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UNIVERSITY OF GLOBAL VILLAGE (UGV), BARISHAL

THE UNIVERSITY FOR HI-TECH AND HUMANITY

Water Resource Engineering Lab

Content of Laboratory Course

Prepared By

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Program: B.Sc. in Civil Engineering

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BASIC COURSE INFORMATION

Course Title	Water Resource Engineering Lab
Course Code	CE 0732-2204 CE 0732-3106
Credits	01
CIE Marks	30
SEE Marks	20
Exam Hours	2 hours (Semester Final Exam)
Level	4th Semester

Water Resource Engineering Lab

COURSE CODE: CE 0732-2204
CE 0732-3106

CREDIT: 01
CIE MARKS: 30

SEE MARKS: 20

CLO 01 **Explain** principle of conservation of mechanical energy of fluid, **Measure** the volumetric flow rate of fluids flowing through a pipe..
CLO 02 **Examine** how a fluid accelerates as it constricts through an orifice and forms a jet, **Construct** the formula of coefficient of discharge and coefficient of velocity.
CLO 03 Ability to **understand** the operating principles and usages of different flow measuring devices in open channels
CLO 04 Ability to **estimate** different flow characteristics (force, energy and momentum) in open channels

Sl.	Course Contents	Hours	CLOs
1	Derivation of Bernoulli’s theorem & Verification of Bernoulli’s Theorem -**theoretical foundation and practical application** of Bernoulli's principle in fluid mechanics, covering its derivation and experimental verification.	11	CLO 1,
2	Flow through Venturi meter -**Principle, derivation of discharge equation**, practical applications.	10	CLO 1
3	Determination of the coefficient of velocity by orificemeter -**Experiment** to measure the velocity coefficient of a fluid flowing through an orifice using an orificemeter and analyzing the collected data.	11	CLO 2
4	Determination coefficient of discharge under constant head by orificemeter -**Determine** the coefficient of discharge of an orificemeter under constant head conditions through experimental measurements and data analysis.	10	CLO 2

5	Determination of state of flow & critical depth in open channel -**Analysis and calculation** of flow regimes (subcritical, supercritical) and the critical depth of fluid flow within an open channel.	**10**	**CLO3,CLO 4**
6	Flow over a broad-crested weir -**Analysis** of fluid flow characteristics and pressure distribution over a broad-crested weir.	11	CLO3,CLO 4
7	Flow through a Venturi flume -**Study** of fluid flow principles through a Venturi flume, including pressure measurement, flow rate calculation, and application in open channel flow measurement.	11	CLO3,CLO 4
8	Flow through a Parshall flume -**Study** of open channel flow measurement using a Parshall flume, including principles of operation, calibration methods, and practical applications in water resource management.	11	CLO3,CLO 4

ASSESSMENT PATTERN

CIE- Continuous Internal Evaluation (30 Marks)

SEE- Semester End Examination (20 Marks)

SEE- Semester End Examination (40 Marks) (should be converted in actual marks (20))

Bloom's Category	**Tests**
Remember	**05**
Understand	**07**
Apply	**08**
Analyze	**07**
Evaluate	**08**
Create	**05**

CIE- Continuous Internal Evaluation (100 Marks) (should be converted in actual marks (30))

Bloom's Category Marks (out of 100)	Lab Final (30)	Lab Report (10)	**Continuous lab performance** (30)	Presentation & Viva (10)	External Participation in Curricular/**Final Project Exhibition** (10)
Remember/**Imitation**	05		05	02	
Understand/**manipulation**	05	05	05	03	
Apply/**Precision**	05		05		Attendance
Analyze/**Articulation**	05		05		10
Evaluate/**Naturalisation**	05	05	05		
Create	05		05	05	

Week	Topic	Teaching Learning Strategy	Assessment Strategy	CLOs
1,2	Derivation of Bernoulli's Theorem & Verification of Bernoulli's Theorem	Lecture, Oral presentation	Lab Test, Quiz and Report	CLO 1
3	Flow through Venturi meter	Lecture, Discussion	Lab Test, Quiz and Report	CLO 1
4	Determination of the coefficient of velocity by orificemeter	Lecture, Discussion	Lab Test, Quiz and Report	CLO 2
5	Determination of the coefficient of discharge by orificemeter	Lecture, Discussion	Lab Test, Quiz and Report	CLO 2
6,7	Determination of state of flow & critical depth in open channel	Lecture, Discussion	Lab Test, Quiz and Report	CLO 3, CLO 4
8,9	Flow over a broad-crested weir	Lecture, Discussion	Lab Test, Quiz and Report	CLO 3 CLO 4
10	Flow through a Venturi flume	Lecture, Discussion	Lab Test, Quiz and Report	CLO 3, CLO 4

11-12	**Flow through a Parshall flume**	Lecture, Discussion	Lab Test, Quiz and Report	**CLO3, CLO 4**
13-14	Practice ,review & Lab Report Assessment, Self study	Lecture, Discussion	Lab Test, Quiz and Report	CLO 4
15-17	Lab Test, Viva, Quiz, Overall Assessment, Skill Development Test (Competency)	Lecture, Discussion	Lab Test, Quiz and Report	CLO 4

References

1. **A Textbook of Fluid Mechanics and Hydraulic Machines By R. K. Bansal**
2. **A Textbook of Fluid Mechanics By RK Rajput**
3. Ven Te Chow, 1959. Open channel Hydraulics
4. Chaundhury, M.H. 2008, Open Channel Flow, 2nd Edition

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Derivation of Bernoulli's Theorem &
Verification of Bernoulli's Theorem
Week 1-2

Experiment No: 01

Verification of Bernoulli's Theorem

Aim

To verify Bernoulli's Theorem

Apparatus

Bernoulli's Apparatus

Experimental setup which consists of flow channel 700 mm long, transparent acrylic, Supply with control valve, Manometric tubes (11 no)fixed over flow channel with separate scale, Sump tank, Measuring tank and inlet and outlet pipe (150mm diameter) with stop watch and accessories .

Theory

Kinetic Energy:-

The kinetic energy of an object is the energy which it possesses due to its motion. It is defined as the work needed to accelerate a body of a given mass from rest to its stated velocity. Having gained this energy during its acceleration, the body maintains this kinetic energy unless its speed changes. The same amount of work is done by the body in decelerating from its current speed to a state of rest.

