USER GUIDE FOR

HYDRAULIC LABORATORY

ENVIRONMENTAL ENGINEERING

WAN NURHAZIRAH BINTI KAMARUZAMAN
ROZILAILI BINTI MUSTAPA

USER GUIDE FOR HYDRAULIC LABORATORY

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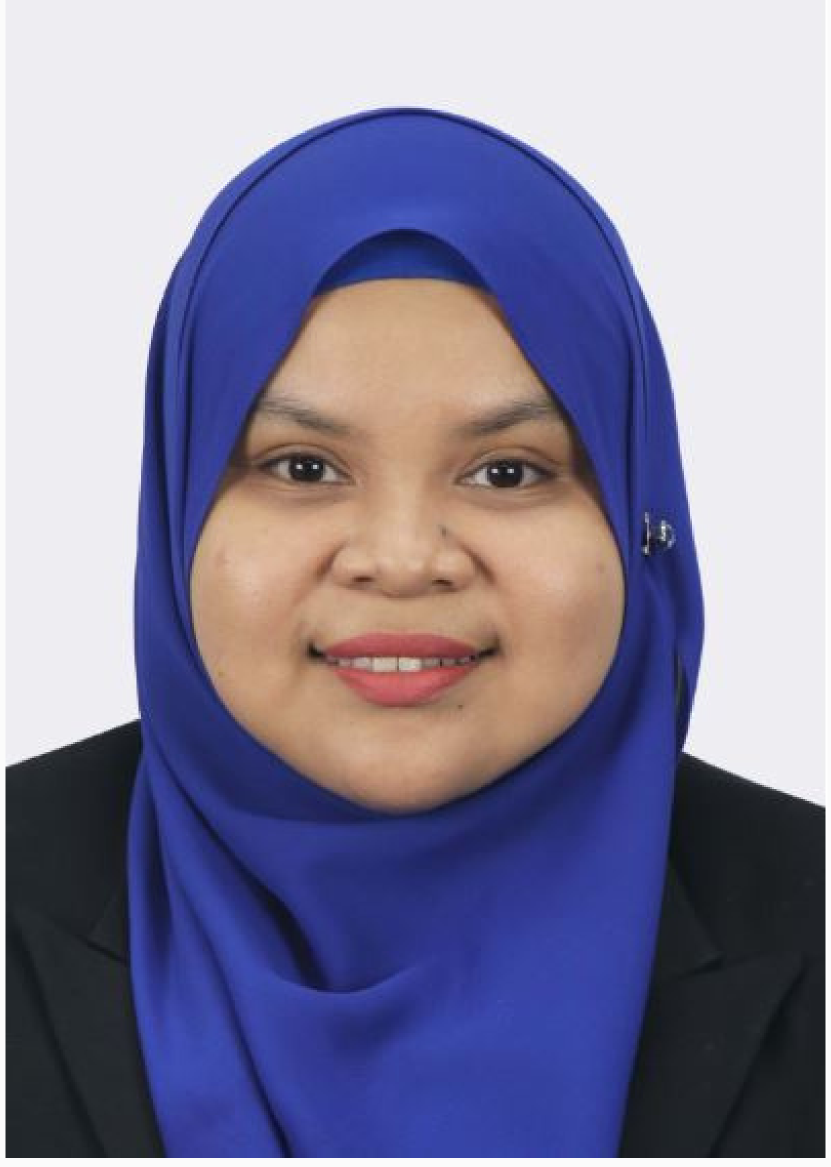
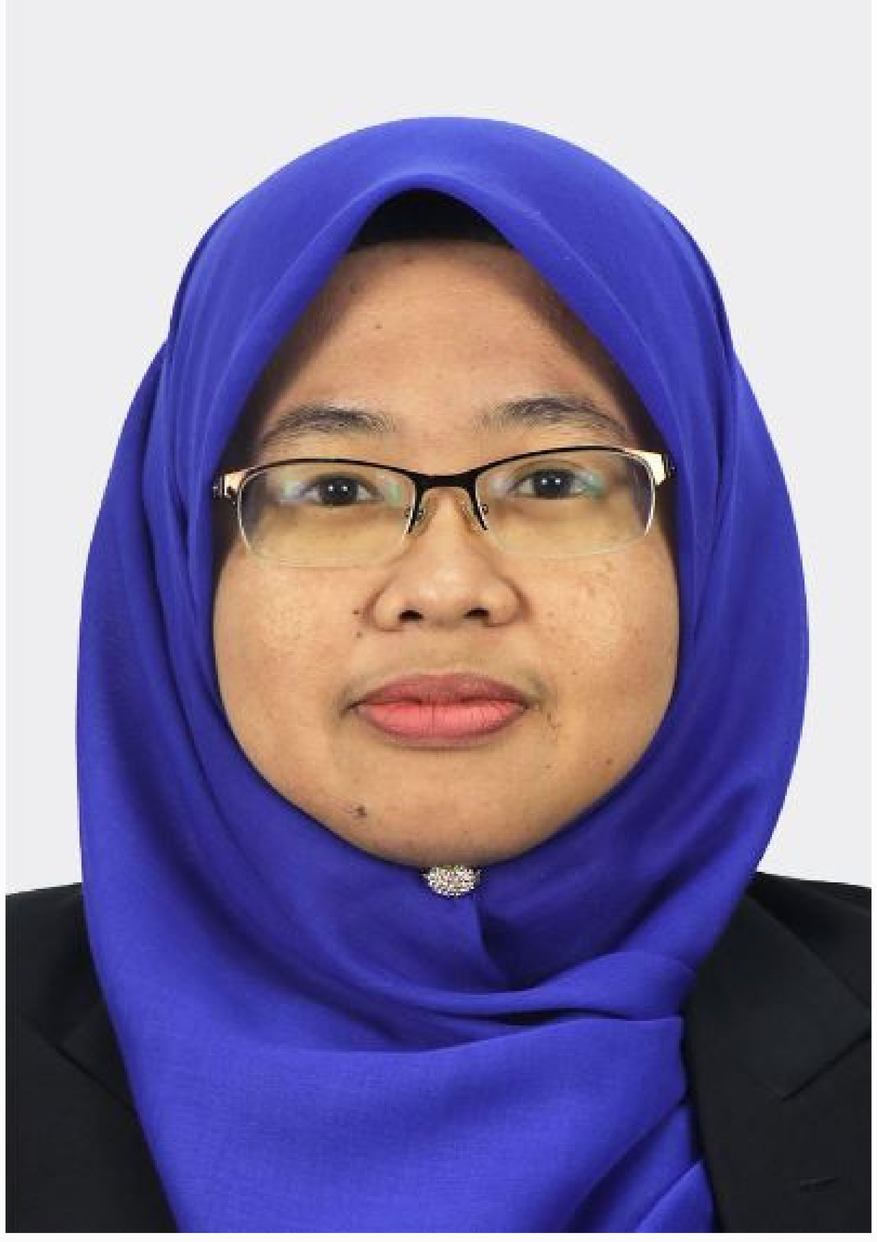
AUTHORS



