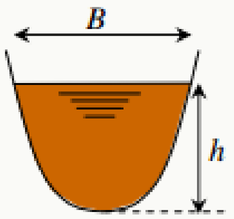
Effective Forces In Flow Analysis

Example 1-3

Determine the hydraulic radius for the following circular channel.



Effective Forces In Flow Analysis

	rectangular	*trapezoidal*	*triangular*	*circular*	*parabolic*
					
flow area A	bh	$(b+mh)h$	mh^2	$\frac{1}{8}(\theta-\sin\theta)D^2$	$\frac{2}{3}Bh$
wetted perimeter P	$b+2h$	$b+2h\sqrt{1+m^2}$	$2h\sqrt{1+m^2}$	$\frac{1}{2}\theta D$	$B+\frac{8}{3}\frac{h^2}{B}$ *
hydraulic radius R_h	$\frac{bh}{b+2h}$	$\frac{(b+mh)h}{b+2h\sqrt{1+m^2}}$	$\frac{mh}{2\sqrt{1+m^2}}$	$\frac{1}{4}\left[1-\frac{\sin\theta}{\theta}\right]D$	$\frac{2B^2h}{3B^2+8h^2}$ *
top width B	b	$b+2mh$	$2mh$	$(\sin\theta/2)D$ *or* $2\sqrt{h(D-h)}$	$\frac{3}{2}Ah$
hydraulic depth D_h	h	$\frac{(b+mh)h}{b+2mh}$	$\frac{1}{2}h$	$\left[\frac{\theta-\sin\theta}{\sin\theta/2}\right]\frac{D}{8}$	$\frac{2}{3}h$

Effective Forces In Flow Analysis (Froude number)

- Viscous
- Inertia
- Gravity

Dimensionless number

$$Fr = \frac{Inetria\ Forces}{Gravity\ \ Forces} = \frac{V}{\sqrt{gR_h}}$$

Fr < 1 : Flow is subcritical

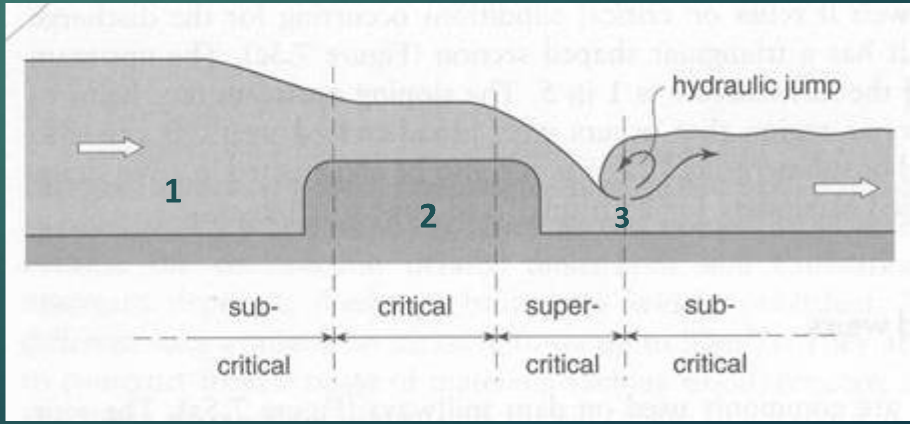
Flow is **deep**, **slow** with a **low energy** state

Fr = 1 : Flow is critical

There is a perfect **balance** between the gravitational and inertial forces.

Fr > 1 : Flow is supercritical

Flow is **fast flow** with a **high energy** state



Effective Forces In Flow Analysis (Critical Depth)

