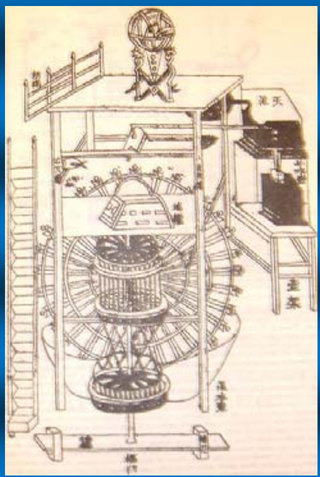
The City College of New York

HYDRAULIC ENGINEERING LABORATORY

EXPERIMENTS

FOR

CE 365, HYDRAULICS AND HYDROLOGY



Department of Civil Engineering
The City College of New York

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<u>Experiment 1</u>

Center of Pressure on Partially and Fully Submerged Plates

Objective

- To determine the center of pressure on a partially submerged and fully submerged plane surface.

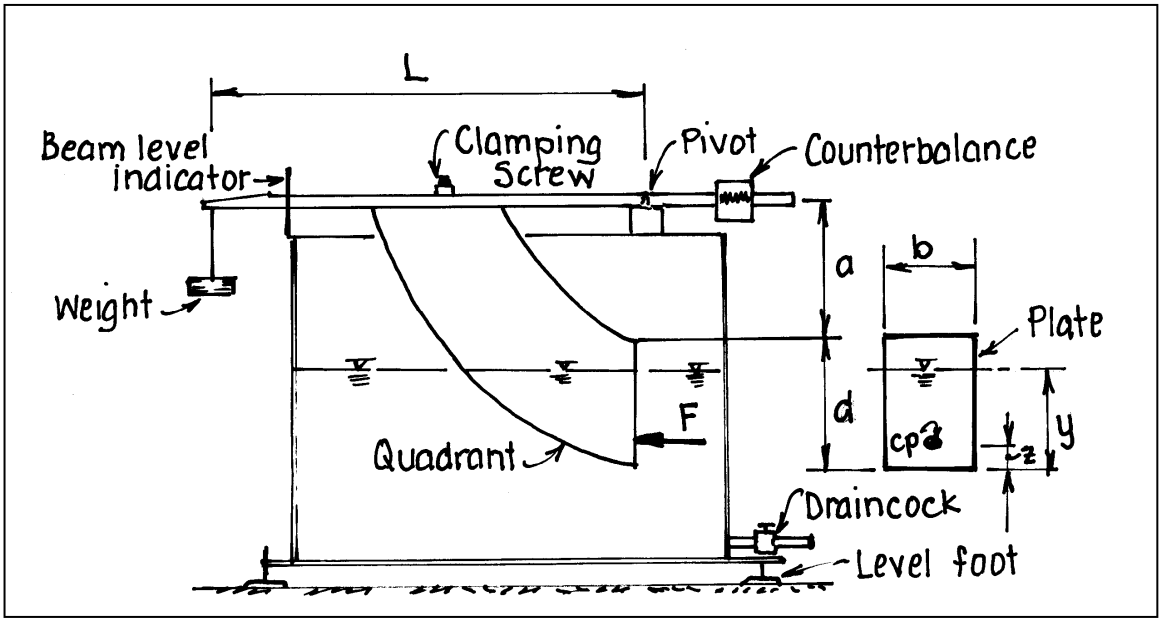

Figure 1-1 Hydrostatic Pressure Apparatus

Procedure:

1. Place the quadrant on the two dowel pins and, using clamping screw, fasten it to the balance arm.
2. Level the Plexiglas tank by adjusting the screwed feet. The level is indicated on the circular spirit level.
3. Hang the balance pan and make the balance arm horizontal by moving the counter balance weight.
4. Measure a, L, d, b as shown in Figure 1-1.
5. Close the drain cock and fill the tank with water until the water level reaches the bottom edge of the quadrant. Level the arm by moving the counterbalance weight.
6. Place 50 grams on the balance pan and slowly add water to the tank until the balance arm is again horizontal. Record the water level (y) on the quadrant and the weight on the balance pan (W = mg).

7. Repeat Step 6 for several increments placing about 50 grams on the balance pan for each step until the water level reaches the top of the quadrant end face. Repeat Step 6 one more time so that the quadrant end face is totally submerged for this last run.
8. Remove each increment of weight and allow the water to drain until the balance arm is level. Note the weights and water levels for each increment as the weights are removed.

Interpretation of Results:

You want to find the center of pressure on the plate for each reading taken during filling and draining the tank. To do this, take moments about the pivot. Thus,

$$-mg(L) + F(a + d - z) = 0 \quad (1\text{-}1)$$

in which *z* = the height of the center of pressure above the bottom of the plate. The force on the submerged plate is given by,

$$F = \rho g \bar{y} A \text{ with } \bar{y} = \frac{1}{2} y \text{ and } A = by \quad (1\text{-}2)$$

Therefore,

$$F = \rho g b \frac{y^2}{2} \quad (1\text{-}3)$$

Substituting,

$$-mg(L) + \left(\frac{\rho g y^2 b}{2}\right)(a + d - z) = 0 \quad (1\text{-}4)$$

Solving for *z* we get,

$$z = a + d - \frac{2mL}{\rho y^2 b} \quad (1\text{-}5)$$

Note that ρ = 1 gm/cm^3 or 1000 kg/m^3.

For each of the readings obtained during filling and draining the tank calculate the height above the bottom of the plate of the center of pressure (*z*) and plot the calculated values of *z* against *y*. Fit a straight line to the data.

