

# Hydraulics and Hydraulic Machines

## 1. Open channel hydraulics

### 1.1 Introduction and channel characteristics

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## What is open channel flow?

- Flows that are not entirely included within rigid boundaries
- Water surface is in contact with the atmosphere → a free surface



## Open channel flow

- Water surface is in contact with the atmosphere (Free water surface is present)
- Pressure at the water surface is constant
- Gravitational force controls the flow
- Pressure distribution along the channel is hydrostatic

## Open channels

- **Canals:** Long, mild-sloped channel on the ground
- **Flume:** Channel of wood, metal, concrete or masonry supported on or above surface
- **Chute:** channel having steep slope
- **Culvert:** Covered channel, which is partially full
- **Water tunnel:** Long covered channels used to carry water through hill or obstruction

## Types of channels

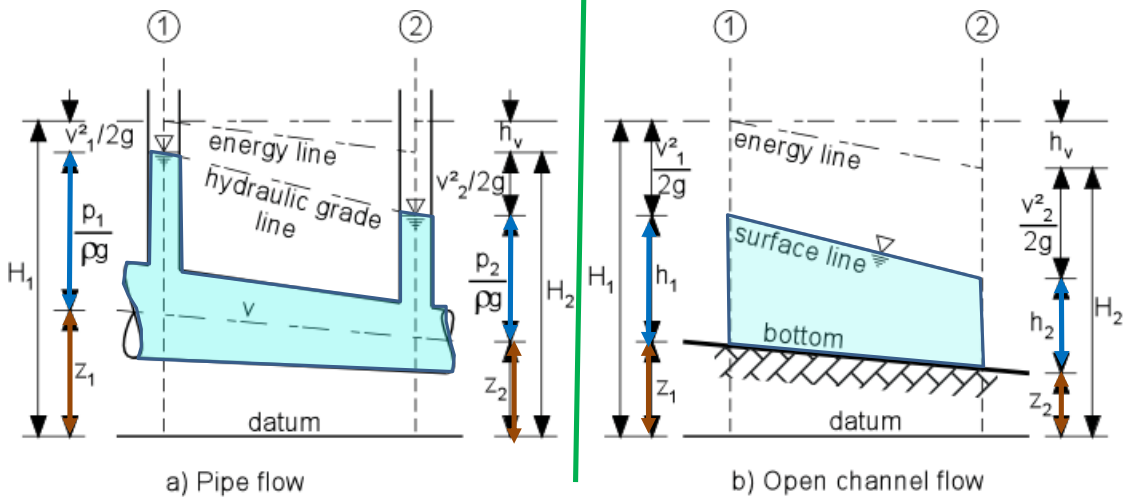
- |   |
|---|
| <ul style="list-style-type: none"> <li>• <b>Natural</b> : Rivers, estuaries</li> <li>• <b>Man made</b>: Irrigation canals, drainages, roadside gutters</li> </ul>   |
| <ul style="list-style-type: none"> <li>• <b>Prismatic</b>: Size, shape and slope of the channel are uniform</li> <li>• <b>Non-prismatic</b> : Size, shape and/or slope of the channel are not uniform<br/>→ Most of the natural channels</li> </ul>       |
| <ul style="list-style-type: none"> <li>• <b>Rigid channels</b> : Boundary is not deformable → Lined canals and non-erodible unlined canals</li> <li>• <b>Deformable boundary channels</b> : Bed width, depth of flow and slope undergo changes</li> </ul> |
| <ul style="list-style-type: none"> <li>• <b>Open channel</b> : No closed perimeter</li> <li>• <b>Closed channels</b>: Closed conduits that are only partially full</li> </ul>   |

## Flow Regimes

- |  |
|--|
| <ul style="list-style-type: none"> <li>• <b>Steady Flow</b> : Flow properties like depth or discharge do not change with time</li> <li>• <b>Unsteady flow</b>: Flow properties changes with time</li> </ul>  |
| <ul style="list-style-type: none"> <li>• <b>Uniform flow</b>: Flow properties remain constant along the length of the channel <ul style="list-style-type: none"> <li>– Flow in a prismatic channel</li> <li>– Gravity force is balanced by the frictional resistance along the bed and sides</li> </ul> </li> <li>• <b>Non-uniform flow</b>: Flow properties vary along the channel</li> </ul> |
| <ul style="list-style-type: none"> <li>• <b>Gradually varied flow</b>: Depth of flow varies gradually over a longer reach of channel</li> <li>• <b>Rapidly varied flow</b>: Depth of flow changes appreciably over a shorter length channel</li> </ul>   |
| <ul style="list-style-type: none"> <li>• <b>Laminar and turbulent flow</b>: Reynold's number <math>\leq 500</math> : Laminar,<br/><math>500 &lt; Re \leq 2000</math> : Transition,<br/><math>2000 &lt; Re</math> : Turbulent flow</li> </ul>   |
| <ul style="list-style-type: none"> <li>• <b>State of flow</b>: Critical flow (energy is minimum, <math>Fr = 1</math>), Super critical flow (<math>Fr &gt; 1</math>), Sub-critical flow (<math>Fr &lt; 1</math>)</li> </ul>   |