Wan Nurhazirah binti Kamaruzaman

Lecturer
Departmen of Civil Engineering
Politeknik Sultan Idris Shah



Rozilaili binti Mustapa

Lecturer
Departmen of Civil Engineering
Politeknik Sultan Idris Shah

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PREFACE

This book aims to provide a broad base for Hydraulic Laboratory learning and subsequently pave the way for Diploma in Environmental Engineering or other qualifications. The book's emphasis is on practical knowledge to explain and justify the methods in conducting the experiment.

The book is consist of six experiment which are Fluid Properties, Hydrostatic Forces, Bernoulli's Theorem, Reynold Test, Uniform Flow for Open Channel and Hydraulic Jump. User Guide of Hydraulic Laboratory provide readers with the knowledge and understanding of application based on the concepts and the theories learned in the class. The emphasis of the book is on the method of conducting experiments, analysis and understanding its relationship with the theories learned. Hydraulic Laboratory which are the core of the environmental engineering field.

FLUID PROPERTIES

02

A. OBJECTIVES

To determine fluid density

B. THEORY

Fluid is a substance of flowing. It has no definite shape of its own but con forms to the shape of container. Fluid continues to deform when subjected to shear force. When fluid is at rest, no shearing forces can act on it and thus all forces are normal to the planes on which they act.

A liquid is a fluid which varies slightly with temperature and pressure. Under ordinary conditions, liquids are difficult to compress and therefore, they are being treated as mostly incompressible except in some situations such as water hammer, etc. It forms a free surface if exposed to atmosphere.

One of fluid property is density. Density is the most important value in mechanical calculation in fluid works. It is a measure of concentration of mass, i.e. mass per unit volume is called density.

Density;

$$\rho = \frac{\text{mass of fluid}}{\text{Volume of fluid}}$$

The density of liquid maybe considered constant as liquids are mostly incompressible while the density of gases changes with pressure and temperature. In SI units, mass density is expressed in kg/m^3. For water, ρ is 1000 kg/m^3

Specific Gravity;

$$s = \frac{\text{Density of liquid}}{\text{Density of water}}$$

Specific Weight;

$$\omega = \text{Density x gravity}$$

C. APPARATUS

- Measuring cylinder
- Thermometer
- Weighing balance
- Water
- Oil

D. PROCEDURE

1. Weight an empty measuring cylinder.
2. Fill in water into the measuring cylinder until desired volume. Record the volume.
3. Weight the measuring cylinder with water.
4. Record the water temperature.
5. Repeat the procedure for different volume.
6. Replace water with oil and repeat step 1 to 5.
7. Replace water with other solution and repeat step 1 to 5.

E. ANALYSIS DATA/ RESULTS

Analysis table of Fluid Characteristic experiment

	Water			Oil			Solution :__________		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
Mass of empty measuring cylinder, (kg)									
Mass of measuring cylinder containing substance, (kg)									
Mass of substance, (kg)									
Volume of substance, (m^3)									
Temperature, °C									
Density, (kg/ m^3)									
Average density									
Specific Gravity									
Specific Weight									

F. DISCCUSSION

In your discussion should be include

1. Compare the experimental and theoretical value.
2. Discuss the factors that influenced the value.
3. Show all the calculation involve.

USER GUIDELINE FOR HYDRAULIC LABORATORY

HYDROSTATIC FORCES

07

CENTRE OF PRESSURE AND HYDROSTATICS FORCES ACTING ON A:

i. Partially Submerged Body

ii. Fully Submerged Body

A. OBJECTIVES

a. To understand the concepts of hydrostatic forces acting on submerged bodies.

b. To verify the location of centre of pressure

c. To determine the magnitude and position of hydrostatic forces from observed data and compare the value to the theoretical value.