Questions:

1. What is the slope of the straight line?
2. How far above the bottom of the plate should the center of pressure be?
3. Theoretically, what should the value of the slope be? Did you get this value? If not, why not?
4. If the plate had been a isosceles triangle with its base at the bottom, what would the theoretical slope of the line be?

Data:

Water temperature=

a= 10.2 cm; L=27.5 cm; d= 10.0 cm; b=7.5 cm

Tank Filling		Tank Draining	
m (gm)	y (cm)	m (gm)	y (cm)

Experiment 2

Fluid Friction- and Local Losses for Water Flow through Pipes

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Objective:

- To determine fluid friction coefficient and Reynolds' number for flow of water through a pipe having smooth bore.
- Head loss due to fluid friction and velocity for flow of water through smooth pipes.
- Head loss coefficients due to pipe fittings at a sudden expansion and a sudden contraction.

Theory:

For a circular pipe flowing full, the head loss due to friction may be calculated from the formula:

$$h = \frac{fLV^2}{2gD}$$

L is the length of the pipe between tappings, D is the internal diameter of the pipe, V is the mean velocity of water through the pipe in m/s, g is the acceleration due to gravity in m/s^2 and f is the pipe friction coefficient.

Reynolds' number, Re, can be found using the following equation:

$$Re = \frac{\rho VD}{\mu}$$

where μ is the dynamic viscosity and ρ is the density.

In addition to the spatially continuous head loss due to friction, local head losses occur at changes of cross section (Ex.: elbows, bends, contractions, expansions or valves). These local losses are referred to as 'minor' losses since in long pipelines their effect may be small in relation to the friction loss.

The loss coefficient for sudden expansion is:

$$h_L = \left(\frac{V_1^2 - V_2^2}{2g}\right) = K_L\left(\frac{V_1^2}{2g}\right), K_L = (1 - \frac{A_1}{A_2})^2$$

The loss coefficient for sudden contraction is:

$$K_c = \frac{h_L}{\left(\frac{V_2^2}{2g}\right)}$$

h_L = Head loss (m)

V_2 = Mean velocity in downstream section of Diameter D_2 (m/s)

g = Acceleration due to gravity (m/s^2)

The loss coefficient for pipe bends is:

$$K_b = \frac{h_b}{\left(\frac{V_2^2}{2g}\right)}$$

h_b = Loss of head in pipe bends (m)

V_2 = Mean velocity (m/s)

g = Acceleration due to gravity (m/s^2)

Requirements for parallel pipe flow:

$$h_{L1} = h_{L2}$$

$$Q_T = Q_1 + Q_2$$

Procedure:

1. Prime the pipe network with water. Open and close the appropriate valves to obtain flow of water through the required test pipe.
2. Measure flow rates using the volumetric tank.
3. Take readings at three different flow rates for each pipe, altering the flow using the control valve on the hydraulics bench.
4. Major Head losses measurements:
   - Measure the internal diameter of each test pipe sample.
   - Measure head loss between the tappings using the hand-held meter for each pipe.
   - Using the corresponding pipe lengths estimate f using Darcy-Weisbach equation.
   - Find f using Moody diagram.
   - Obtain readings on all four smooth test pipes.
5. Minor Head loss measurement
   - Measure head loss between the tappings on three fittings using the portable pressure meter.

Processing Results:

All readings should be tabulated. As references you can use the tables on the last section of the manual.

Results:

1. For Major losses:
   a. Plot a graph of pipe friction coefficient versus Reynolds number (log scale) for each size of pipe.
   b. Plot a graph of head loss versus velocity for each size of pipe. State if the flow is laminar, transitional or turbulent.

2. For Minor Losses:
   a. Plot a graph of $V^2/2g$ versus head loss for each fitting. Fit the curve with a straight line. Determine the value of K from the slope of the line. Compare with available data from the literature.

Data:

Table 1 - Table for Major Losses

Pipe Number	Volume Vol [litres]	Time T [Secs]	Flow rate Q [m^3/s]	Pipe Diam. D [m]	Velocity V [m/s]	Reynolds Number Re	Measured Head Loss h	Friction factor f	Friction factor f
			$\frac{Vol \times 10^{-3}}{T}$		$\frac{4Q}{\pi D^2}$	$\frac{\rho VD}{\mu}$		Darcy-Weisbach	Moody Diagram

Table 2 - Table for minor Losses

Pipe Fitting	Volume (L)	Time (secs)	Pipe Diameter 1 (mm)	Pipe Diameter 2 (mm)	ΔP (Kpa)
Minor loss 1					
Minor loss 1					
Minor loss 1					
Minor loss 2					
Minor loss 2					
Minor loss 2					
Minor loss 3					
Minor loss 3					
Minor loss 3					

Experiment 3

Verification of Bernoulli's Theorem

Objective:

- The purpose of this experiment is to illustrate Bernoulli's Theorem by demonstrating the relationship between pressure head and kinetic energy head for a conduit of varying cross-section.

Pre-Lab Setup:

1. Set up the Bernoulli apparatus on the working surface and level it.
2. Connect the supply hose to the inlet stub and tighten the hose.
3. If not already open, open the drain cock on the outlet tank.