Potential Energy:-

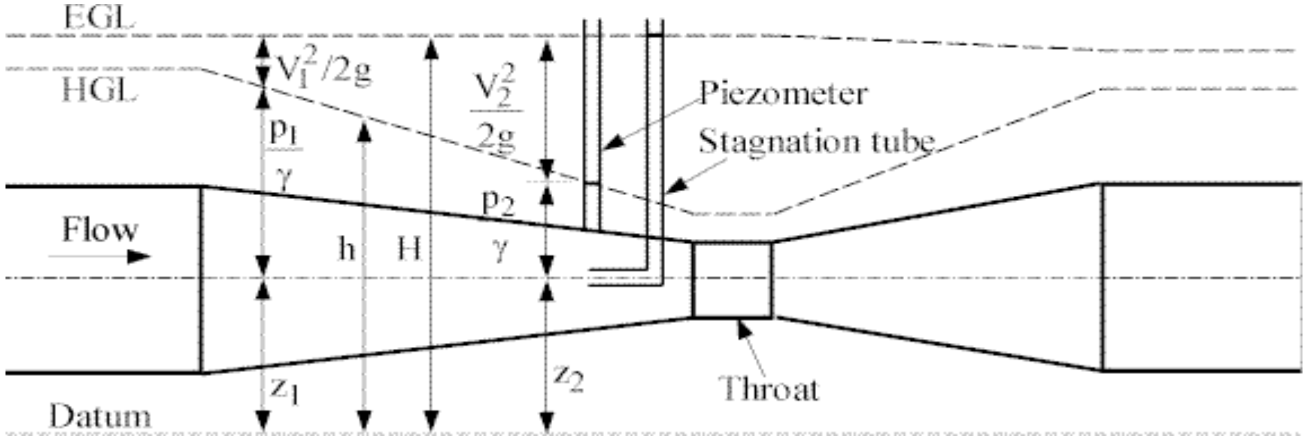
The potential energy is the energy of an object or a system due to the position of the body or the arrangement of the particles of the system. The SI unit for measuring work and energy is the joule (symbol J). If the work of forces of this type acting on a body that moves from a start to an end positionis defined only by these two positions and does not depend on the trajectory of the body between the two,then there is a function known as a potential that can be evaluated at the two positions to determine this work. Furthermore, the force field is defined by this potential function, also called potential energy.

Pressure Energy:-

Pressure in a fluid may be considered to be a measure of energy per unit volume or energy density. For a force exerted on a fluid, this can be seen from the definition of pressure. Pressure in a fluid can be seen to be a measure of energy per unit volume by means of the definition of work. This energy is related to other forms of fluid energy by the Bernoulli equation.

Bernoulli's theorem:-

Bernoulli's principle can be derived from the principle of conservation of energy. This states that, in a steady flow, the sum of all forms of mechanical energy in a fluid along a streamline is the same at all points on that streamline. This requires that the sum of kinetic energy and potential energy remain constant. Thus an increase in the speed of the fluid occurs proportionately with an increase in both its dynamic pressure and kinetic energy, and a decrease in its static pressure and potential energy. If the fluidis flowing out of a reservoir, the sum of all forms of energy is the same on all streamlines because in a reservoir the energy per unit volume (the sum of pressure and gravitational potential $\rho g h$) is the same everywhere.



Experimental procedure

(1) Start the motor.
(2) Open the bypass valve fully.
(3) Control the gate valve for steady flow.
(4) Allow some time to raise the water level in manometer tubes.
(5) Take the height level in manometer tubes.
(6) Take the time required for 100 mm rise in water level of measuring tank.

Precautions & Tips

1) Carefully kept some level of fluid in inlet and outlet supply tank.
2) When fluid is flowing there is fluctuation in the height of piezometer tubes, note the mean position carefully.

Observations

Size of the sump tank = 1 x 0.5 x 0.4(height) m^3
Size of the measuring tank = 0.5 x 0.4 x 0.4(height) m^3
Width of channel = 0.05 m

Tabulation:

S. no.	Tubes No.	Head h in meters	Height of the channel in mts	*C/s* area of channel. A in m^2	*P/w*	$V^2/2g$	$P/w+ V^2/2g$
1							
2							
3							
4							

Working Sheet

1. Discharge, Q = Area of measuring tank x rise in water level of measuring tank / Time required =.........................m^3/sec.
2. Velocity, V = Q/A =----------------m/sec
3. Pressure, P = ρ. g. h =-----------------N/m^2

Where,
ρ=Density of the liquid, kg/m^3
g = Acceleration due to gravity, 9.81 m^2/sec
h = Head in meters.

4. Pressure head = P/w =---------------- meters.of water.
   Where,
   w = Specific weight of water, $9810 N/m^3$

Results & conclusions

On the basis of above results it concludes that the sum of kinetic, potential and pressure energy of fluid is same at any point in the tube. Hence Bernoulli's theorem is verified.

Viva questions

1) Briefly Explain the various term involve in Bernoulli's Equation.
2) What is Piezometer tube?
3) What Assumptions made to get Bernoulli's equation from Euler equation?

Flow through Venturi meter
Week 2

Experiment No: 02

Flow through Venturimeter

Aim

To measure the discharge through a venturimeter.