B. THEORY

Centre Of Pressure

The hydrostatic pressure of liquids is the “gravitational pressure” ρ_{hyd}. It arises due to the intrinsic weight as the depth h, increases, and is calculated from :

$$P_{hyd} = \rho \cdot g \cdot h$$

ρ = Density of water

g = Acceleration due to gravity (9.81 m/s)

h = Distance from liquid surface

To calculate forces acting on masonry dams or ships hulls, for example, from the hydrostatics pressure, two step are required:

i. Reduce the pressure load on an active surface down to a resultant force Fr, which is applied at a point of application of force, the “centre of pressure” and vertical to the active surface.

ii. Determine the position of this centre of pressure by determining a planar centre of force on the active surface.

It is first demonstrated how the center of pressure can be determined. The resultant force F_r is then calculated.

To Determining The Centre Of Pressure

At a water level s, **below the 100mm** mark, the height of the active surface changes with the water level. If the water level is above that mark, the height of the active surface is always 100mm.

For water level s < 100mm : (Pressure has a triangular profile)

$$e = {}^{1}/_{6}\ s \qquad (1)$$

$$l_D = 200mm - {}^{1}/_{3}\ s \qquad (2)$$

For water level s > 100mm : (Pressure has a trapezoidal profile)

$$e = {}^{1}/_{12}\cdot {}^{(100\ mm^2)}/_{s-50\ mm} \qquad (3)$$

$$l_D = 150mm + e \qquad (4)$$

Meaning:

s = water level

e = Distance of centre of pressure D from planar centre of force C of the active surface

l_D = Distance to centre of motion of the unit:

To Determining The resultant Force

The resultant force corresponds to the hydrostatic pressure at the planar centre of force C of the active surface. Thus, the height of water level ,s must again be differentiated:

Meaning:

A_{act} = Superficial content of active surface

b = 74 mm (width of liquid vessel)

p_c = Hydrostatic pressure at planar centre of force

F_r = Resultant force for hydrostatic pressure on active surface

For s < 100mm:

$$p_c = \rho \cdot g \cdot \tfrac{1}{2} s \quad \text{and} \quad A_{act} = s \cdot b \qquad (5)$$

For s > 100mm:

$$p_c = \rho \cdot g \cdot (s - 50\text{mm}) \quad \text{and} \quad A_{act} = 100\text{mm} \cdot b \qquad (6)$$

The resultant force is produced as

$$F_r = p_c \cdot A_{act} \qquad (7)$$

Equilibrium Of Moment

Calculated variables :

F_G = Appended weight

L = Lever arm of appended weight referred to centre of a motion, O

To check the theory, the moment equilibrium towards point , O can be established and checked:

$$\sum M^{(0)} = 0 \quad : \quad F_G \times L = F_r \times l_D \qquad (8)$$

C. APPARATUS

The apparatus shown in Figure 1 is designed in a way that only the moment due to hydrostatics pressure distribution on the vertical end of water vessel should be included. The water vessel is designed as a ring segment with constant cross – section. The top and bottom faces are concentric circular arcs centre on the pivot so that, the resultant hydrostatic force at every point passes through the pivot axis and does not contribute to the moment. The radius of the external and internal arcs are 200 and 100mm, respectively and the width of the vessel is 74mm.

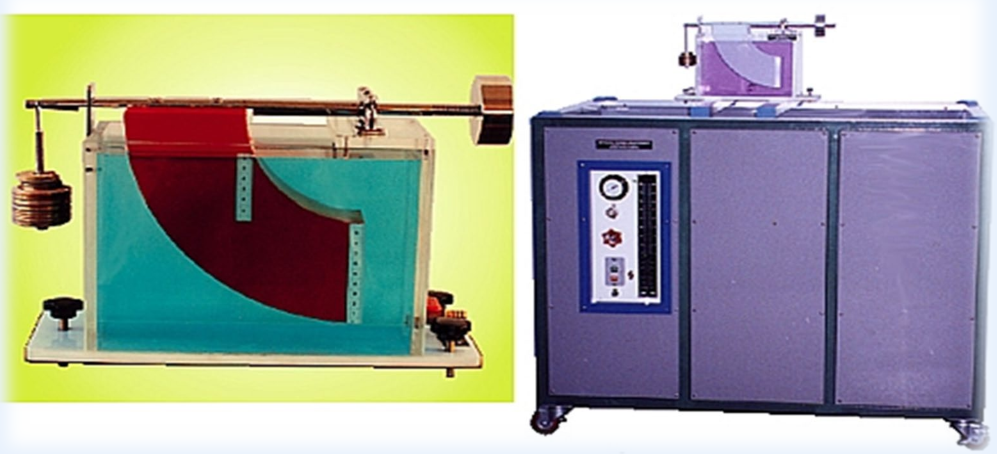

Figure 1 : Hydrostatic Pressure Apparatus

Figure 2 is a sketch of the device used to measure the center of pressure on a submerged vertical surface. It consists of an annular sector of solid material attached to a balance beam. When the device is properly balanced the face of the sector that is not attached to the beam is directly below (coplanar) with the pivot axis. The solid sector and the balance beam is supported above a tank of water.