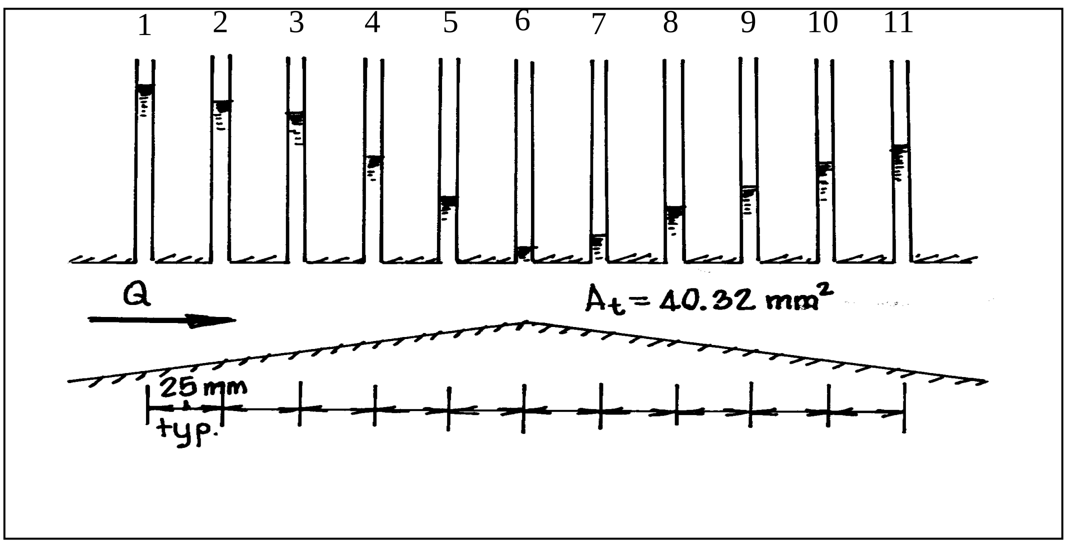

Figure 3-1 Bernoulli Apparatus

Theory:

Bernoulli's equation is derived by integrating the equations of fluid motion. Assumptions used to obtain the simplified version of the equation are that the fluid is inviscid and incompressible and that the flow is steady. Bernoulli's equation is a mathematical statement of the work-energy principle which directly corresponds to the equations of motion. This principle states that the work done on a particle is equal to the change in kinetic energy of the particle. Along a streamline,

$$\frac{p}{\gamma} + \frac{v^2}{2g} + z = const. \qquad (3\text{-}1)$$

Conservation of Mass:

For a given cross-sectional area the product of the velocity and density is proportional to the mass flow rate.

$$M = \rho Q = \rho v A_n \qquad (3\text{-}2)$$

$$v = \frac{M}{\rho A_n} = \frac{(mass / time)}{(mass / vol) A_n} = \frac{(vol / time)}{A_n} = \frac{Q}{A_n} \qquad (3\text{-}3)$$

$Q = vA_n$ (continuity equation for incompressible fluid)

where, M = mass flow rate,

Q = volumetric flow rate,

v = average velocity,

A_n = area normal to the direction of flow, and

ρ = mass density.

Between any two points in the flow, Inflow = Outflow. Therefore,

$$M_{in} = M_{out} \qquad (3\text{-}4)$$

$$\rho_1 v_1 A_1 = \rho_2 v_2 A_2 \qquad (3\text{-}5)$$

which for an incompressible fluid becomes,

$$v_1 A_1 = v_2 A_2 = Q \qquad (3\text{-}6)$$

If the cross-sectional area decreases, the velocity must increase to satisfy continuity. Applying Bernoulli's equation to a flow where there is no change in elevation (z = constant), a decrease in velocity must be accompanied by an increase in pressure and vice versa. Bernoulli's equation expresses the conservation of energy and that the work done on the fluid shows up as a change in kinetic and/or potential energy.

Procedure:

1. Close the main control valve and start the pump.
2. Regulate the pump flow to fill the header tank and maintain it at a steady level. The flow through the channel will be quite rapid and the pressure at the throat may be too low to show on the piezometer tube.
3. Increase the back pressure in the channel and the outlet tank by slowly closing the drain cock. This will tend to raise the level in the outlet tank so the pump flow control valve should also be carefully regulated.
4. Adjust both pump flow and drain cock until there is the widest possible difference in pressure between the inlet and throat of the channel, with the water level visible in every piezometer tube.
5. Measure the volumetric flow rate with a graduated cylinder and stop watch.
6. Measure the height of the water level in each piezometer tube and record on the data sheet together with the corresponding distance from the channel entrance.
7. Measure the height of the water level in both the inlet and outlet tank.
8. Switch off the pump and close the main valve.

Questions: (interpretation of results)

1. Using your measured discharge rate, calculate the velocity at the throat of the flow conduit if the cross-sectional area of the throat is 40.32 mm^2 (0.4032 cm^2)
2. Calculate the total head, H, at the throat. (The total head is the sum of the measured pressure head and the velocity head at the throat.)
3. Plot the total head, H, as a function of distance, x, where x = 0 at the inlet, x = 2.5 cm at the first tube, etc., x = 15.0 cm at the throat and x = 30.0 cm at the outlet.
4. What is the head loss between the inlet and the throat?
5. What is the head loss between the throat and the outlet?
6. Assume that the total head varies linearly between x = 0 and x = 15.0 cm and also from x = 15.0 cm to x = 30.0 cm, and determine the total head at each piezometer tube.
7. Determine the velocity head at each piezometer tube.
8. Determine the velocity at each piezometer tube.
9. Determine the cross-sectional area of the flow at each piezometer tube and plot that area as a function of x.
10. Calculate the degree of pressure recovery. See Appendix 2. What does this indicate about the energy of the fluid as it passes through contractions and expansions?

Data:

Water Temp =

γ =

Q = mL/sec

Width of channel = 6.72 mm (for cross-check ONLY)

Ht. of top of channel from given datum = 50.5 mm

Ht. of water in inlet tank =

Ht. of water in outlet tank =

Tube no.	Ht. of channel x-section, d (mm)	X-section area (mm^2) (for cross-check ONLY)	Ht. of water in tube from datum (cm)	Ht. of water in tube from mid-ht. of channel (cm)
1	15.0			
2	13.0			
3	12.0			
4	10.0			
5	8.0			
6	6.0			
7	8.0			
8	10.5			
9	12.0			
10	13.5			
11	15.5			

Experiment 4

Pumps in Series and Pumps in Parallel

Objectives:

- Learn how a single pump and pump combinations work by measuring flow rate (Q) for different pump configurations.
- To develop your own analysis using experimentally derived data.
- Construct a system curve based on your data [the Qs] and the provided pump characteristic curve.