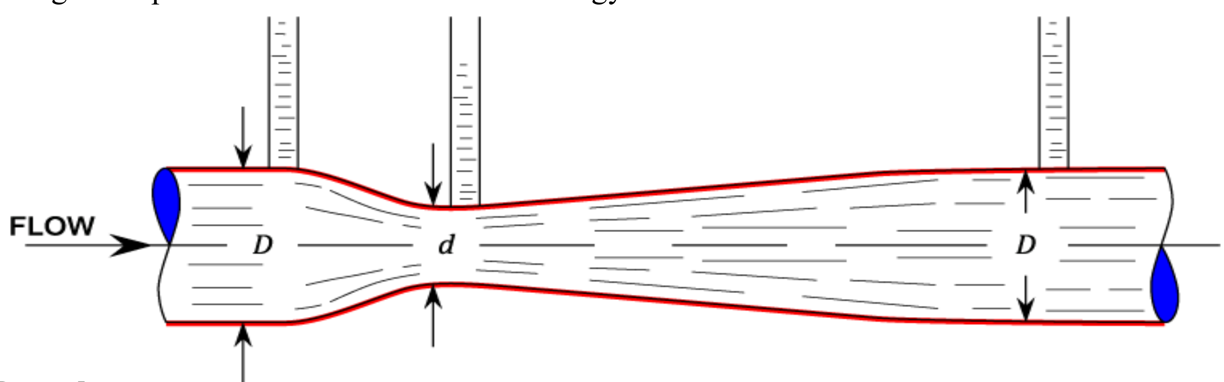
Apparatus

Venturimeter, U-tube manometer, Stop watch, water tank

Theory

Principle on which venturimeter works:-

The fluid whose flow rate is to be measured enters the entry section of the venturimeter with a pressure P1.As the fluid from the entry section of venturimeter flows into the converging section, its pressure keeps on reducing and attains a minimum value P2 when it enters the throat. That is, in the throat, the fluid pressure P2 will be minimum.The differential pressure sensor attached between the entry and throat section of the venturimeter records the pressure difference (P1-P2) which becomes an indication of the flow rate of the fluid through the pipewhen calibrated. The diverging section has been provided to enable the fluid to regain its pressure and hence its kinetic energy



Procedure

1. Start the Centrifugal pump which supplies water to the Venturimeter.
2. Regulate the supply of water to the Venturimeter by adjusting the valve to a particular Discharge Position.
3. Note down the time (t) taken for a given amount to rise (y meters) in the level of water in the Measuring tank.
4. Note down the manometer reading.
5. Repeat the procedure Nos. (1) to (4) for different discharge through the venturimeter.
6. Tabulate the result: and determine the average value of the coefficient of discharge.

Precautions & Tips

1. Keep the other valve closed while taking reading through one pipe.
2. The intial error in manometer should be subtracted final reading.
3. The parallax error should be avoided.
4. Maintain a constant discharge for each reading.
5. The parallax error should be while taking reading the manometer.

Observations

Diameter of Venturimeter at inlet, d_1 = meters

Diameter of Venturimeter at throat, d_2 = meters

Specific gravity of manometer liquid, S_m = 13.6 (Hg)

Specific gravity of water, S_w =

Area of the measuring tank, A = meters

Rise in level of water in measuring tank, y = meters

Tabulations:

S. no.	Manometer reading Mts. of Hg		$X=X_1-X_2$ mts of Hg	Head,(h) mts of H_2O	Time taken for 2 cm rise, sec	Q_{the} m^3/sec	Q_{act} m^3/sec	C_d	Avg. C_d
	X_1	X_2							
1									
2									
3									
4									
5									
6									
7									

Specimen Calculations:

1. C/ S area of venturimeter at inlet $A_1 = \pi. (d_1)^2/4$ = ----------m^2
2. C/ S area of venturimeter at throat $A_2 = \pi. (d_2)^2/4$ =---------- m^2
3. Reading differential manometer, $X = X_1 - X_2$ =----------------------- mts of Hg.
4. Head in mts of water, $h = X[(S_m/ S_w)-1]$ = ----------mts of water.
5. Theoretical Discharge, $Q_{theo.} = \{A_1A_2(2gh)^{1/2}] / [A_1^2 - A_2^2]^{1/2}$
6. Actual discharge, $Q_{act} = Ay/t$
7. Coefficient of discharge, $C_d = Q_{act} / Q_{theo.}$

Results & Conclusion

From the experiments it concludes that the mass flow rate of fluid is constant. By using the venturimeter we calculate the difference of manometer reading & coefficient of discharge for different sets of reading.

Viva questions

1. Venturimeter are used for flow measuring. How?
2. Define coefficient of discharge?
3. Define parallax error?
4. Define Throat?
5. Define diverging part?

Determination of the coefficient of velocity by orificemeter & Determination of the coefficient of dischargeby orificemeter

Week 4-5

Experiment No: 03

Flow through Orifice and Jetflow

1. INTRODUCTION

An orifice is an opening, of any size or shape, in a pipe or at the bottom or side wall of a container (water tank, reservoir, etc.), through which fluid is discharged. If the geometric properties of the orifice and the inherent properties of the fluid are known, the orifice can be used to measure flow rates. Flow measurement by an orifice is based on the application of Bernoulli's equation, which states that a relationship exists between the pressure of the fluid and its velocity. The flow velocity and discharge calculated based on the Bernoulli's equation should be corrected to include the effects of energy loss and viscosity. Therefore, for accurate results, the coefficient of velocity (C_v) and the coefficient of discharge (C_d) should be calculated for an orifice. This experiment is being conducted to calibrate the coefficients of the given orifices in the lab.

2. PRACTICAL APPLICATION

Orifices have many applications in engineering practice besides the metering of fluid flow in pipes and reservoirs. Flow entering a culvert or storm drain inlet may act as orifice flow; the bottom outlet of a dam is another example. The coefficients of velocity and discharge are necessary to accurately predict flow rates from orifices.

3. OBJECTIVE

The objective of this lab experiment is to determine the coefficients of velocity and discharge of two small orifices in the lab and compare them with values in textbooks and other reliable sources.

4. METHOD

The coefficients of velocity and discharge are determined by measuring the trajectory of a jet issuing fluid from an orifice in the side of a reservoir under steady flow conditions, i.e., a constant reservoir head.

5. EQUIPMENT

The following equipment is required to perform the orifice and free jet flow experiment:

- F1-10 hydraulics bench;
- F1-17 orifice and free jet flow apparatus, with two orifices having diameters of 3 and 6 mm;

- Measuring cylinder for flow measurement; and
- Stopwatch for timing the flow measurement.

6. EQUIPMENT DESCRIPTION

The orifice and free jet flow apparatus consists of a cylindrical head tank with an orifice plate set into its side (Figure 6.1). An adjustable overflow pipe is adjacent to the head tank to allow changes in the water level. A flexible hose attached to the overflow pipe returns excess water to the hydraulics bench. A scale attached to the head tank indicates the water level. A baffle at the base of the head tank promotes smooth flow conditions inside the tank, behind the orifice plate. Two orifice plates with 3 and 6 mm diameters are provided and may be interchanged by slackening the two thumb nuts. The trajectory of the jet may be measured, using the vertical needles. For this purpose, a sheet of paper should be attached to the backboard, and the needles should be adjusted to follow the trajectory of the water jet. The needles may be locked, using a screw on the mounting bar. The positions of the tops of the needles can be marked to plot the trajectory. A drain plug in the base of the head tank allows water to be drained from the equipment at the end of the experiment [6].