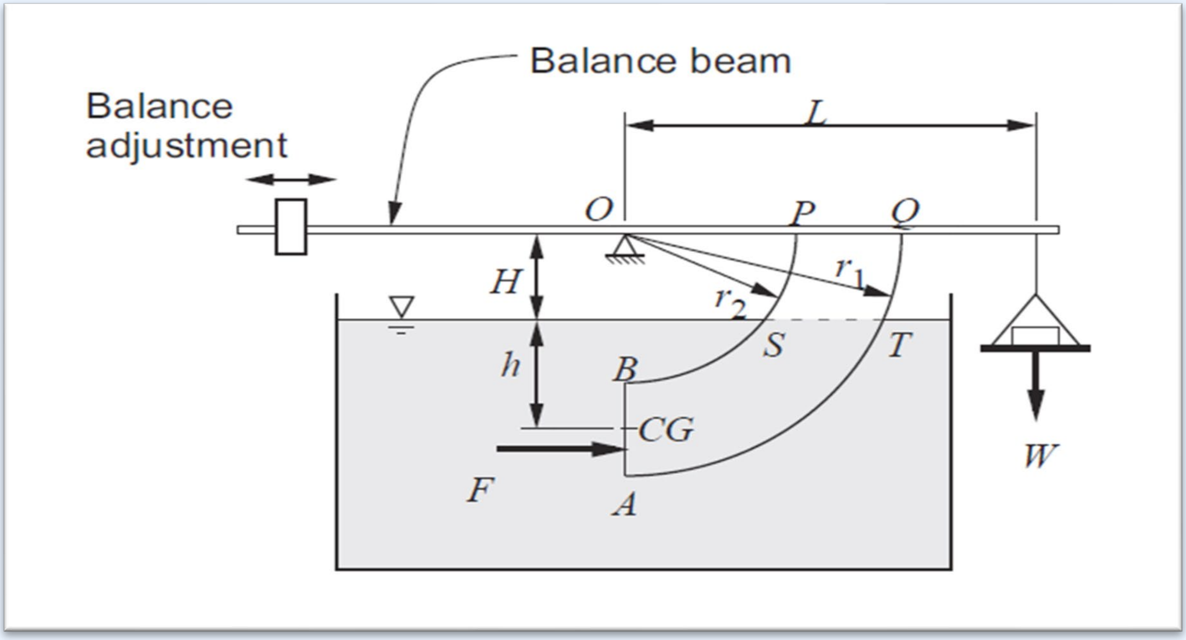

Figure 2 :

Apparatus For Measuring The Location Of The Center Of Pressure.

D. PROCEDURE

1. Place the hydrostatic pressure apparatus on a horizontal, waterproof surface.
2. Set the water vessel to an angle of α = 0° using the detent .
3. Counterbalance the unit with a rotating slider
4. The stop pin must be precisely in the middle of the hole for this. Alternatively, use the red mark to balance the lever arm precisely.
5. Mount the rider, set the lever arm on the scale (e.g. L = 280mm)
6. Top up with water until the unit is balanced or until the red mark (stop pin at centre of hole)
7. Read off water level, s and enter it in the prepared worksheet.
8. Increased the appended weights in increment of 20g (or more, as appropriate) and repeat the experiment to record 7 sets of observation.

E. ANALYSIS DATA/ RESULTS

Experiment: Centre Of Pressure And Hydrostatic Forces On Submerged Bodies

Data Observed :

(i) For a Partially Immersed Surface:

Lever Arm,L = 280 mm

= 0.28 m

Analysis table of Hydrostatic force experiment

(Partially Immersed Surface)

Observation No.	Appended Weights, (N)	Water Level Readings, S, (m)	Calculated Lever Arm, l_D (m)	Resultant Force, Fr (N)	Theoretical Analysis			Percentage Error Between The Forces (%)
					Area, A (m^2)	Position of Centroid, ý (m)	Hydrostatic Force $F_H = \rho.g.A.\acute{y}$ (N)	

Experiment : Centre Of Pressure And Hydrostatic Forces On Submerged Bodies

Data Observed :

(ii) For a fully immersed surface :

Lever Arm, L = 280 mm

= 0.28 m

Analysis table of Hydrostatic force experiment

(Fully Immersed Surface)

Observation No.	Appended Weights, (N)	Water Level Readings, S, (m)	Calculated Lever Arm, I_D (m)	Resultant Force, Fr (N)	Theoretical Analysis			Percentage Error Between The Forces (%)
					Area, A (m^2)	Position of Centroid, ý (m)	Hydrostatic Force $F_H = \rho.g.A.ý$ (N)	

F. DISCCUSSION

In your discussion should be include

1. Discuss the percentage of error for both partially immersed and fully immersed plate.
2. Explain why are there differences between the resultant forces and hydrostatic forces.
3. State some examples of the practical applications of hydrostatic forces in civil engineering. Discuss.

BERNOULLI'S THEOREM

A. OBJECTIVES

To investigate the validity of Bernoulli's Theorem as applied to the flow of water in a venturi meter.