Background:

Read chapter 5.6, [5.11]; look at example 5.4 (& fig. 5.13) & [5.5 & 5.6]; [] – optional

Pumps are used to transfer fluid in a system, either at the same elevation or to a new height. The obtained flow rate depends on the height to which the fluid is pumped. Each pump has a head-discharge relationship that is inversely proportional. The pump manufacturer provides this relationship, also known as the pump characteristic curve (figure 1).

In civil engineering applications, a single pump often cannot deliver the flow rate or head necessary for a particular system. However, two pumps (or more) can be combined in series to increase the height to which the fluid can be pumped at a given flow rate, or combined in parallel to increase the flow rate associated with a given value of head.

Theory:

Using the pump characteristic curve, shown in figure 1, it is possible to infer what the pump head (and therefore system head) is at a given Q (which you can measure), for different pump configurations. When pumps are combined in series and parallel, the pump characteristic curve changes as described in chapter 5.6, Q and therefore the system curve changes. So, it is possible to use the characteristic pump curve as a reference to infer what the system curve is, because the discharge is determined by the intersection of the two curves (see example 5.4 and fig. 5.13).

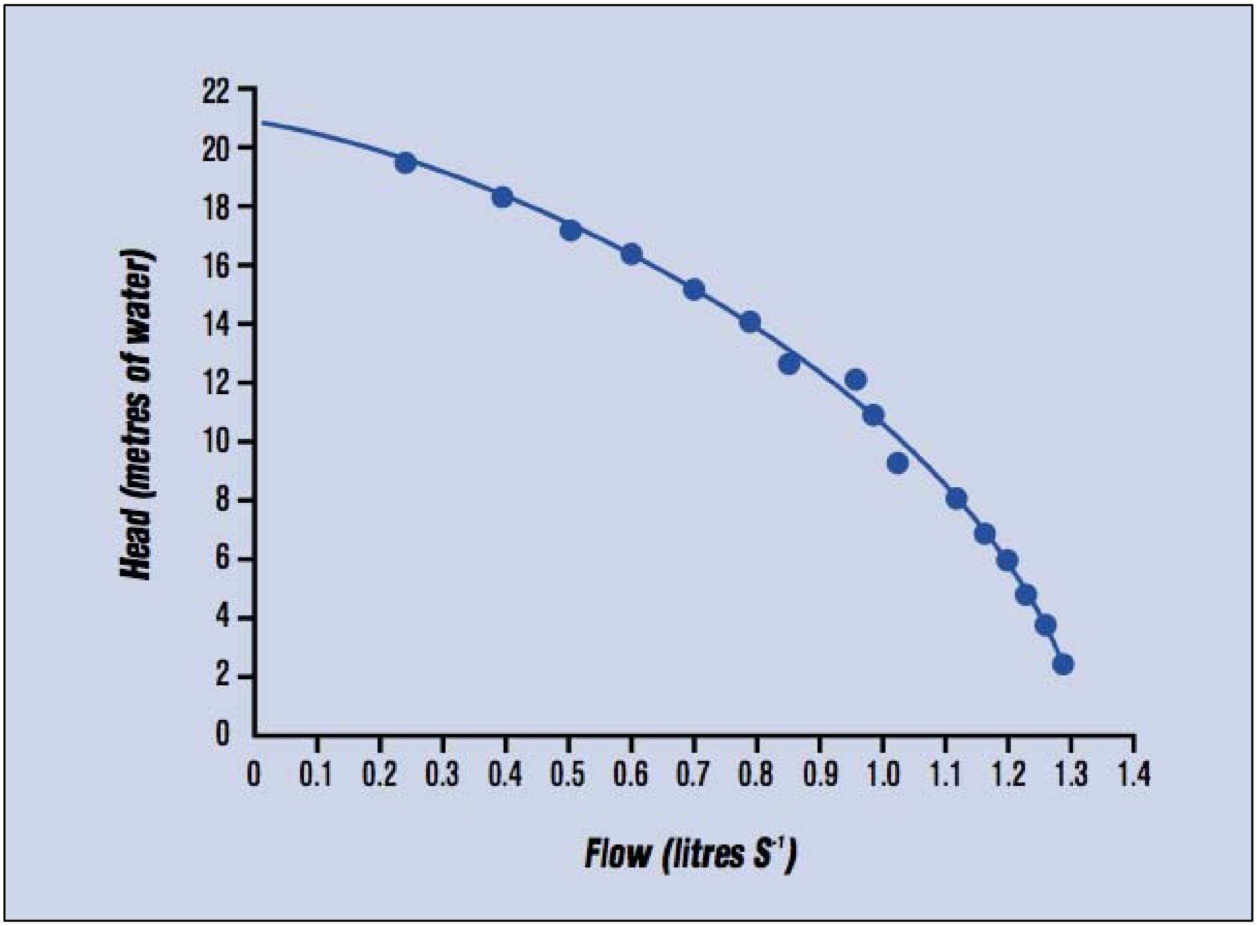

Figure 1: The pump characteristic curve of the Armfield internal pump

For any system (single, parallel or series pumps) it can be written that:

$$Z_1 + \frac{P_1}{\gamma} + \frac{V_1^{\ 2}}{2g} + H_{pump} = Z_2 + \frac{P_2}{\gamma} + \frac{V_2^{\ 2}}{2g} + H_L$$

Point one is the storage tank where the pumps are getting water, and point 2 is the discharge above the hydraulic bench. H_L is the losses of the system. For each flow, you have a H_L and thus a system curve.