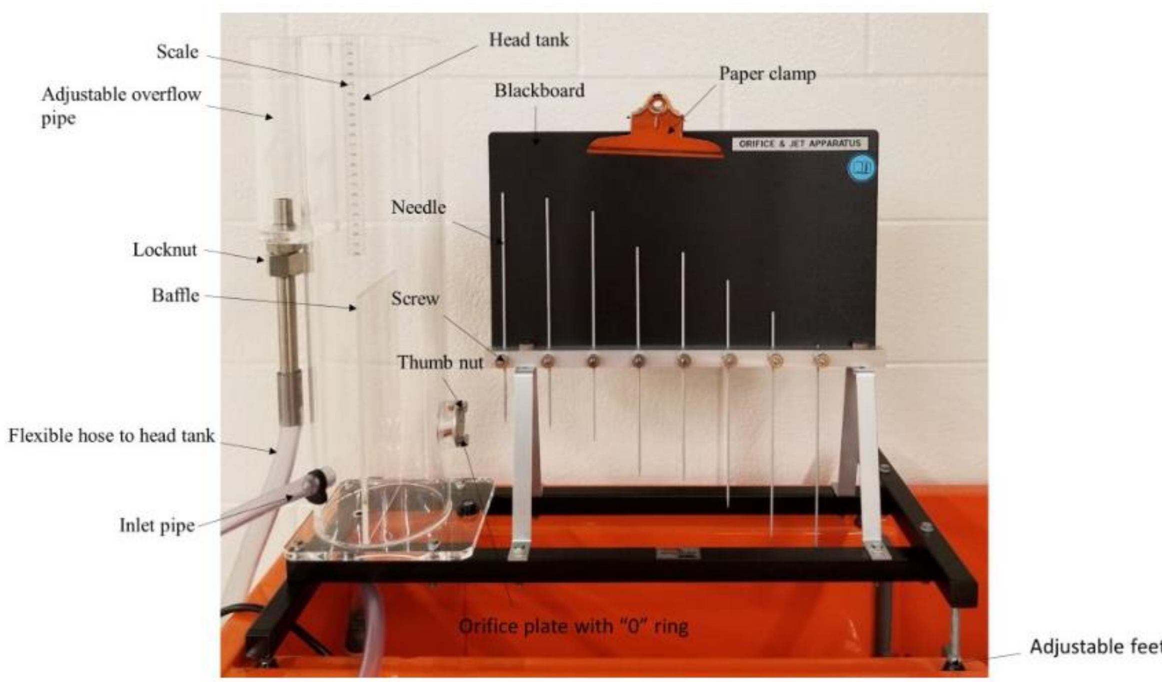


Figure 6.1: Armfield F1-17 Orifice and Jet Apparatus

7. THEORY

The orifice outflow velocity can be calculated by applying Bernoulli's equation (for a steady, incompressible, frictionless flow) to a large reservoir with an opening (orifice) on its side (Figure 6.2):

$$v_i = \sqrt{2gh} \qquad (1)$$

where *h* is the height of fluid above the orifice. This is the ideal velocity since the effect of fluid viscosity is not considered in deriving Equation 1. The actual flow velocity, however, is smaller than v_i and is calculated as:

$$v = C_v\sqrt{2gh} \qquad (2)$$

C_v is the *coefficient of velocity*, which allows for the effects of viscosity; therefore, $C_v<1$. The actual outflow velocity calculated by Equation (2) is the velocity at the **vena contracta,** where the diameter of the jet is the least and the flow velocity is at its maximum (Figure 6.2).

The actual outflow rate may be calculated as:

$$Q = vA_c \qquad (3)$$

where A_c is the flow area at the vena contracta. A_c is smaller than the orifice area, A_o (Figure 6.2), and is given by:

$$A_c = C_cA_o \qquad (4)$$

where C_c is the coefficient of contraction; therefore, $C_c < 1$.

Substituting *v* and A_c from Equations 2 and 4 into Equation 3 results in:

$$Q = C_vC_cA_0\sqrt{2gh} \qquad (5)$$

The product C_vC_c is called the coefficient of discharge, C_d; Thus, Equation 5 can be written as:

$$Q = C_dA_0\sqrt{2gh} \qquad (6)$$

The coefficient of velocity, C_v, and coefficient of discharge, C_d, are determined experimentally as follows.

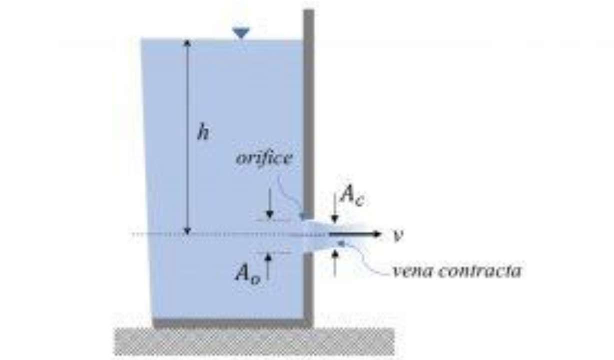


Figure 6.2: Orifice and Jet Flow Parameters

7.1. DETERMINATION OF THE COEFFICIENT OF VELOCITY

If the effect of air resistance on the jet leaving the orifice is neglected, the horizontal component of the jet velocity can be assumed to remain constant. Therefore, the horizontal distance traveled by jet (x) in time (t) is equal to:

$$x = v.t \qquad (7)$$

The vertical component of the trajectory of the jet will have a constant acceleration downward due to the force of gravity. Therefore, at any time, t, the y-position of the jet may be calculated as:

$$y = \frac{1}{2}gt^2 \qquad (8)$$

Rearranging Equation (8) gives:

$$t = (\frac{2y}{g})^{0.5} \qquad (9)$$

Substitution of t and *v* from Equations 9 and 2 into Equation 7 results in:

$$x = C_v\sqrt{2gh}(\frac{2y}{g})^{0.5} \qquad (10)$$

Equations (10) can be rearranged to find C_v:

$$C_v = \frac{x}{2\sqrt{yh}} \qquad (11)$$

Therefore, for steady flow conditions (i.e., constant h in the head tank), the value of C_v can be determined from the x, y coordinates of the jet trajectory. A graph of *x* plotted against will have a slope of $2C_v$.