Open channel flow: Flows that are not entirely included within rigid boundaries

Pipe flow	Open channel flow
Flow takes place from higher to lower pressure	Flow takes place due to gravity
Reynold's number is important	Froude's number is important
Free surface is absent	Free surface is present
Water level is below the HGL	Water surface coincides with the HGL

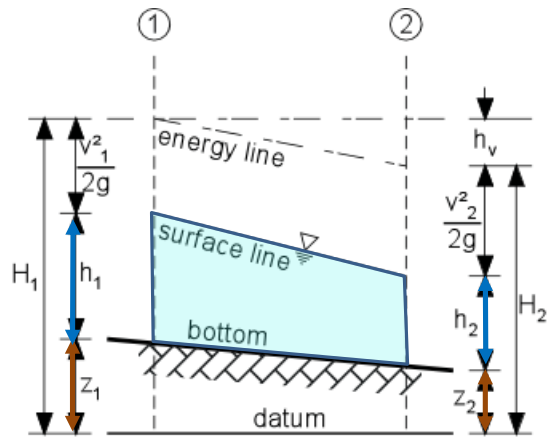


$S_o = \text{Bed slope } (z_1 - z_2 / L)$

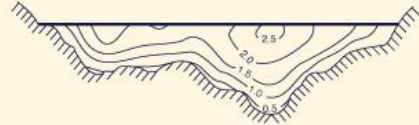
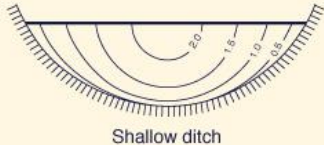
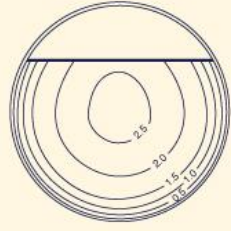
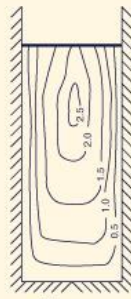
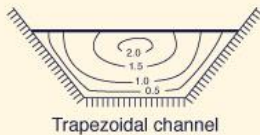
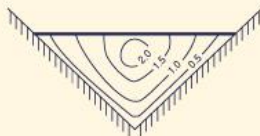
$S_f = \text{Slope of the total energy line}$   
 $= [ (z_1 + y_1 - v_1^2 / 2g) - (z_2 + y_2 - v_2^2 / 2g) ] / L$

$S_w = \text{Slope of the water surface}$   
 $= [ (z_1 + y_1) - (z_2 + y_2) ] / L$

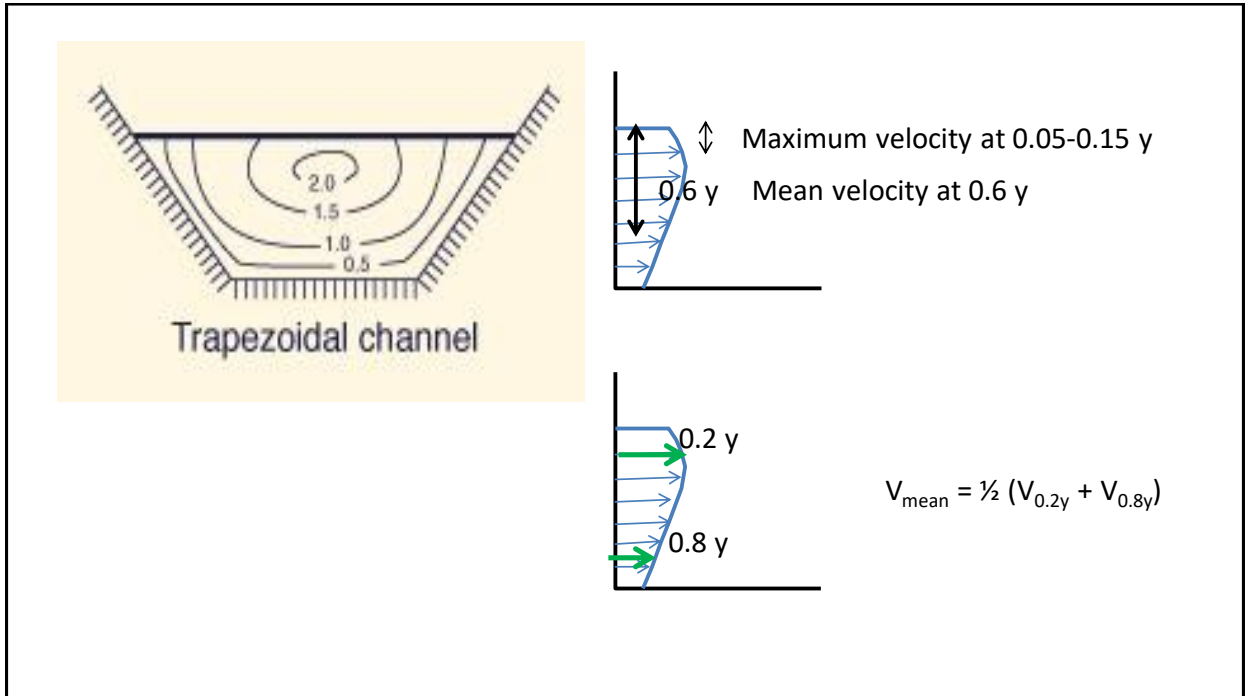
$dy/dx = \text{Slope of the water surface wrt bottom}$   
 $= y_1 - y_2 / L$