To simplify, it can be said that:

$V_1 = 0$ Because it is a tank.

$P_2=P_1=0$ Because it is open to atmosphere.

$Z_2 - Z_1=dZ=$ Measure In the lab.

Set up Apparatus:

The apparatus can be set such that pumps can be combined in series and parallel. For a series or parallel pump operation, two or more pumps are required. It needs to be said that the flow system is changed between the series and parallel setting. A single pump (whether it is the outside or inside one) can only be measured when the circuit is set to parallel.

Three other notes:

1) Two pumps in parallel vs either the inside/outside can only be measured on the same system, when the setting is parallel
2) When the flow control valve is turned, the system is also changed – a partially closed valve has a higher loss coefficient, and the head loss is as usual proportional to $v^2/2g$.
3) In series connection, one pump is pushing, the other is sucking – both must be turned on and have nonzero regulator setting

Experimental Tasks:

Measure the head, and flow rate (2 trials) of each pump individually at the 100% setting.

Measure the head and flow rate (2 trials) of the regulated pump only at 2 settings other than 100%.

Measure the flow rate of the pumps, in series at 100% setting.

Measure the flow rate of the pumps, in series with the regulated pump set at 2 settings other than 100%

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Data Sheet

Trial 1:

Table 1. Single pump (inside)

Trial	**Time [s]**	**Vol [L]**	**Q [L/s]**	**Pin [m]**	**Pout [m]**	**Ptot [m]**
1 (100%)						

Table 2. Single pump (outside)

Trial	**Time [s]**	**Vol [L]**	**Q [L/s]**	**Pin [m]**	**Pout [m]**	**Ptot [m]**
1 (100%)						
2 (____%)						
3 (____%)						

Table 3. Pumps in parallel; (___%'s same as in table 2)

Trial	**Time [s]**	**Vol [L]**	**Q [L/s]**	**Pin [m]**	**Pout [m]**	**Ptot [m]**
1 (100%,100%)						
2 (100%,____%)						
3 (100%,____%)						

Table 4. Pumps in series; (___%'s same as in table 2,3)

Trial	**Time [s]**	**Vol [L]**	**Q [L/s]**	**Pin [m]**	**Pout [m]**	**Ptot [m]**
1 (100%,100%)						
2 (100%,____%)						
3 (100%,____%)						

City College of New York **Department of Civil Engineering**

CE 36500 - Hydrology and Hydraulics Engineering

Data Sheet

Trial 2:

Table 1. Single pump (inside)

Trial	**Time [s]**	**Vol [L]**	**Q [L/s]**	**Pin [m]**	**Pout [m]**	**Ptot [m]**
1 (100%)						

Table 2. Single pump (outside)

Trial	**Time [s]**	**Vol [L]**	**Q [L/s]**	**Pin [m]**	**Pout [m]**	**Ptot [m]**
1 (100%)						
2 (____%)						
3 (____%)						

Table 3. Pumps in parallel; (___%'s same as in table 2)

Trial	**Time [s]**	**Vol [L]**	**Q [L/s]**	**Pin [m]**	**Pout [m]**	**Ptot [m]**
1 (100%,100%)						
2 (100%,____%)						
3 (100%,____%)						

Table 4. Pumps in series; (___%'s same as in table 2,3)

Trial	**Time [s]**	**Vol [L]**	**Q [L/s]**	**Pin [m]**	**Pout [m]**	**Ptot [m]**
1 (100%,100%)						
2 (100%,____%)						
3 (100%,____%)						

Experiment 5

Calibration of Sharp-Crested Weirs

Objectives:

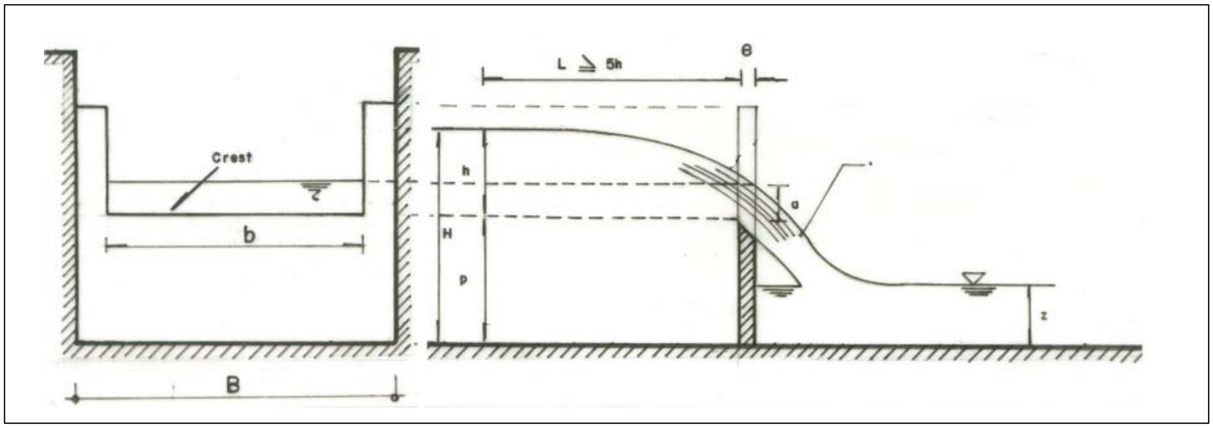
- Verify the discharge equation and estimate discharge coefficients for a rectangular and a V-notch weir.
- Measure flow data that is depend on the flow rate and shape of the weir, and use these data points to modify he equation that results from the theoretical relationships between these variables

Background:

A weir is an overflow structure extending across a stream of a channel and normal to the direction of the flow. They are normally categorized by their shape as either sharp-crested or broad-crested. This laboratory experiment focuses on sharp-crested weirs only. Two different types of weirs will be introduced: The rectangular weir and the V-notch weir.