B. THEORY

Considering flow at two sections in a pipe, Bernoulli's equation may be written as:

$$\frac{V_1{}^2}{2g} + \frac{P_1}{\rho g} + Z_1 = \frac{V_2{}^2}{2g} + \frac{P_2}{\rho g} + Z_2$$

Hence, if Bernoulli's Theorem is obeyed:

$H = \frac{V_1{}^2}{2g} + h$ and is constant a tall sections along the duct.

C. APPARATUS

Bernoulli's Theorem apparatus

D. PROCEDURES

1. Record horizontal distance between inlet with piezometer tubes and internal diameter at every section.
2. Start pump.
3. Open the supply valve in Venturi metre and control valve in hydraulic bench.
4. Fill the apparatus and piezometer tubes with water to discharge all pockets of air from the system and ensure all connecting pipes are free from air.
5. Discharge all pockets of air by opening air hole above piezometer. After that, close the air hole.
6. Turn off pump. Open air hole so that water level in piezometer decrease. When water level still at the middle, close the air hole. You will find out that water level remained at his position

E. ANALYSIS DATA/ RESULTS

Flow rate, Q (m^3/s) =______________________________

Analysis table of Bernoulli's Theorem experiment

Tube No.	Diameter of cross section (mm).	Area of cross section, m^2.	Manometer level (mm)	Fluid velocity, m/s	Pressure head, m.	Kinetic head, m.	Total head, m
1	25.0						
2	13.9						
3	11.9						
4	10.7						
5	10.0						
6	25.0						

F. DISCCUSSION

In your discussion should be include

1. Discuss the error occur while carry out the experiment which is effect to the data
2. Explain why are there differences of total head with diameter cross section of the tube.

REYNOLD TEST

A. OBJECTIVES

a. To observe the laminar, transitional, turbulent flow and velocity profile

b. To determine the exact Reynolds number for each flows.

B. THEORY

There are in general three types of flow in pipes, Laminar, turbulent and transition flow. The type of flow is determined from the Reynold Number by Professor Osborne Reynold (1883). Reynold number formula is generally defined as :

$$Re = \frac{\rho V d}{\mu} \quad \text{or} \quad Re = \frac{V d}{v}$$

Where,

Re = Reynold Number

ρ = Density (kg/m^3)

V = Velocity based on the actual cross section area of the duct or pipe (m/s)

μ = Dynamic viscosity (Ns/m^2)

v = Kinematic viscosity (m^2/s) – $0.9 \times 10^{-6} m^2/s$

d = Hydraulic diameter (m) – 10mm

In Reynold experiment, the water from the tank was allowed to flow through the glass tube. The velocity of flow was varied by the regulating valve. A liquid dye having same specific weight as water was introduced into the glass tube as Figure 1.

Having three observations were made by experiment, Firstly when the velocity of flow was low, the dye filament in the glass tube was in the form of straight line. This straight line of dye filament was parallel to the glass tube, which was the case of laminar flow as shown in Figure 2 (a). Secondly, with the increase of velocity of flow the dye-filament was no longer a straight-line but it become a wavy one as show in Figure 2(b) This shows that flow is no longer laminar, which was the case of Transition flow. Finally with further increase of velocity of flow, the wavy dye-filament broke-up and diffused in water as shown Figure 2 (c). This means that the fluid particles of the dye at this higher velocity are moving in random fashion, which shows the case of turbulent flow. This in case of turbulent flow the maxing of dye-filament and water is intense and flow is irregular, random and disorderly.