Critical depth y_c occurs at Fr = 1

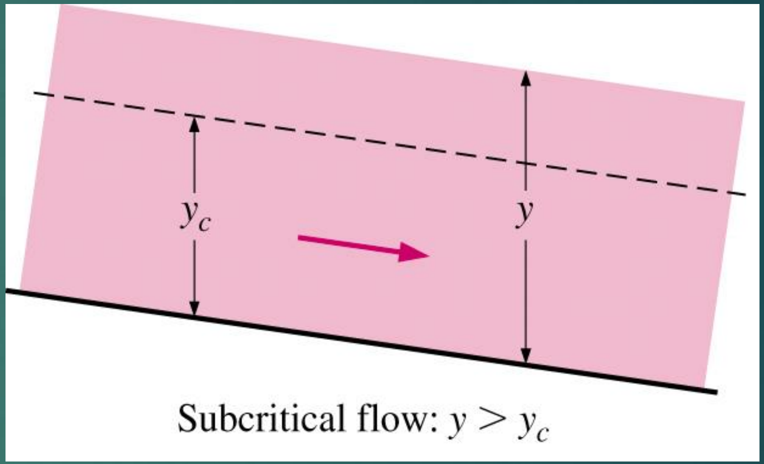
$$Fr = 1$$

$$R_h = y$$

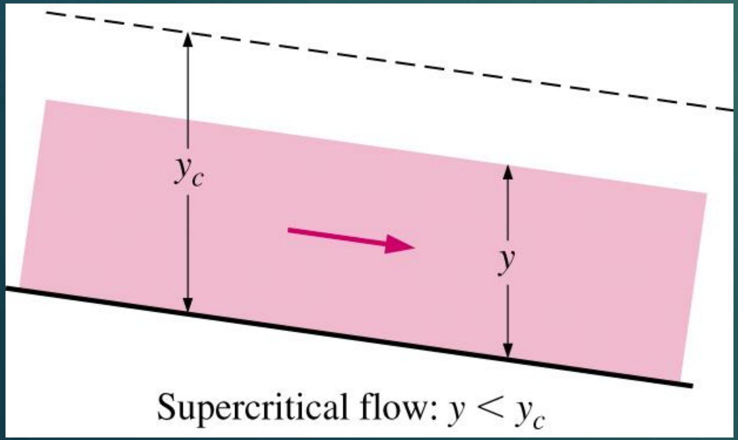
$$Fr^2 = \frac{V^2}{gy}$$

$$y = y_c = \frac{V^2}{g}$$

At low flow velocities (Fr < 1), So: **$y > y_c$**



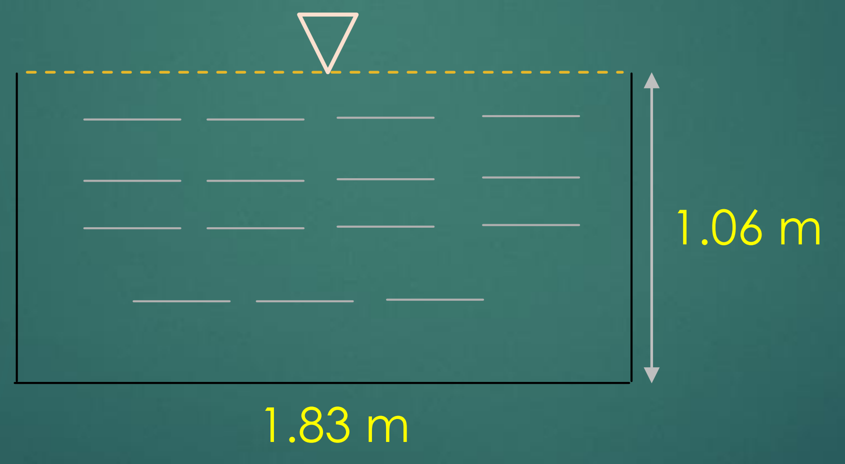
At high flow velocities (Fr > 1), So: **$y < y_c$**



Effective Forces In Flow Analysis

Example 1-4

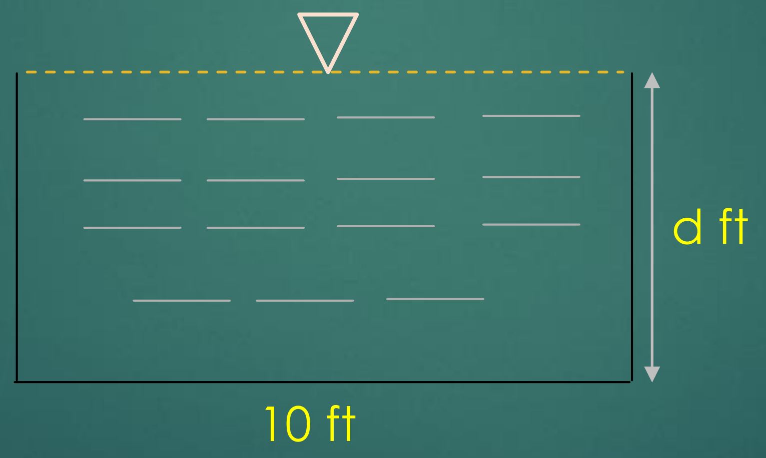
Determine the flow condition (subcritical, critical or supercritical) for a rectangular channel with the flow velocity of 2.32 m/s.



Effective Forces In Flow Analysis

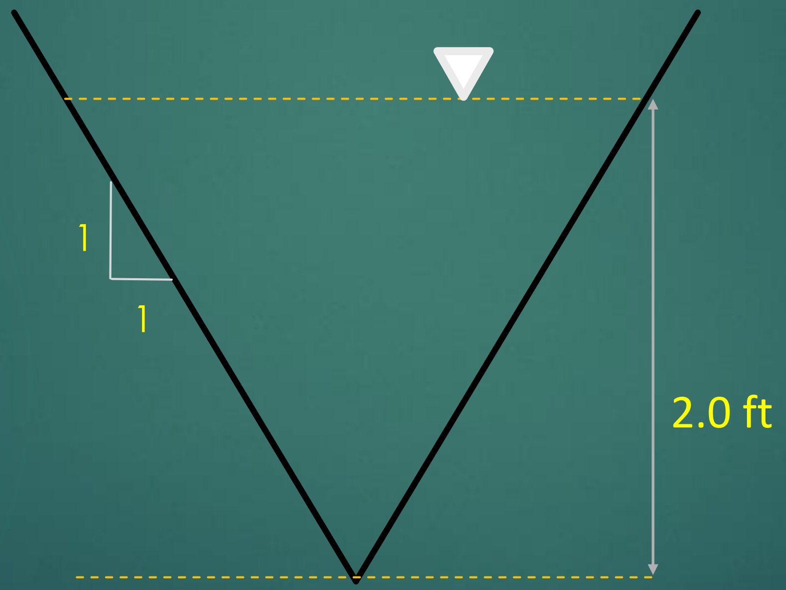
Example 1-5

Flow in a rectangular channel with the width of <u>10</u> ft is critical with the velocity of <u>11.35</u> ft/s. Find the depth of flow.