Theory:

1. **Rectangular Weir**



Consider the flow through a rectangular notch or sharp-crested weir as shown in Figure 8-1. A horizontal differential element is taken at a depth y below the free surface. The area of the element is given by,

$$dA = B\,dy \tag{5-1}$$

The velocity through the element is given by,

$$v = \sqrt{2gy} \tag{5-2}$$

Therefore, the theoretical discharge through the element is,

$$dQ = B\sqrt{2gy}dy \tag{5-3}$$

Integrating Eq. 8-3 yields the theoretical discharge,

$$Q_t = B\sqrt{2g}\int_0^H y^{1/2}dy \tag{5-4}$$

or,

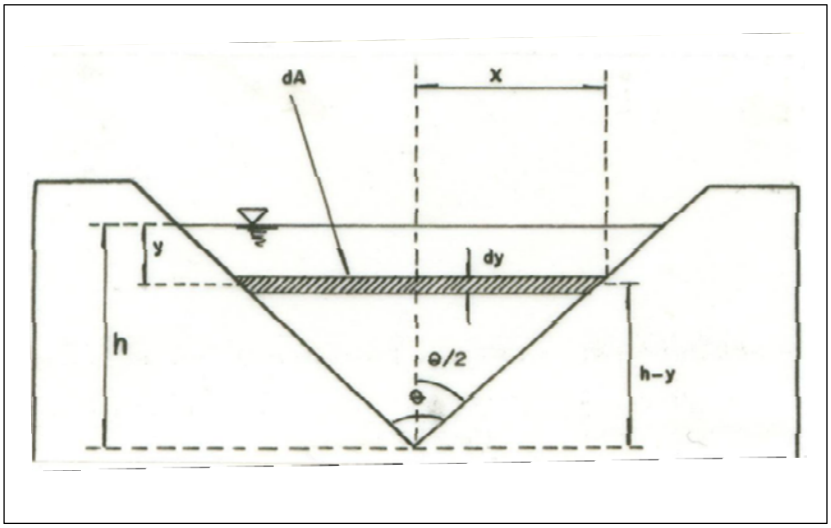
$$Q_t = \frac{2}{3}B\sqrt{2g}H^{3/2} \tag{5-5}$$

The actual discharge is given by,

$$Q_a = C_d\,\frac{2}{3}B\sqrt{2g}H^{3/2} \tag{5-6}$$

where C_d = the coefficient of discharge, $K = \frac{2}{3}B\sqrt{2g}$, $N = \frac{3}{2}$ and B = 3 cm.

2. V-Notch Weir



Consider the flow through the triangular notched weir shown in above Figure. Consider an element at depth y. The breadth of the element is given by,

$$B = 2\,(H - y)\tan\theta \tag{5-7}$$

and the area of the differential element is then given by,

$$dA = 2\ (H - y)\ \tan\ \theta\, dy \tag{5-8}$$

while the velocity through the element is given by,

$$v = \sqrt{2gy} \tag{5-9}$$

The discharge through the element is,

$$dQ = 2(H - y)\sqrt{2gy}\tan\theta dy \tag{5-10}$$

and the total theoretical discharge is obtained by integrating Eq. 8-10,

$$Q_t = 2\tan\theta\sqrt{2g}\int_0^H (Hy^{1/2} - y^{3/2})dy \tag{5-11}$$

which yields,

$$Q_t = \frac{8}{15}\tan\theta\sqrt{2g}H^{5/2} \tag{5-12}$$

The actual discharge is given by,

$$Q_a = C_d\frac{8}{15}\tan\theta\sqrt{2g}H^{5/2} \tag{5-13}$$

in which C_d = the *coefficient of discharge*.

θ = 1/2 of the machined angle = 45°

N = 5/2 (triangle), and

$$K = \frac{8}{15}\sqrt{2g}\tan\theta$$

Experimental Procedure

- Measure the width of the weir.
- Turn on the pump and open the control valve until water discharges over the weir plate.
- Close the control valve and turn off the pump and allow water level to drop until water flow over the weir stops.
- Set Vernier height gauge to datum reading (water surface in the channel).
- Position the gauge at about halfway between the plate and the stilling baffle.

- Turn on the pump, open the control valve and adjust it to obtain the head H.
- After the conditions are stable, for each flow rate measure and record H.
- Take readings of volume discharged and time of discharge using the volumetric tank.
- Repeat five times for each weir type.

Data Analysis

Rectangular Weir

In a rectangular weir:

$$Q = \frac{2}{3} * C_d * b * \sqrt{2g} * h^{3/2}$$

Determine discharge coefficient as follows (take measurements for at least 4 different discharges (Q) and 2 to 3 trials to determine each value of Q):

1. Tabulate discharge, head and discharge coefficient.
2. By plotting a graph of the logarithm of the flow rate vs. the logarithm of the depth, compare the theoretical power law and coefficient with those obtained from the graph. Comment on your results.
3. Plot C_d vs Q for each measured Q.
4. Fit a function of the form $Y=cX^{3/2}$ for the data in 2. And from this c and what you know about the weir formula above determine C_d.

Answer in your report: Is C_d constant for this weir?