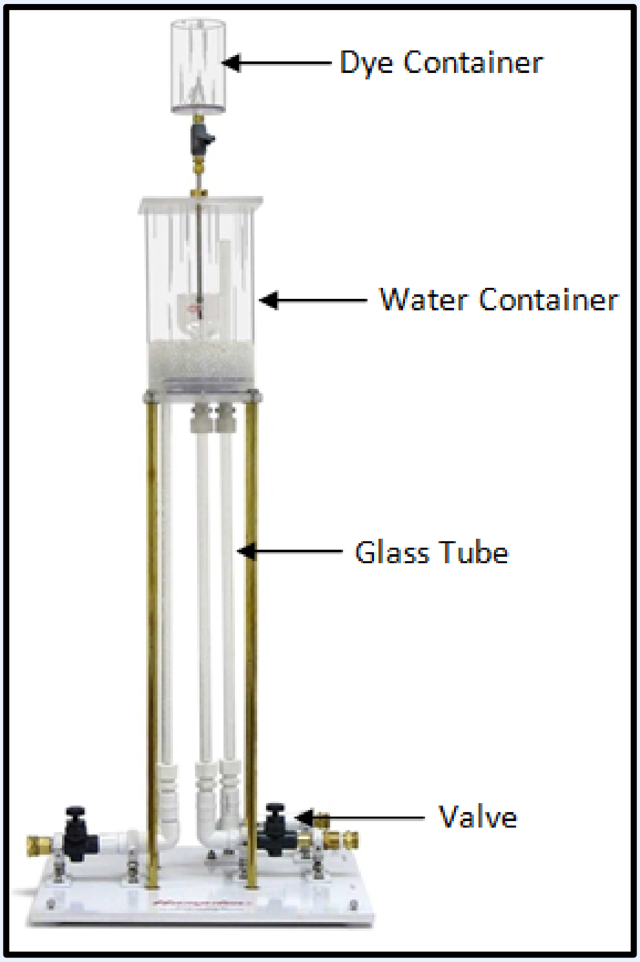

Figure 1 : Osborne Reynolds Apparatus

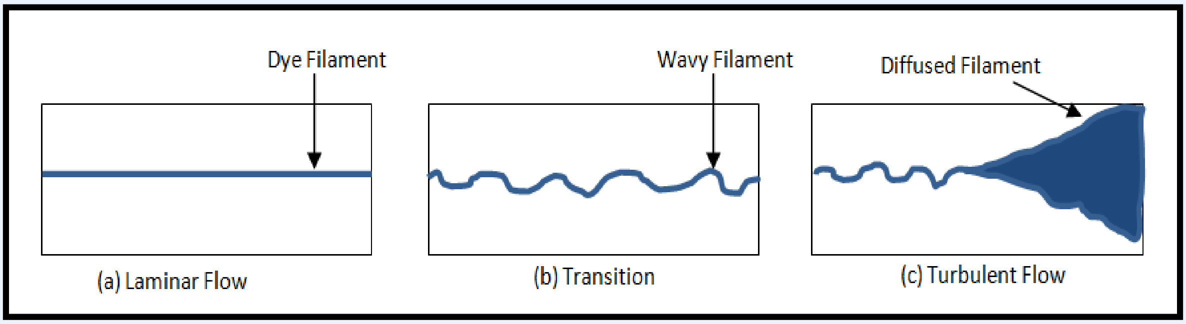

Figure 2 : Type of flow

The quantity $\frac{\rho V d}{\mu}$, is dimensionless quantity, In case of circular pipe if R_e <2000 the flow is laminar. R_e between 2000 and 4000, the transition legion or state exists. If R_e is greater than 4000, the flow is turbulent.

C. APPARATUS

- Reynolds Machine
- Inlet pipe
- Bench feed
- Inlet Valve
- Flow control
- Syrup liquid

D. PROCEDURE

1. Fill the reservoir with dye, position the apparatus on the bench and connect the inlet pipe to bench feed. Lower the dye injection until it is just above the bell mouth inlet. Close the flow control valve. Open the bench inlet valve and slowly fill Head tank to the overflow level, then close the inlet valve. Open and close flow control valve to admit water to the flow visualization pipe. Allow the apparatus to stand at least ten minutes before proceedings
2. Open in inlet valve slightly until water trickles from the outlet pipe. Fractionally open the control valve and adjust dye control valve until slow flow with dye indication is achieved. Measured and note the flow rate
3. Repeat for increasing flow rates by progressively opening the flow control valve. Take a specific measurement of flow rate at the critical condition.
4. Repeat the procedure for decreasing flow rates, taking a specific measurement of flow rate at the critical condition.

E. ANALYSIS DATA/ RESULTS

a. Laminar Flow

Analysis table of Reynold number for Laminar flow

Volume of Water, V (m^3)	Time, T (s)	Flow rate, Q (m^3/s) Q=V/t	Velocity in pipe, v (m/s)	Reynolds Number $R_e = \frac{\rho v d}{\mu}$	Visual Dye Condition (Sketch)
Average R_e					

b. Turbulent Flow

Analysis table of Reynold number for Turbulent flow

Volume of Water, V (m^3)	Time, T (s)	Flow rate, Q (m^3/s) Q=V/t	Velocity in pipe, v (m/s)	Reynolds Number $R_e = \frac{\rho v d}{\mu}$	Visual Dye Condition (Sketch)
Average R_e					

c. Transition Flow

Analysis table of Reynold number for Transition flow

Volume of Water, V (m^3)	Time, T (s)	Flow rate, Q (m^3/s) Q=V/t	Velocity in pipe, v (m/s)	Reynolds Number $R_e = \frac{\rho v d}{\mu}$	Visual Dye Condition (Sketch)
Average R_e					

F. DISCCUSSION

In your discussion should be include

1. Calculate the Reynold Number (Re) and identify the type of flow
2. Compare and discus the value of $Re_{Experimental}$ and $Re_{Theorycal}$ for each type

UNIFORM FLOW FOR OPEN CHANNEL

A. OBJECTIVES

Determine the Manning roughness coefficient for the wall surface and open channel.

B. THEORY

Uniform flow in the canal is the channel width and depth of water at the base is the same base on which the section along the canal. In this case the velocity, n can be determined using the Manning formula, :

$$Q = \frac{A m^{\frac{2}{3}} i^{\frac{1}{2}}}{n}$$

Where :	m	=	Hydraulic mean depth = A/P
	A	=	Cross section area
	P	=	Wetted perimeter = b + 2d
	b	=	Width of the channel
	d	=	depth of the channel
	i	=	Bed of slope
	n	=	Manning roughness coefficient

Manning roughness coefficient, n indicates the degree of roughness of a surface of the canal. Although these values changes according to water depth, it is not obvious and can be regarded as equal.

C. APPARATUS

Open channel apparatus

D. PROCEDURE

1. Start pump and open the valve slowly.
2. Get to the depth of water at any part along the channel is uniform. Use the gauge to make sure this point.
3. Get the high of the water by using a point gauge and manometer reading, x for the each flow determined.
4. Record the reading in the table provided
5. Get six (6) with increasing flow rate reading.