7.2. DETERMINATION OF THE COEFFICIENT OF DISCHARGE

If C_d is assumed to be constant, then a graph of *Q* plotted against √h (Equation 6) will be linear, and the slope of this graph will be:

$$s = C_d A_o \sqrt{2g} \qquad (12)$$

This experiment will be performed in two parts. Part A is performed to determine the coefficient of velocity, and Part B is conducted to determine the coefficient of discharge.

Set up the equipment as follows:

- Locate the apparatus over the channel in the top of the bench.
- Using the spirit level attached to the base, level the apparatus by adjusting the feet.
- Connect the flexible inlet tube on the side of the head tank to the bench quick-release fitting.
- Place the free end of the flexible tube from the adjustable overflow on the side of the head tank into the volumetric. Make sure that this tube will not interfere with the trajectory of the jet flowing from the orifice
- Secure each needle in the raised position by tightening the knurled screw.

PART A: DETERMINATION OF COEFFICIENT OF VELOCITY FROM JET TRAJECTORY UNDER CONSTANT HEAD

- Install the 3-mm orifice in the fitting on the right-hand side of the head tank, using the two securing screws supplied. Ensure that the O-ring seal is fitted between the orifice and the tank.
- Close the bench flow control valve, switch on the pump, and then gradually open the bench flow control valve. When the water level in the head tank reaches the top of the overflow tube, adjust the bench flow control valve to provide a water level of 2 to 3 mm above the overflow pipe level. This will ensure a constant head and produce a steady flow through the orifice.
- If necessary, adjust the frame so that the row of needles is parallel with the jet, but is located 1 or 2 mm behind it. This will avoid disturbing the jet, but will minimize errors due to parallax.

- Attach a sheet of paper to the backboard, between the needles and board, and secure it in place with the clamp provided so that its upper edge is horizontal.
- Position the overflow tube to give a high head (e.g., 320 mm). The jet trajectory is obtained by using the needles mounted on the vertical backboard to follow the profile of the jet.
- Release the securing screw for each needle, and move the needle until its point is just immediately above the jet. Re-tighten the screw.
- Mark the location of the top of each needle on the paper. Note the horizontal distance from the plane of the orifice (taken as) to the coordinate point marking the position of the first needle. This first coordinate point should be close enough to the orifice to treat it as having the value of y=0. Thus, y displacements are measured relative to this position.
- The volumetric flowrate through the orifice can be determined by intercepting the jet, using the measuring cylinder and a stopwatch. The measured flow rates will be used in Part B.

- Repeat this test for lower reservoir heads (e.g., 280 mm and 240 mm)

Repeat the above procedure for the second orifice with diameter of 6 mm.

PART B: DETERMINATION OF COEFFICIENT OF DISCHARGE UNDER CONSTANT HEAD

- Position the overflow tube to have a head of 300 mm in the tank. (You may have to adjust the level of the overflow tube to achieve this.)
- Measure the flow rate by timed collection, using the measuring cylinder provided.

- Repeat this procedure for a head of 260 mm.

The procedure should also be repeated for the second orifice.

9.1. RESULTS

Use the following tables to record your measurements.

Raw Data Table: Part A

Needle No.	Orifice Diameter (m)	x (m)	Head (m)			y(m)		
			Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
1	0.003	0.014						
2		0.064						
3		0.114						
4		0.164						
5		0.214						
6		0.264						
7		0.314						
8		0.364						

Needle No.	Orifice Diameter (m)	x (m)	Head (m)			y(m)		
			Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
1	0.006	0.014						
2		0.064						
3		0.114						
4		0.164						
5		0.214						
6		0.264						
7		0.314						
8		0.364						

Raw Data Table: Part B

Test No.	Orifice Diameter (m)	Head (m)	Volume (L)	Time (s)
1	0.003			
2				
3				
4				
5				
6	0.006			
7				
8				
9				
10				

9.2. CALCULATIONS

Calculate the values of $(y.h)^{1/2}$ for Part A and discharge (Q) and ($h^{0.5}$) for Part B. Record your calculations in the following Result Tables.

The following dimensions of the equipment are used in the appropriate calculations. If necessary, these values may be checked as part of the experimental procedure and replaced with your

measurements [6].
– Diameter of the small orifice: 0.003 m
– Diameter of the large orifice: 0.006 m
– Pitch of needles: 0.05 m

Result Table- Part A

Needle No.	Orifice Diameter (m)	x (m)	Head (m)			y(m)			$(y.h)^{1/2}$(m)		
			Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
1	0.003	0.014									
2		0.064									
3		0.114									
4		0.164									
5		0.214									
6		0.264									
7		0.314									
8		0.364									

Needle No.	Orifice Diameter (m)	x (m)	Head (m)			y(m)			$(y.h)^{1/2}$(m)		
			Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
1	0.006	0.014									
2		0.064									
3		0.114									
4		0.164									
5		0.214									
6		0.264									
7		0.314									
8		0.364									

Result Table- Part B

Test No.	Orifice Diameter (m)	Head (m)	Volume (L)	Time (s)	Volume (m^3)	Q (m^3/sec)	$h^{0.5}$ ($m^{0.5}$)
1	0.003						
2							
3							
4							
5							
6	0.006						
7							
8							
9							
10							

10. REPORT

Use the template provided to prepare your lab report for this experiment. Your report should include the following:

- Table(s) of raw data
- Table(s) of results
- Graph(s)

Part A: On one chart, plot a graph of *x* values (y-axis) against $(y.h)^{1/2}$ values (x-axis) for each test. Calculate the slope of these graphs, using the equation of the best-fit for your experimental data and by setting the intercept to zero. Using Equation 11, calculate the coefficient of velocity for each orifice as:

$$C_v = \frac{average\ of\ the\ slopes\ from\ three\ experiments}{2}$$

Part B: Plot Q values (y-axis) against $(h)^{0.5}$ values (x-axis). Determine the slope of this graph, using the equation of the best- fit for your experimental data and by setting the intercept to zero. Based on Equation 12, calculate the coefficient of discharge for each orifice, using the equation of the best-fit for your experimental data and the following relationship:

$$C_d = \frac{slope\,of\,the\,graph}{A_o\sqrt{2g}}$$

- Find the recommended values for C_v and C_d of the orifices utilized in this experiment from reliable sources (e.g., textbooks). Comment on the agreement between the textbook values and experimental results, and give reasons for any differences.
- Comment on the significance of any experimental errors.