V-notch Weir

In a V-notch weir:

$$Q = \frac{8}{15} * C_d * \tan\left(\frac{\theta}{2}\right) * \sqrt{2g} * h^{5/2}$$

Determine discharge coefficient as follows (take measurements for at least 4 different discharges (Q) and 2 to 3 trials to determine each value of Q):

1. Tabulate discharge, head and discharge coefficient.
2. By plotting a graph of the logarithm of the flow rate vs. the logarithm of the depth, compare the theoretical power law and coefficient with those obtained from the graph. Comment on your results.
3. Plot C_d vs Q for each measured Q.
4. Fit a function of the form $Y=cX^{5/2}$ for the data in 2. And from this c and what you know about the weir formula above determine C_d.

Answer in your report: Is C_d constant for this weir?

Data Table:

Rect. Weir		Vol (L)	t (s)	V. weir		Vol (L)	t (s)
Q1	trial 1			Q1	trial 1		
	trial 2				trial 2		
	trial 3				trial 3		
h				h			
Q2	trial 1			Q2	trial 1		
	trial 2				trial 2		
	trial 3				trial 3		
h				h			
Q3	trial 1			Q3	trial 1		
	trial 2				trial 2		
	trial 3				trial 3		
h				h			
Q4	trial 1			Q4	trial 1		
	trial 2				trial 2		
	trial 3				trial 3		
h				h			
b				Theta			

<u>Experiment 6</u>

Hydraulic Jump

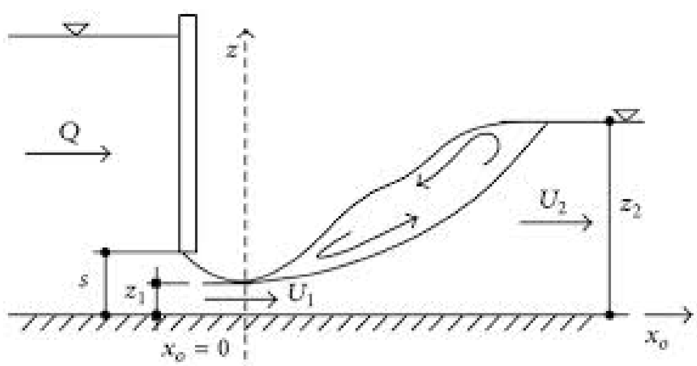
Objectives:

- Observe a standing Hydraulic Jump that forms between a super-critical flow section (generated through a gate) and a sub-critical section generated through a channel end gate).
- Measure heights before and after the hydraulic jump to compute conjugate depths. Measure the velocity to obtain flow velocity in the sub-critical section and derive the relationships for the HJ equation using continuity and momentum principles.

Background:

Hydraulic jumps mostly occur naturally in open channels. They are very efficient in dissipating the energy of the flow to make it more controllable and less erosive. In a hydraulic jump the flow goes from supercritical (high velocity) to subcritical (low velocity) regime. In fact, occasionally it might be necessary to create a jump to consume the excessive energy. For instance when water flows down from an outlet of an arch dam, it carries an enormous amount of kinetic energy, which might damage the receiving channels. To avoid damage, a hydraulic structure called stilling basin is built underneath the dam. This structure produces a controlled hydraulic jump, where the damaging energy is lost in the transition from supercritical to subcritical.

Set up:



Experimental Procedure

A hydraulic jump has been established in the elevated flume of the Hydraulics Laboratory. The following tasks must be accomplished in this experiment:

- Measure the width of the channel;
- Measure the sequent depths of the jump;
- Measure the flow depth upstream from the jump (subcritical region);
- Estimate the flow velocity in the subcritical region of the flow;
- Choose two points in the channel in the subcritical region downstream from the jump and measure their distance;
- Put a piece of paper on the flow surface and measure the time it takes for the paper to travel from one point to the other. Repeat this procedure three times and take the average travel time;
- Divide the distance by the average travel time to approximate the flow velocity at the water surface;

Data Analysis

1. Compute the average velocity.
2. Estimate the flow rate.
3. Estimate the critical depth.
4. Estimate the Froude number before and after the jump.
5. Using the initial depth, approximate the sequent depth of the jump with the appropriate relations given in your text book and compare it with your measurement, find % error.
6. Repeat step 5 but use sequent depth to obtain the initial depth, find % error;
7. Estimate the energy loss in the jump.
8. Draw the specific force and energy curve. [Momentum equation: $M= y^2/2 + Q^2/(g*y*b^2)$; b is width, y is depth, g is gravity, Q is discharge.]

Specify the sequent depths on each curve and answer the following questions:

(a) Are the specific forces of the initial depth and the sequent depth exactly the same? Why?

(b) Is the energy loss that you obtain from the specific energy curve the same as the one in step 9? Why?

Remember, mention sources of error in your lab!!

Experiment 7

Outfall Diffuser

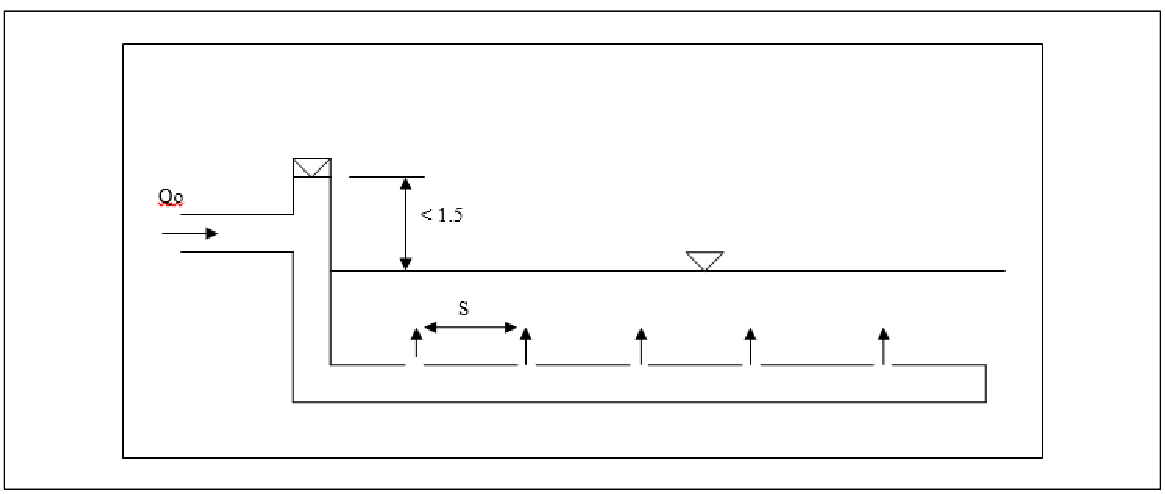
Objectives:

- Observe a standing Hydraulic Jump that forms between a super-critical flow section (generated through a gate) and a sub-critical section generated through a channel end gate).
- Measure heights before and after the hydraulic jump to compute conjugate depths. Measure the velocity to obtain flow velocity in the sub-critical section and derive the relationships for the HJ equation using continuity and momentum principles.

Background:

In general, it is possible to specify the desired flow distribution in a multi-port distribution system and to solve for the required flow areas to achieve this distribution provided that the upstream energy in the system is known. However, for a diffuser, a range of discharges may be experienced and the upstream energy level is likely to be a variable as well. In addition, the construction of different sized orifices at each discharge point is generally not feasible from an economic point of view. Therefore, it is generally better to specify a given diameter for all the discharge orifices or at least a combination of only a few different orifice diameters and then to compute the flow distribution from the proposed system.

Set up:



Experimental Procedure

Prepare a computer program or spreadsheet, which calculates the distribution of flow in a diffuser pipeline. The following design parameters will be used in the analysis:

design discharge:	Q_o	Diffuser diameter:	DIA
# of orifices:	N	Spacing between Orif.:	S
Diffuser pipe friction:	F		

Discharge coefficient for orifice: $c_d = 0.63 - 0.58\frac{v^2}{2gE}$

in which v is the velocity (in the pipe) just upstream from the orifice and E is the difference between the total energy inside the pipeline and the static head outside.

The analysis should begin with an assumed energy head at the upstream end of the diffuser and proceed downstream with repeated applications of orifice and energy equations. The repeated calculations will include the following steps:

1. Calculation of the orifice c_d based on local conditions.
2. Calculation of orifice flow, $Q_i = c_d A_i \sqrt{2gE}$.
3. Calculation of velocity in the pipe downstream from the orifice.
4. Calculation of the friction loss to the next orifice.
5. Calculation of the velocity head and energy at the next downstream orifice.

The repeated calculations will yield a total orifice discharge associated with the assumed upstream energy. Adjustments in this energy will then be necessary until the computed discharge agrees with the design discharge, while satisfying the following constraints:

1. The flow rates from the orifices must be within 7% of each other.
2. At the design discharge, the available head at the upstream end of the manifold cannot exceed a specific value.

Questions:

Prepare a brief description of the computations including a description of the input and output. Details of the computations must be submitted with the attached output to show your solution. The output must include the orifice diameters and the flow distribution from the orifices. Also, provide a listing of the required energy head at the upstream orifice to develop this flow condition. It is also useful to print out the maximum and minimum orifice discharges. Repeat the analysis for a flow rate of 0.5 m^3/s to see how changing the rate affects the flow distribution. Comment on all relevant results.

Data:

Q_0 = 5.0 m^3/s; DIA = 2.0 m; F = 0.02; S = 3.0 m; N = 40;
allowable upstream head difference = 1.5 m.

Experiment 8

Water Distribution Network

Objectives:

- Use principles of kinetic and potential energy together with conservation of mass and principles of parallel and pipes in series to learn about how water loops and distributes itself in branched systems.
- Use a commercial software package (Water GEMS from Bentley Publishers, Computer Applications in Hydraulic Engineering, 8th Ed.) to design a water distribution network. with sources, demands, and run time scenarios for a "real" system with varying elevations. Use alternative solutions to find an optimum design in terms of required pipe diameters and also the necessary network devices such as valves and manholes.

Background:

This program is commercial grade and gives you a great introduction into working with real-world water distribution systems. While the student is limited in terms of what size of project you can actually analyze it provides you with all the bells and whistles that the full license program makes available. We recommend that you work through the Tutorial #1 (Bentley book page 236) to get you familiar with the system.

Set up:

For this term please work on the following problem:

Problem #3 in chapter 6 of Bentley book (page 264)

Procedure

We expect you to submit a regular lab report in which you answer all the questions of the problems and also submit graphs and maps of the problem set up.

LAB REPORT INSTRUCTIONS

The lab report is a group report, i.e. there is only one report per group. The group is expected to self-organize itself so work on the reports is evenly distributed. We expect you to hand in a printed copy.

The lab report is always due exactly **one** week later, except when stated otherwise. Hand-in time is during the lab hours, i.e. between 2:00pm and 5:00pm and must presented to the TA running the lab for that day.

The report you will submit should contain the following sections:

1. Cover page.
2. Table of Contents.
3. List of Figures.
4. List of Tables.
5. Abstract (10%)
6. Introduction: Stating the problem, describing the significance and the objective of the work done (10%)
7. Procedure and Results (25%)
8. Discussion of results: Giving a thorough analysis and interpretation of results (25%)
9. Conclusions: Summarizing the findings (10%)
10. References (5%)
11. Appendix: Showing important calculations and formulas if necessary.

Presentation: 10%

Participation during lab experiment: 5%

Figures and tables should be numbered and must have captions explaining what they are illustrating. You must always show units of axes in the figures and units of the numbers listed in the tables.