E. ANALYSIS DATA/ RESULTS

i. Slope = ________________

Analysis table of Manning Roughness for open channel experiment

Flow Rate, Q (m^3/s)	Depth of Water, H (m)	Area Cross section, A (m^2)	Wet Parameter (P)	Hydraulic gradient , R (m)	Flow Rate, Q (m^3/s)	Manning roughness value, n
			Average roughness value			

ii. Slope = ________________

Analysis table of Manning Roughness for open channel experiment

Flow Rate, Q (m^3/s)	Depth of Water, H (m)	Area Cross section, A (m^2)	Wet Parameter (P)	Hydraulic gradient , R (m)	Flow Rate, Q (m^3/s)	Manning roughness value, n
Average roughness value						

F. DISCCUSSION

In your discussion should be include

1. Calculate the Manning roughness value
2. Compare and discus the value of $n_{Experimental}$ and $n_{Theorycal}$

HYDRAULIC JUMP

A. OBJECTIVES

a. To observe and investigate the relationship between Alternate Depth Flow (h) and Specific Energy (E) when Discharge (Q) are constant.

b. To study the force and energy conditions in a hydraulic jump.

B. THEORY

When spillways or other similar open channels are opened by the lifting of a gate, liquid passing below the gate has a high velocity and an associated high kinetic energy. Due to the erosive properties of a high velocity fluid, it may be desirable to convert the high kinetic energy (e.g. high velocity) to a high potential energy (e.g., a deeper stream). The problem then becomes one of rapidly varying the liquid depth over a short channel length. Rapidly varied flow of this type produces what is known as a hydraulic jump.

A hydraulic jump can be defined as an abruptly increase in depth in the direction of flow when a change from fast to slow flow occurs in open channel.

It is mainly used to dissipate energy and reduce the velocity of flow and as a mixing device, and is caused by changing the slope (free jump) or by placing a flow weir in the bed of the channel (force jump).

Due to the energy losses in a hydraulic jump, the equality between energy upstream and downstream the jump can't be used in the analysis of flow, however, a force analysis of can be used (figure 1).

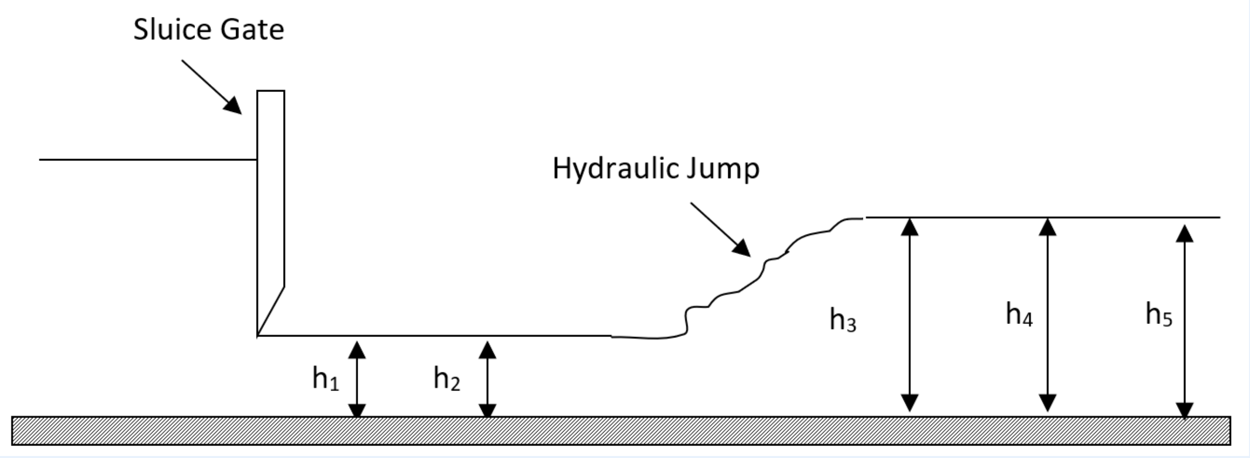

Figure 1 : The hydraulic jump illustration

Specific Energy, E between point 1 and 2, in terms of water depth can be written as:

$$E_1 = h_1 + \left[\frac{(V_1)^2}{2g}\right]$$

$$E_2 = h_2 + \left[\frac{(V_2)^2}{2g}\right]$$

and E_3 is usually less than E_1 and E_2

Where ; Q = water flow rate (m^3/s) / Channel depth

h = depth of water (m)