References

1. Daugherty, R.L., Franzini, J.B. and Finnemore, E.J., Fluid Mechanics with Engineering Applications, McGraw-Hill Book Co, Singapore-1989

2. Department of Water Resources Engineering, Bangladesh University of Engineering and Technology, Fluid Mechanics Sessional

DETERMINATION OF STATE OF FLOW AND CRITICAL DEPTH IN OPEN CHANNEL

week 6-7

Experiment No. 5

DETERMINATION OF STATE OF FLOW AND CRITICAL DEPTH IN OPEN CHANNEL

1.1 General

The state of open channel flow is mainly governed by the combined effect of viscous and gravity forces relative to the inertial forces. This experiment mainly deals with determination of the state of flow in an open channel at a particular section. The state of flow is very important, as the flow behavior depends on it. In order to construct different structures in rivers and canals and to predict the river response, the state of flow must be known. The experiment also deals with determination of critical depth, which is very useful in determining the types of flow in practice.

1.2 Theory

1.2.1State of flow

Depending on the effect of viscosity relative to inertia, the flow may be laminar, turbulent or transitional. The effect of viscosity relative to the inertia is expressed by the Reynolds number, given by

$$Re = \frac{VR}{\nu} \qquad (1.1)$$

Where, V is the mean velocity of flow, R is the hydraulic radius (=A/P), A is the wetted cross-sectional area, P is the wetted perimeter and ν is the kinematic viscosity of water. Kinematic viscosity varies with temperature. The values of kinematic viscosity of water at different temperatures are given in Table 1.1. The value of υ at 20^0C ($=1.003\times10^{-6}$ m^2/s) is normally used to compute the Reynolds number of open channel flow.

When,	$Re < 500$	the flow is laminar
	$500 \le Re \le 12{,}500$	the flow is transitional
	$Re > 12{,}500$	the flow is turbulent.

Most open channel flows including those in rivers and canals are turbulent. The Reynolds number of most open channel flows is high, of the order of 10^6, indicating that the viscous forces are weak relative to the inertia forces and do not play a significant role in determining the flow behavior.

When the flow is dominated by the gravity, then the type of flow can be identified by a dimensionless number, known as Froude Number. Given by

$$Fr = \frac{V}{\sqrt{gD}} \qquad (1.2)$$

Where, V is the mean velocity of flow, D is the hydraulic depth (= A/T), A is the cross-sectional area, T is the top width and g is the acceleration due to gravity (= 9.81 m/s^2).Depending on the effect of gravity relative to inertia, the flow may be subcritical, critical or supercritical-

When,	$Fr<1$	the flow is subcritical
	$Fr = 1$	the flow is critical
	$Fr>1$	the flow is supercritical.

The flow in most rivers and canals is subcritical. Supercritical flow normally occurs downstream of a sluice gate and at the foot of drops and spillways. The Froude number of open channel flow varies over a wide range covering both subcritical and supercritical flows and the state or behavior of open channel flow is primarily governed by the gravity force relative to the inertia force. Therefore, the Froude number is the most important parameter to indicate the state or behavior of open channel flow.

Depending on the numerical values of Reynolds and Froude numbers, the following four states of flow are possible in an open channel:

i) Subcritical laminar $Fr<1, Re<500$
ii) Supercritical laminar $Fr>1, Re<500$
iii) Subcritical turbulent $Fr<1, Re>12{,}500$
iv) Supercritical turbulent $Fr>1, Re>12{,}500$

The first two states of flow, subcritical laminar and supercritical laminar, are not commonly encountered in applied open channel hydraulics. Since the flow is generally turbulent is open channel, the last two states of flow are encountered is engineering problems.

Table 1.1 Kinematic viscosity of water at different temperatures

Temperature, ^{0}C	Kinematic viscosity, $\nu \times 10^{-6}$, m^2/s
0	1.781
5	1.518
10	1.307
15	1.139
20	1.003
25	0.890
30	0.798
40	0.653
50	0.547
60	0.466
70	0.404
80	0.354
90	0.315
100	0.282

1.2.2 Critical depth

Flow in an open channel is critical when the Froude number of the flow is equal to unity. Critical flow in a channel depends on the discharge and the geometry of channel section. For a rectangular section, the critical depth is given by

$$y_c = \sqrt[3]{\frac{Q^2}{gB^2}} \qquad (1.3)$$

Where, y_c is the critical depth, Q is the discharge and B is the width of the channel.

When the depth is greater than the critical depth, the flow is subcritical. When the depth is less than the critical depth, the flow is supercritical.

1.3 Objectives of the experimen

1) To measure water depth both upstream and downstream of a weir.
2) To determine the Reynolds number (Re) and the Froude number (Fr).
3) To determine the state of flow.
4) To determine critical depth (y_c).
5) To observe the subcritical and the supercritical flows.

1.4 Experimental setup

To develop different states of flow, the following laboratory setup is used.