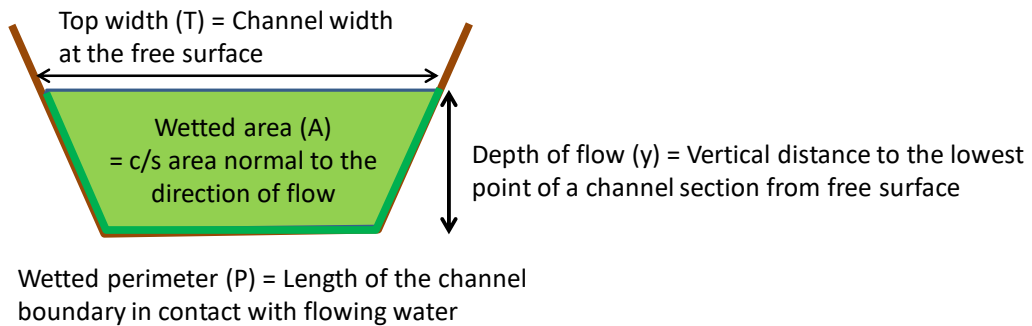
b) Open channel flow



Velocity profile



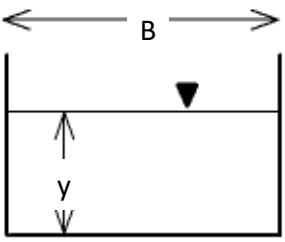
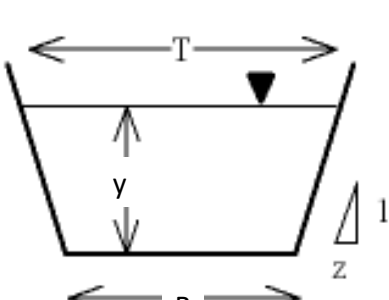
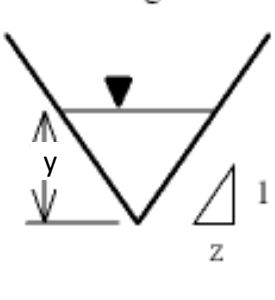
## Geometric properties of channel section

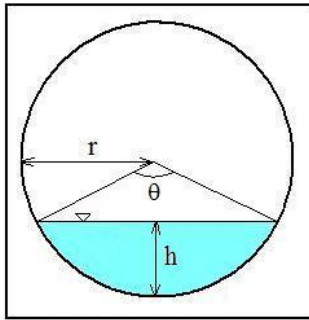


## Geometric properties of channel section

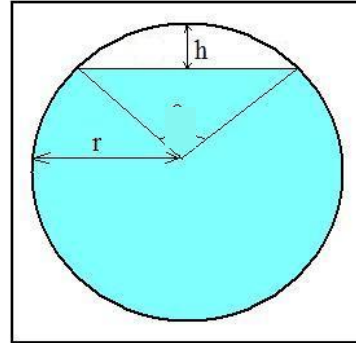
- Depth of flow ( $y$ ) = Vertical distance to the lowest point of a channel section from free surface
- Top width ( $T$ ) = Channel width at the free surface
- Wetted area ( $A$ ) = c/s area normal to the direction of flow
- Wetted perimeter ( $P$ ) = Length of the channel boundary in contact with flowing water

- Hydraulic radius =  $R$   
= wetted area / wetted perimeter  
=  $A/P$
- Hydraulic depth =  $D$   
= wetted area / top width =  $A/T$
- Section factor  $z = A \sqrt{D}$

Rectangular	Trapezoidal	Triangular
		
$A = By$ $P = B + 2y$ $R = By / (B+2y)$ $T = B$ $D = A/T = A/B=y$ $Z = A \sqrt{y}$	$A = (B+zy) y$ $P = B + 2y\sqrt{1+z^2}$ $R = A/P$ $T = B + 2zy$	$A = zy^2$ $P = 2y\sqrt{z^2 + 1}$ $T = 2zy$



Partially Full Pipe Flow Parameters  
(Less Than Half Full)



Partially Full Pipe Flow Parameters  
(More Than Half Full)

$$P = r\theta$$

$$A = \frac{r^2}{2}(\theta - \sin\theta)$$

## Summary

- Open channel flow: without a closed periphery
- HGL and water surface are same, gravitational force controls the flow
- Bed slope ( $S_o$ ), Slope of the total energy line ( $S_f$ ), Slope of the water surface ( $S_w$ ), slope of the water surface wrt. channel bottom ( $dy/dx$ )
- Characteristics :  $A$ ,  $P$ ,  $R$