$E_2 - E_3 = \Delta E$,

where ΔE = Energy loss due to hydraulic jump

Graph of Specific energy when Q are constant as shown in Figure 2

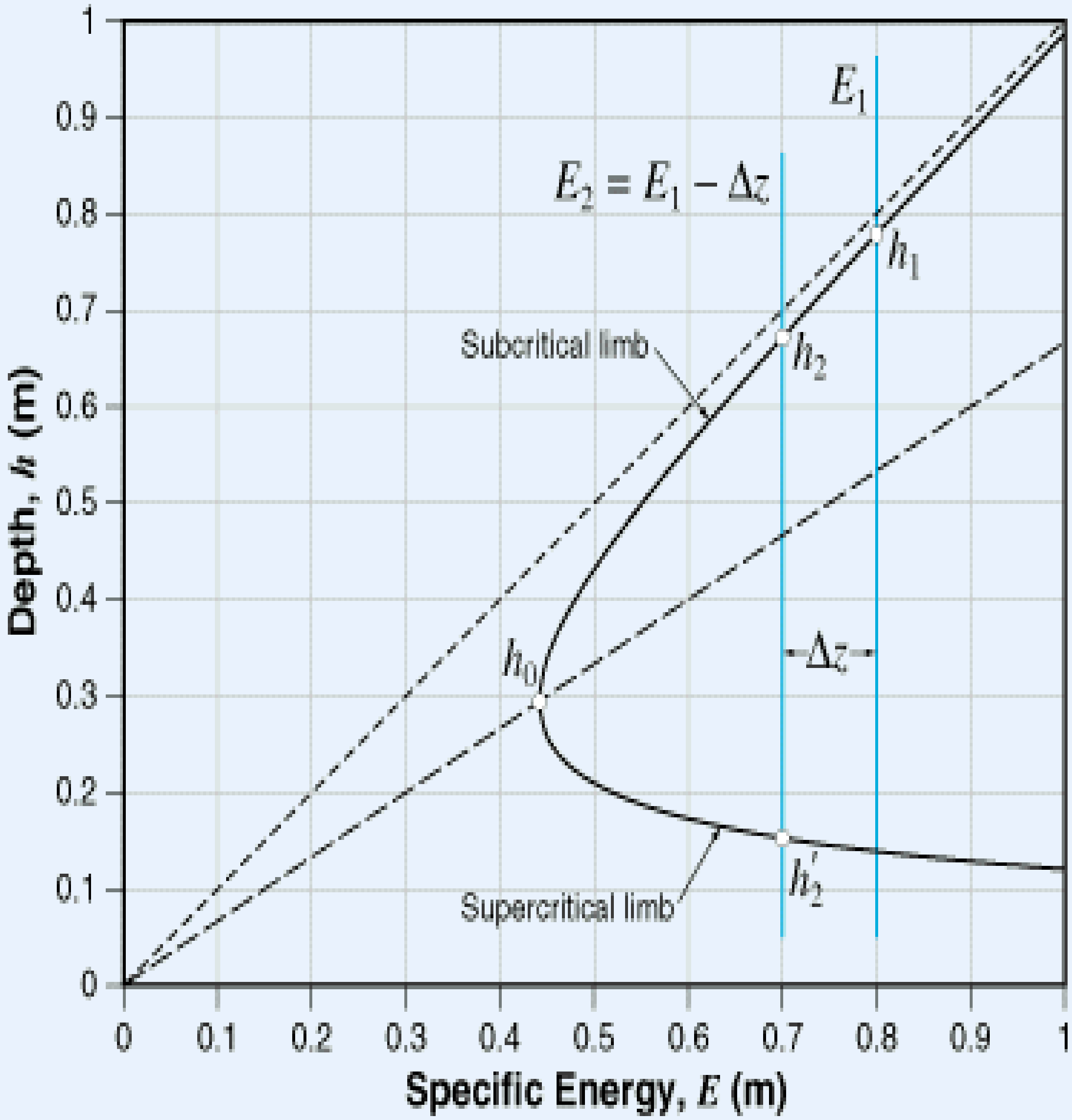

Figure 2 : Graph of specific energy

C. PROCEDURES

1. Make sure the apparatus is in good condition and set the channel slope to desired position, normally 0%
2. Position the sluice gate at multipurpose teaching flume.
3. Switch on the water pump, lets the water flow below the sluice gate and adjust the cock to get the stable flow.
4. When the water flow was stable, started to measures the height of water (h_1, h_2, h_3, h_4, and h_5) and record the water flow rate (Q).
5. Change the water flow rate (Q) and repeat procedure no.4 with at least 3 reading of water flow rate.

D. ANALYSIS DATA/ RESULTS

Height of water with different flowrate

Q (m^3/s)	h_1(m)	h_2(m)	h_3(m)	h_4(m)	h_5(m)

Analysis table of Hydraulic Jump experiment for 1st flowrate

	Depth, h(m)		Area ,A (m^2)	Velocity, v (m/s)	$v^2/2g$ (m)	Specific Energy, E(m)
Q_a = ____m^3/s	h_1					
	h_2					
	h_3					
	h_4					
	h_5					

Analysis table of Hydraulic Jump experiment for 2nd flowrate

	Depth, h(m)		Area ,A (m^2)	Velocity, v (m/s)	$v^2/2g$ (m)	Specific Energy, E(m)
Q_b = ____m^3/s	h_1					
	h_2					
	h_3					
	h_4					
	h_5					

Analysis table of Hydraulic Jump experiment for 3rd flowrate

	Depth, h(m)		Area ,A (m^2)	Velocity, v (m/s)	$v^2/2g$ (m)	Specific Energy, E(m)
Q_c = ____m^3/s	h_1					
	h_2					
	h_3					
	h_4					
	h_5					

REFERENCES

F. DISCCUSSION

In your discussion should be include

1. From the data in last table, plot a graph of specific energy (water depth versus specific energy) for $Q_a - Q_c$
2. Discuss the factors may be effect to the results.

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POLITEKNIK MALAYSIA
SULTAN IDRIS SHAH

Politeknik Sultan Idris Shah
Sg. Lang,
45100 Sg, Air Tawar
Selangor

Telephone No : 03 3280 6200
Fax No : 03 3280 6400
Website : https://psis.mypolycc.edu.my

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