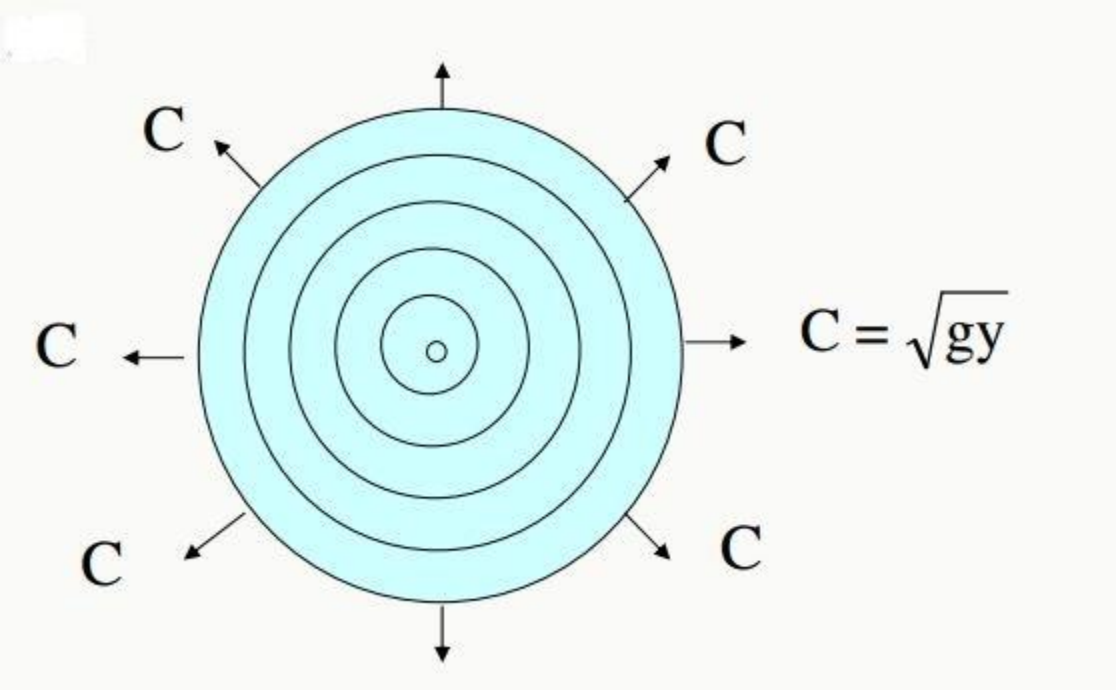
Example 1-6

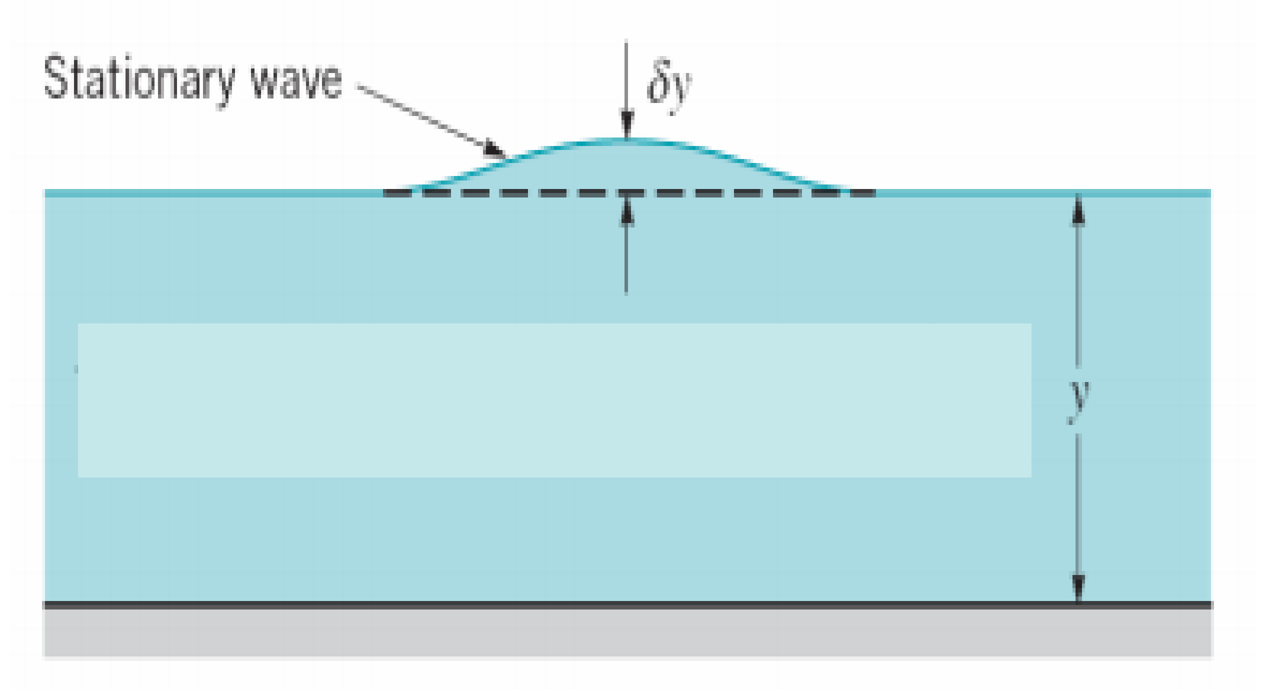
Determine the critical depth and flow condition (sub or super critical) in a triangle channel with the side slope of 1:1, depth of 2 ft, and V= 5.28 ft/s.



Critical Flow and Velocity

- The wave speed (C) is: $C = \sqrt{gy}$





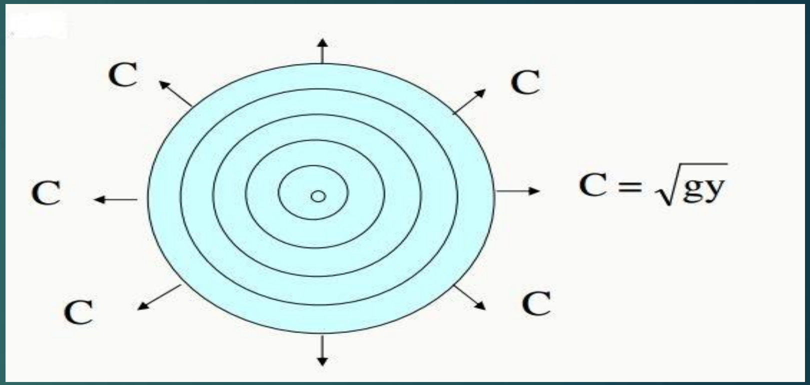
Critical Flow and Velocity

- For a wide rectangular channel, the hydraulic depth, **R_h=y**. Therefore, Froude number becomes:

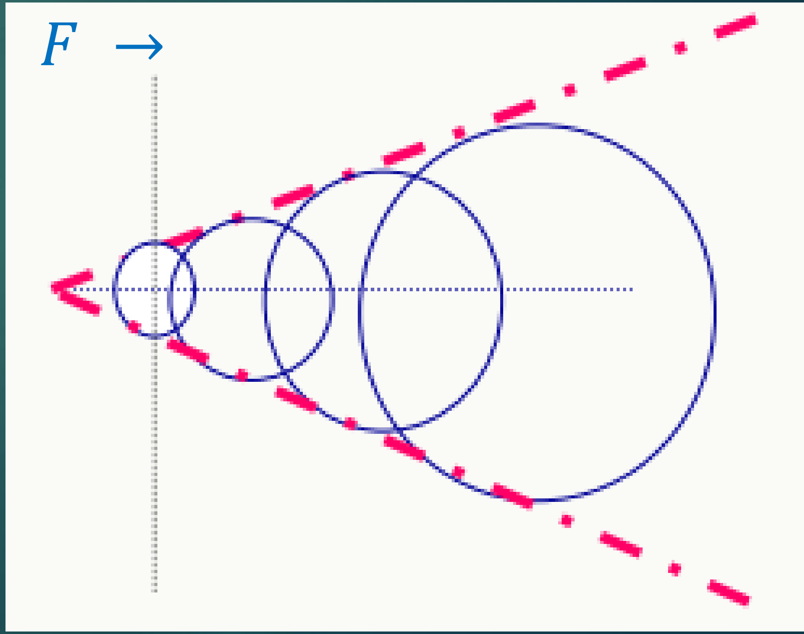
$$Fr = \frac{V}{\sqrt{gy}} = \frac{V}{C}$$

Super Critical

$$Fr > 1 \rightarrow V > C$$



- Since V > C, it CANNOT propagate upstream it can propagate only towards downstream.