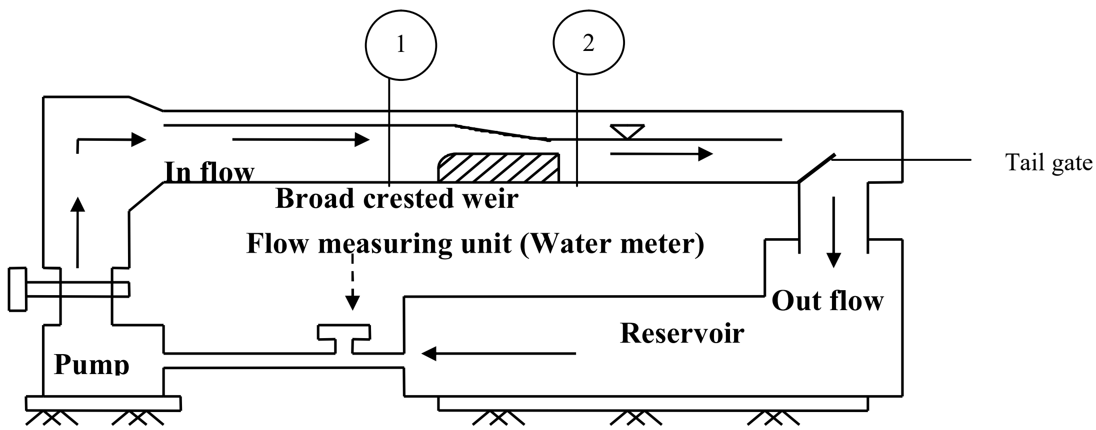


Fig. 1.1 Schematic diagram of experimental setup

1.5 Procedure

i) Measure the depth of flow at sections 1 and 2 by a point gage.
ii) Take the reading of discharge.
iii) Calculate the velocity at both the sections.
iv) Calculate Re and Fr for both the sections using Eqs. (1.1) and (1.2) and determine the state of flow.
v) Calculate the critical depth y_c using Eq. (1.3).

1.6 Assignment

1. Why the state of flow and the critical depth of a river or canal need to be determined?
2. How can you determine that the flow in a river is subcritical, critical or supercritical without taking any measurement?
3. State why the Froude number is more significant than the Reynolds number to determine the state of open channel flow.

DATA SHEET

Experiment Name :
Experiment Date :

Student's Name :
Student's ID :
Year/ Semester :
Section/ Group :

Discharge, Q = cm^3/s Flume width, B = cm

Critical depth, y_c = cm Temperature = °C

Kinematic viscosity, ν = cm^2/s

Section	Depth of flow y (cm)		Area A=B y (cm^2)	Perimeter P=(B+2y) (cm)	Hydraulic Radius R=A/P (cm)	Hydraulic Depth D=A/T (cm)	Velocity V=Q/(By) (cm/s)	Froude number Fr	Reynolds number Re	State of flow
1										
2										

Course Teacher :
Designation :

Signature

FLOW OVER A BROAD -CRESTED WEIR

Week 8-9

Experiment No. 6

FLOW OVER A BROAD-CRESTED WEIR

2.1 General

A broad-crested weir is an overflow structure with a truly level and horizontal crest. It is widely used in irrigation canals for the purpose of flow measurement as it is rugged and can stand up well under field conditions. But practically some problems arise with the weir, as there exists a dead water zone at the upstream of the weir and the head loss is more comparable to other devices. By virtue of being a critical depth meter, the broad crested weir has the advantage that it operates effectively with higher downstream water levels than a sharp crested weir. This experiment deals with measurement of discharge using the broad-crested weir and also calibration of the weir

2.2 Theory

2.2.1 Description of the weir

The broad-crested weir has a definite crest length in the direction of flow. In order to maintain a hydrostatic pressure distribution above the weir crest, i.e. to maintain the streamlines straight and parallel, the length of the weir is designed such that $0.07 \leq H_1/L \leq 0.50$ where H_1 is the head above the crest and L is the length of the weir (Fig. 2.1). Under this condition, critical flow occurs over the weir at section A-A and the weir provides an excellent means of measuring discharge in open channels based on the principle of critical flow. The upstream corner of the weir is rounded in such a manner that flow separation does not occur.

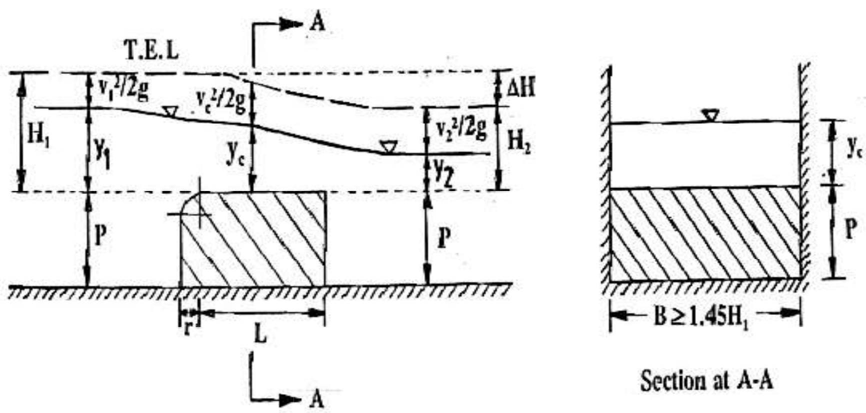


Fig. 2.1 Flow over a broad-crested weir

2.2.2 Theoretical discharge

Consider a rectangular broad-crested weir shown in Fig. 2.1. Based on the principle of critical flow (Fr = 1), the theoretical discharge Q_t over the weir is given by

$$Q_t = \sqrt{g} B y_c^{1.5} \qquad (2.1)$$

Where, B is the width of the weir, y_c is the critical depth and g is the acceleration due to gravity.

The usual difficulty in using Eq. (2.1) for computing discharge lies in locating the critical flow section and measuring the critical depth accurately. This difficulty is, however, overcome by measuring the depth of flow upstream of the weir where the flow is not affected by the presence of the weir. With reference to Fig. 2.1, neglecting the frictional losses and applying the energy equation between the upstream section and the critical flow section, we obtain

$$H_1 = y_c + \frac{V_c^2}{2g}$$

Where, V_c is the critical velocity. Since at the critical state of flow, the velocity head is equal to one-half of the hydraulic depth (D) and for a rectangular channel D = y, the above equation gives

$$H_1 = y_c + \frac{V_c^2}{2g} = y_c + \frac{D_c}{2} = y_c + \frac{y_c}{2} = \frac{3}{2} y_c$$

so that

$$y_c = \frac{2}{3} H_1$$

and Eq.(2.1) becomes

$$Q_t = (2/3)^{1.5} \sqrt{g}\, BH_1^{1.5} \qquad (2.2)$$

2.2.3 Coefficient of discharge

Due to the assumptions made in the derivation of the governing equation, the theoretical discharge and the actual discharge always vary from each other. So, the coefficient of discharge is introduced. If Q_a is the actual discharge, then the coefficient of discharge, C_d, is given by