- This means the flow at upstream will not be affected.

- In other words, there is no hydraulic communication between upstream and downstream flow.

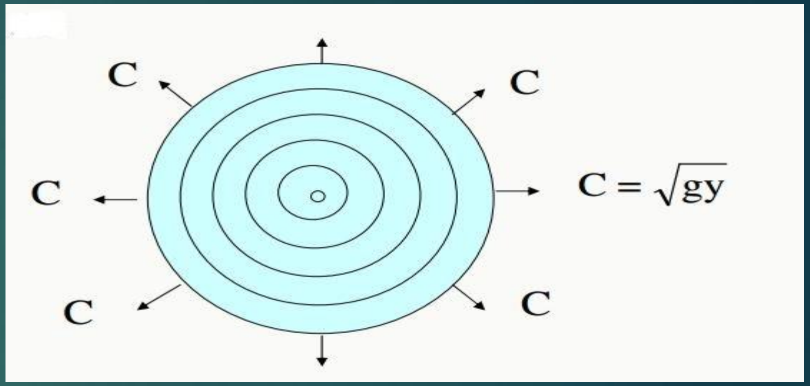
Critical Flow and Velocity

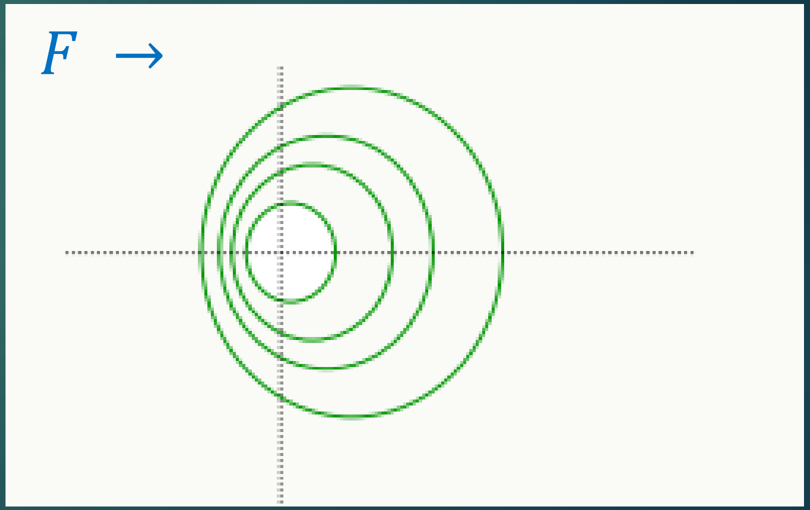
- For a wide rectangular channel:

$$Fr = \frac{V}{\sqrt{gy}} = \frac{V}{C}$$

Subcritical

$$Fr < 1 \rightarrow V < C$$





- Since V < C, it CAN propagate **both** upstream and downstream.

- This means the flow at upstream and downstream will both be affected.

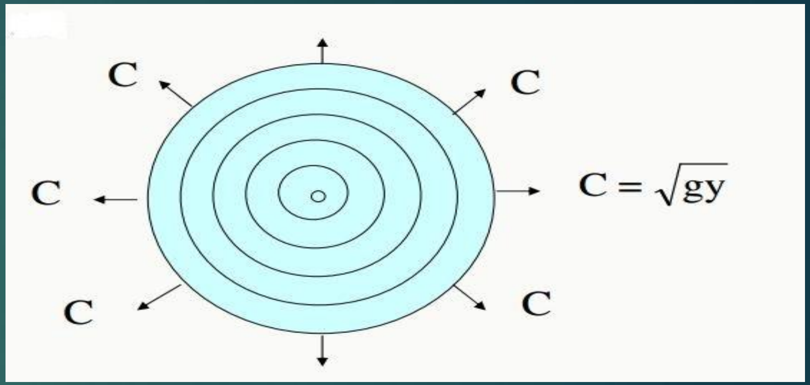
- In other words, there is hydraulic communication between upstream and downstream flow.

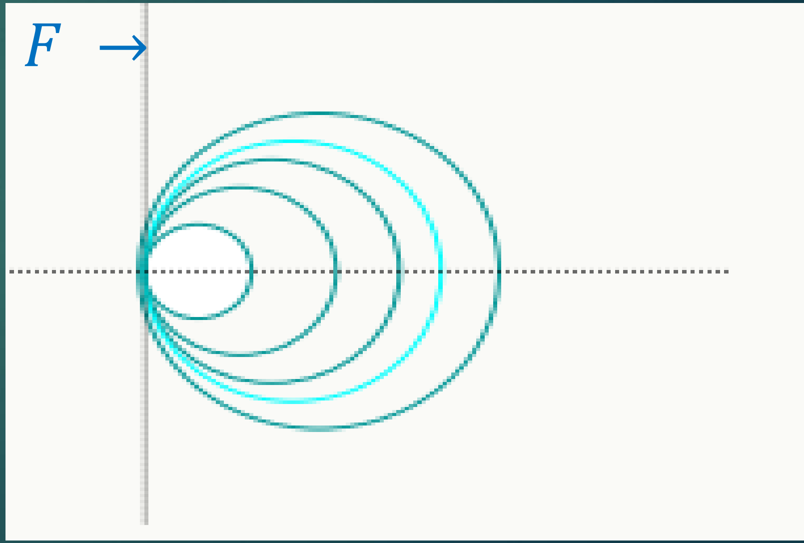
Critical Flow and Velocity

- For a wide rectangular channel:

$$Fr = \frac{V}{\sqrt{gy}} = \frac{V}{C}$$

Critical → $Fr = 1 \rightarrow V = C$

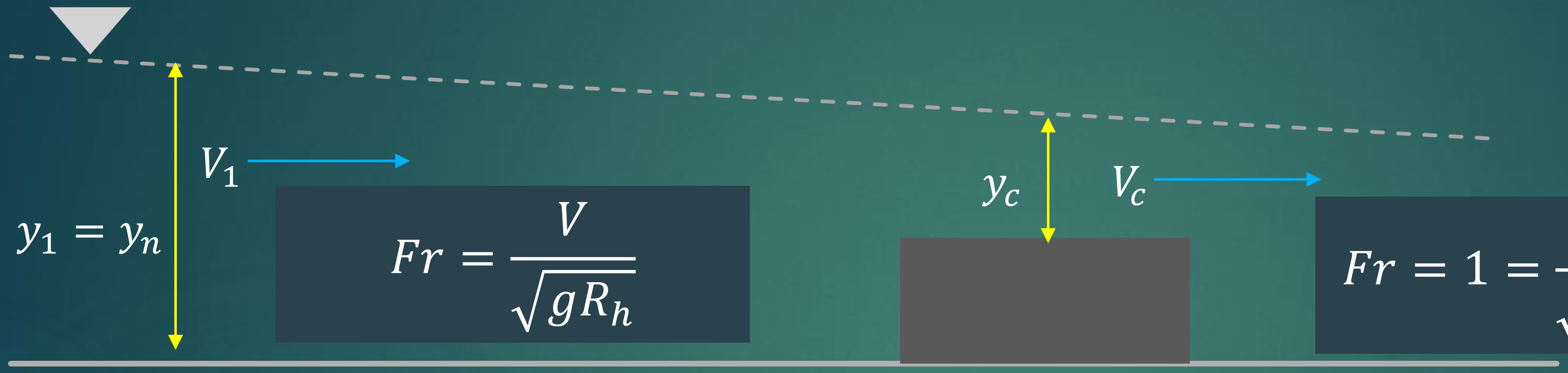




- Since V = C, it <u>CAN</u> propagate **only** downstream.

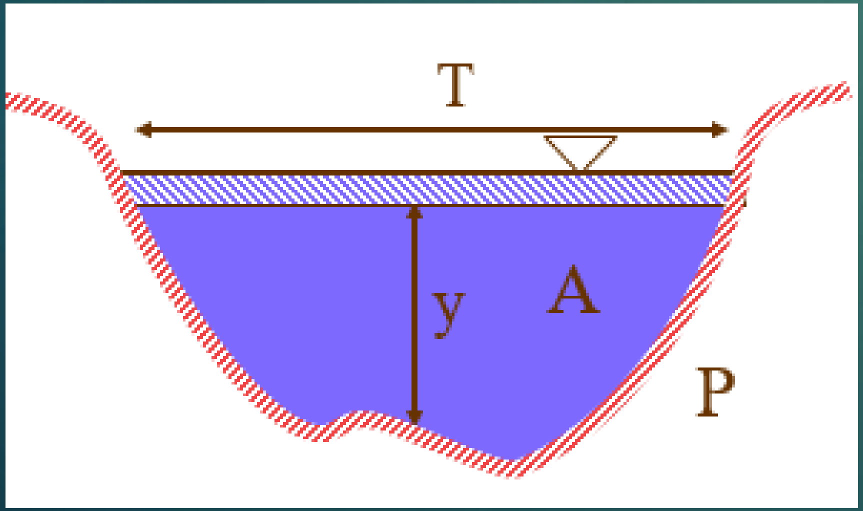
- This means the flow at <u>downstream</u> will be affected.

Critical Flow and Velocity



$$Fr = \frac{V}{\sqrt{gR_h}}$$

$$Fr = 1 = \frac{V_c}{\sqrt{gR_{hc}}}$$



$$\frac{Q^2T}{gA^3} = Fr^2$$

$$\frac{Q^2T_c}{gA^3} = 1$$

Hydraulic Mean Depth = $D_h = \frac{A}{T}$

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

Critical Flow and Velocity

- Critical flow characteristics:

  Unstable surface

  Series of stationary or standing waves

Observed standing waves on the surface of a liquid in a vibrating container

- Occurrence

  Broad crested weir (and other weirs)

  Channel Controls (rapid changes in cross-section)

  Over falls

  Changes in channel slope from mild to steep

- Used for flow measurements

Unique relationship between depth and discharge

Critical Flow and Velocity

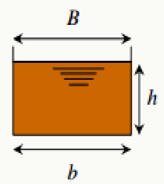
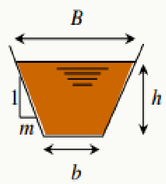
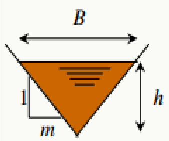
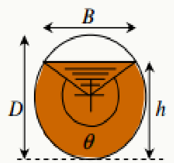
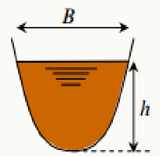
In a **rectangular** channel, we have:

$$\frac{Q^2 T_c}{g A^3} = 1 \quad \Rightarrow \quad y_c = \left(\frac{q^2}{g}\right)^{1/3}$$

$$q\ (m^2/s) = \frac{Q}{b = T}$$

Discharge per unit width

$$q = \sqrt{g y_c^3} \qquad \frac{y_c}{2} = \frac{V_c^2}{2g}$$

	rectangular	trapezoidal	triangular	circular	parabolic
					
flow area A	bh	$(b+mh)h$	mh^2	$\frac{1}{8}(\theta - \sin\theta)D^2$	$\frac{2}{3}Bh$
wetted perimeter P	$b+2h$	$b+2h\sqrt{1+m^2}$	$2h\sqrt{1+m^2}$	$\frac{1}{2}\theta D$	$B+\frac{8}{3}\frac{h^2}{B}$ *
hydraulic radius R_h	$\frac{bh}{b+2h}$	$\frac{(b+mh)h}{b+2h\sqrt{1+m^2}}$	$\frac{mh}{2\sqrt{1+m^2}}$	$\frac{1}{4}\left[1-\frac{\sin\theta}{\theta}\right]D$	$\frac{2B^2h}{3B^2+8h^2}$ *
top width B	b	$b+2mh$	$2mh$	$(\sin\theta/2)D$ or $2\sqrt{h(D-h)}$	$\frac{3}{2}\frac{A}{h}$
hydraulic depth D_h	h	$\frac{(b+mh)h}{b+2mh}$	$\frac{1}{2}h$	$\left[\frac{\theta-\sin\theta}{\sin\theta/2}\right]\frac{D}{8}$	$\frac{2}{3}h$

Critical Flow and Velocity

Example 1-7

Determine the critical depth and critical velocity of flow in a rectangular channel with the width of 2 m and flow rate of 8 m3/s.

Critical Flow and Velocity

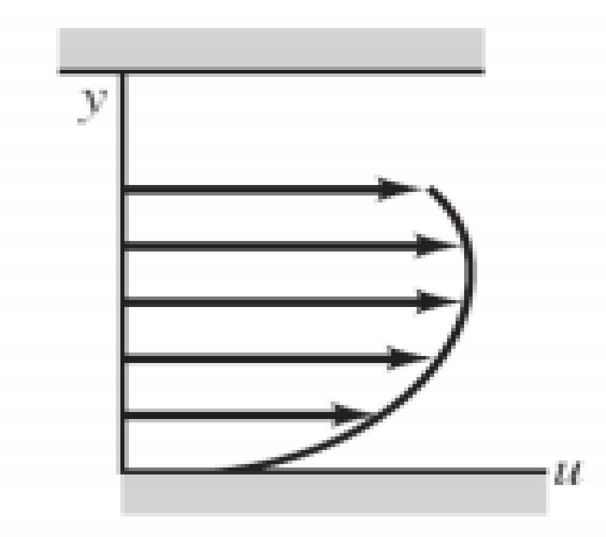
Example 1-8

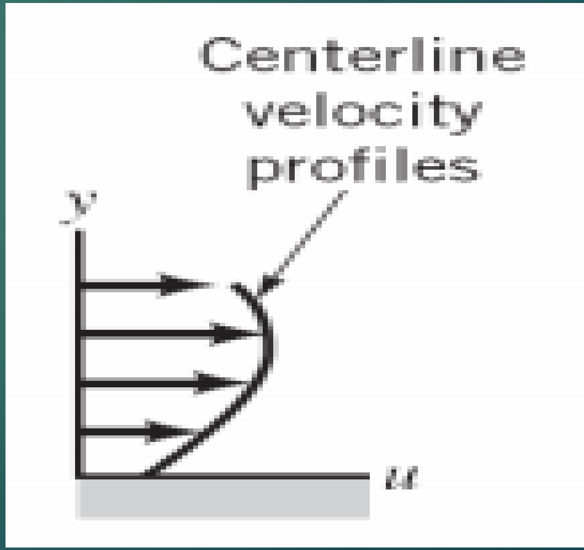
Determine the critical depth and critical velocity of flow in a trapezoidal channel with the width of 2 m, side slope 1:2, and flow rate of 8 m3/s.

Velocity Distribution on Open Channels

- The velocities in channel are not uniformly distributed (usually axisymmetric) in channel section because of presence of a free surface and friction along the channel wall.

- It might be expected to find the maximum velocity at the free surface where the **shear force** is **zero** but this is not the case.



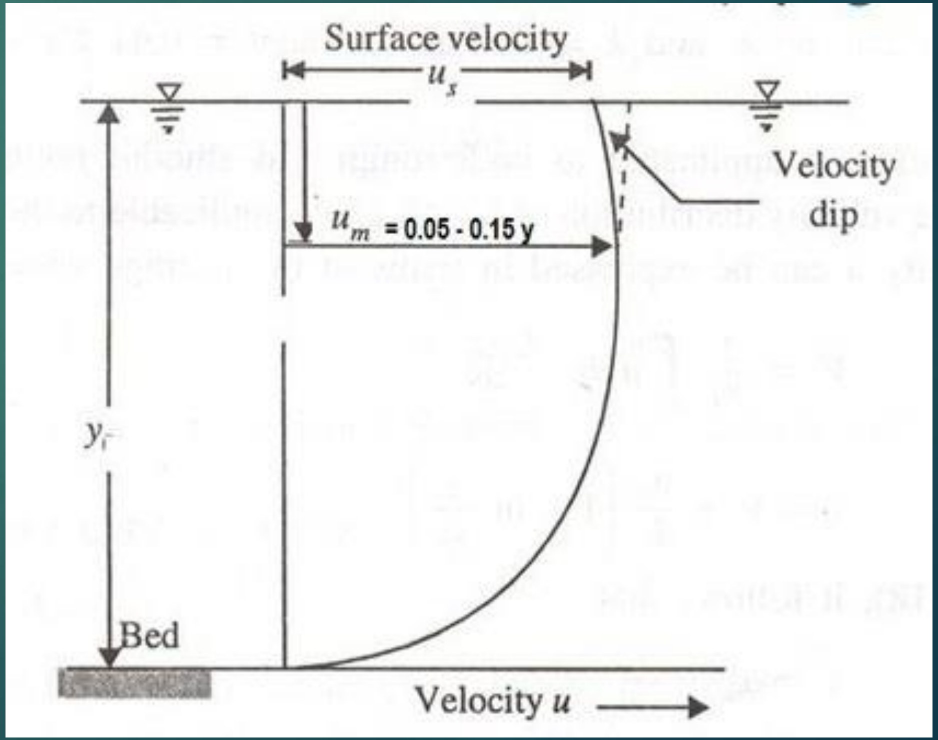


Velocity Distribution on Open Channels

- The <u>maximum</u> velocity is usually found just below the surface.

- The reason is the presence of secondary currents which are circulating from the boundaries towards the section center and resistance at the air/water interface.

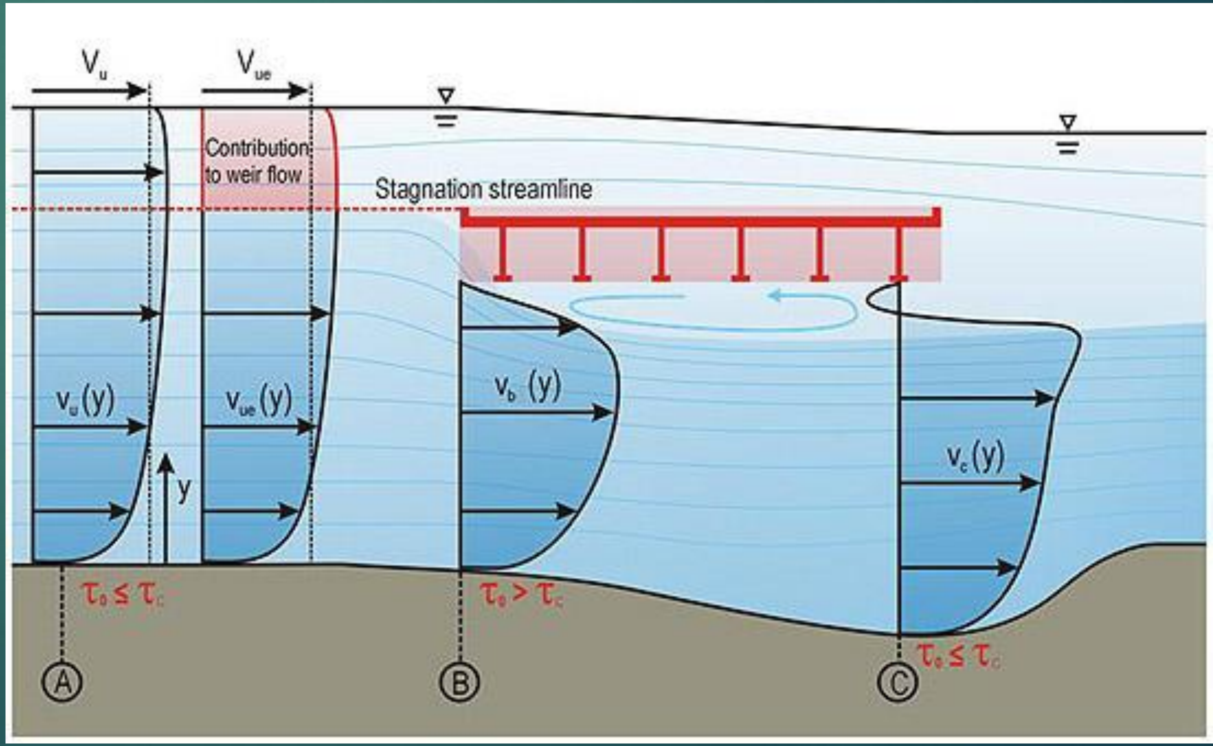
- The measured maximum velocity usually appears to occur below the free surface at a distance <u>**0.05**</u> to <u>**0.15**</u> (some references say <u>**0.25**</u>) of the depth.



Velocity Distribution on Open Channels

- The velocity distribution at each section of a channel depends on many factors including shape of the channel at the section, the channel roughness and the presence of bends.

- The **roughness** causes the **curvature** of vertical velocity distribution increases.



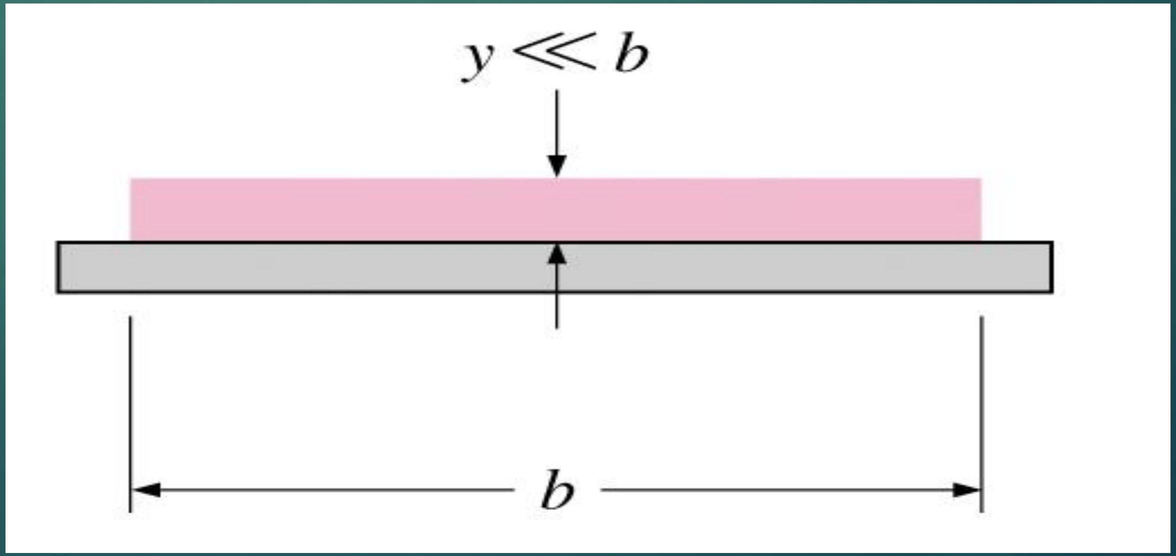
Velocity Distribution on Open Channels

- In a **wide** open channel, the sides of the channel have no influence on the velocity distribution in the central region.
- A wide channel can be defined as rectangular channel that width is greater than 10 times the depth of flow.
- Hydraulic radius for a wide channel will approximate the depth.

$$R_h = \frac{b.y}{b+2y}$$

$$b \gg y$$

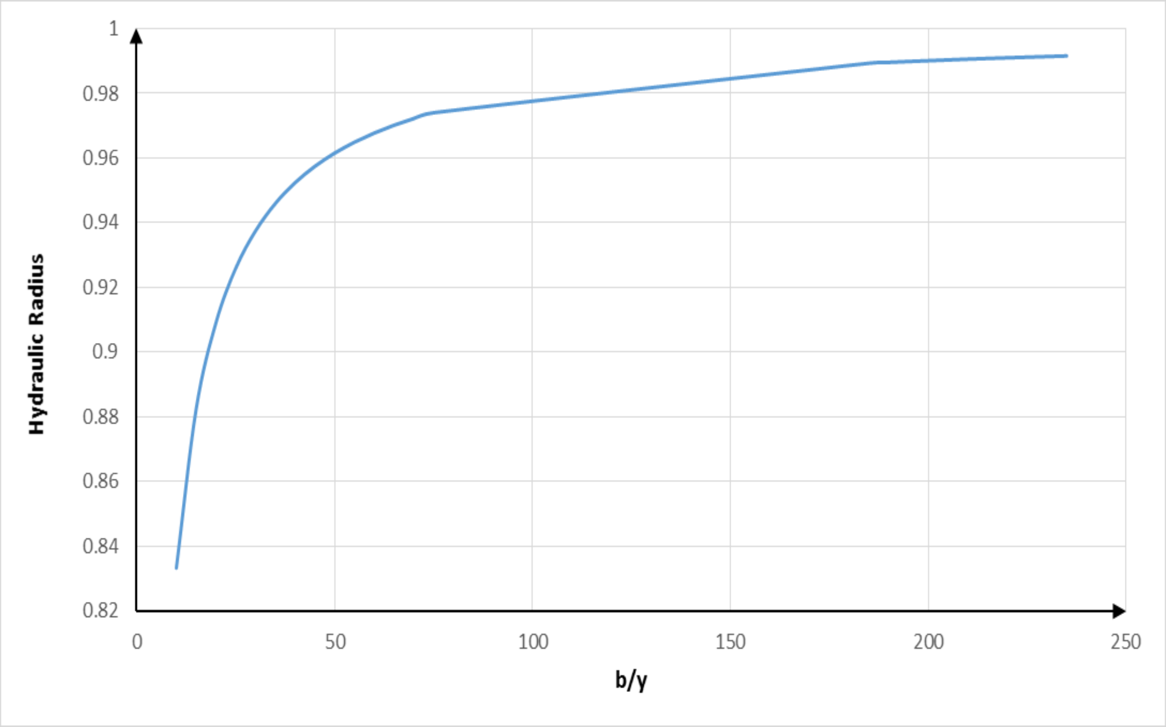
$$\frac{b}{y} > 10 \rightarrow R_h \approx y$$



Velocity Distribution on Open Channels

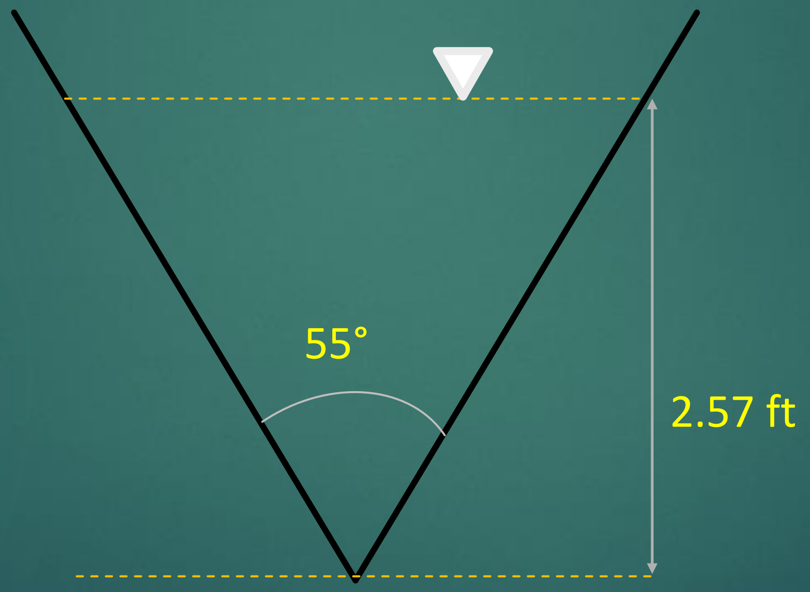
$$\frac{b}{y} = 10 \rightarrow R_h = \frac{10y^2}{12y} = 0.83y$$

$$\frac{b}{y} = 200 \rightarrow R_h = \frac{200y^2}{202y} = 0.99y$$



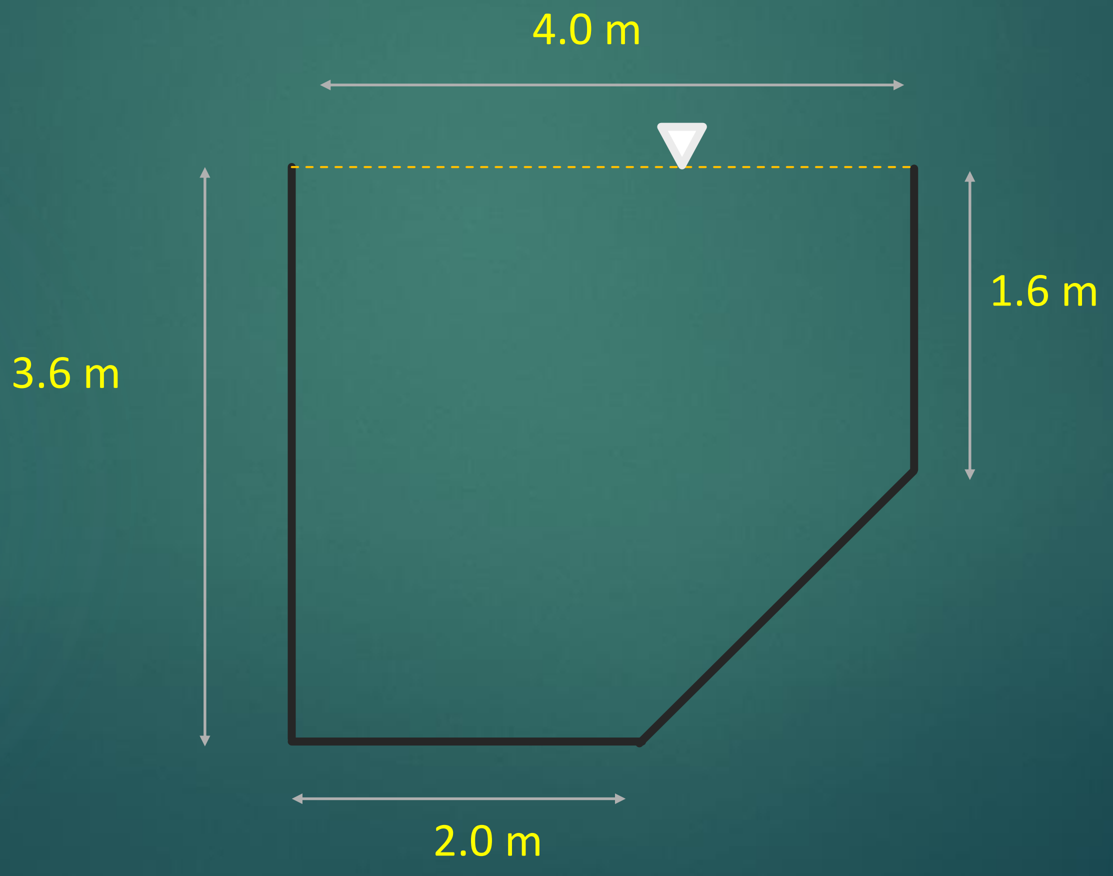
Homework 1

Q1-1 Determine the flow regime (Laminar, Turbulent or Transitional) in the following triangle channel which the flow velocity is 2.9 ft/s.



Homework 1

Q1-2 Calculate the hydraulic radius for the following channel.



Homework 1

Q1-3 Determine the flow condition (sub or supercritical) in a rectangular flume with the flow velocity of 1.52 m/s and width of 1.36 m, if:

a. Ratio of flume width to flow depth is 4.0

b. Ratio flume width to flow depth is 0.5

c. Flume is very wide ($\frac{b}{y} \geq 10$)

Homework 1

Q1-4 What is the critical depth and critical velocity in trapezoidal channel with the side slope of 1:2, width of 3 m, and flow capacity of 20 m3/s.