$$C_d = Q_a/Q_t \qquad (2.3)$$

Then

$$Q_a = C_d (2/3)^{1.5} \sqrt{g}\, BH_1^{1.5} \qquad (2.4)$$

The coefficient of discharge for a broad-crested weir depends on the length of the weir and whether the upstream corner of the weir is rounded or not. Normally, in a field installation it is not possible to measure the energy head H_1 directly and therefore the discharge is related to the upstream depth of flow over the crest, y_1, by the equation

$$Q_a = C_v C_d (2/3)^{1.5} \sqrt{g}\, By_1^{1.5} \qquad (2.5)$$

Where, C_v is the correction coefficient for neglecting the velocity head in the approach channel. Generally the effect of C_v is considered in C_d and finally the governing equation becomes

$$Q_a = C_d (2/3)^{1.5} \sqrt{g}\, By_1^{1.5} \qquad (2.6)$$

and

$$Q_t = (2/3)^{1.5} \sqrt{g}\, By_1^{1.5} \qquad (2.7)$$

2.2.4 Calibration

Calibration is the act of obtaining a definite relationship for the measuring device using the sets of known data. For a broad-crested weir, the Eq.2.7 can be expressed as a relationship between the upstream depth and the discharge, i.e. $Q = ky_1^n$. This relation is known as stage discharge equation for discharge measurement. So calibration deals with determination of coefficient k and exponent n using the sets of experimental data and develop the equation $Q = ky_1^n$ so that the equation can be useful for flow estimation. The plotting of the calibrated equation is known as calibration curve for the measuring device. There are two different ways to develop a calibration equation. These are

i) Plotting best fit line by eye estimation.
ii) Developing best fit line by regression.

By eye estimation

As $\log Q = \log k + n \log y_1$, so if Q and y_1 are plotted in a log log paper, the line will represent a straight line. Different sets of Q and y_1 are plotted in a log log paper keeping y_1 along the x axis and Q along the y axis. The best fit line is drawn by eye estimation. The slope of the line gives the value of n. Then for any value of y the corresponding value of Q is found from the best fit line. Using these values of y, Q and n, the value of k can be found form the equation $Q = ky_1^n$.

By regression

From $Q = ky_1^n$, we have

$$\log Q = \log k + n \log y_1$$

Putting $\log Q = Y$, $\log k = K$ and $\log y_1 = X$, we obtain

$$Y = K + nX$$

Then

$$n = \frac{N(\sum XY) - (\sum X)(\sum Y)}{N(\sum X^2) - (\sum X)^2}$$

$$K = \frac{\sum Y - n\sum X}{N}$$

$$k = \text{antilog } K$$

where N is the number of sets of Q and y_1 plotted. The correlation coefficient r is given by

$$r = \frac{N\left(\sum XY\right) - \left(\sum X\right)\left(\sum Y\right)}{\left(\sqrt{N\left(\sum X^2\right) - \left(\sum X\right)^2}\right)\left(\sqrt{N\left(\sum Y^2\right) - \left(\sum Y\right)^2}\right)}$$

For a perfect correlation, r = 1.0. If r is between 0.6 and 1.0, it is generally taken as a good correlation.

2.3 Objectives of the experiment

i) To determine the theoretical discharge of the weir.
ii) To measure the actual discharge and hence to find out the coefficient of discharge.
iii) To calibrate the weir.

2.4 Experimental setup

The experimental setup for this experiment is given below.

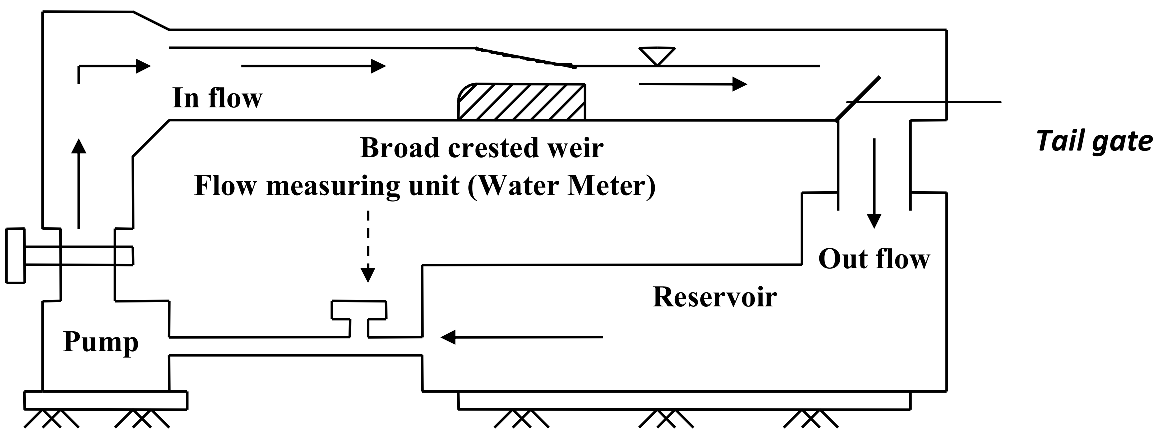


Fig. 2.2 Setup for flow over a broad-crested weir

2.5 Procedure

To determine the theoretical and the actual discharges and the coefficient of discharge

i) Measure the upstream water level over the weir y_1 at three points, then find the average depth and determine the theoretical discharge using Eq. (2.7).
ii) Take the reading of actual discharge and hence find the coefficient of discharge using Eq. (2.3).

To calibrate the weir by eye estimation (should be done by students having odd student number)

i) Plot the actual discharges against the corresponding upstream depths in a log log paper and find the value of n and k as discussed in Art. 2.2.4.
ii) Develop the relationship $Q = ky_1^n$.

To calibrate the weir by regression (should be done by students having even student number)

i) Form a table having columns for Q, y_1, X, Y, XY, X^2, Y^2 as discussed in Art. 2.2.4 and find the value of n, k and r .
ii) Compare the equation with that obtained by the eye estimation method.

2.6 Shape of Q vs y graph

In a plain graph paper the plot of $Q = ky^n$ is non-linear. But in a log log paper $Q = ky^n$ plots as a straight line since $\log Q = \log k + n \log y$ which is an equation of a straight line (of the form $y = mx + c$).

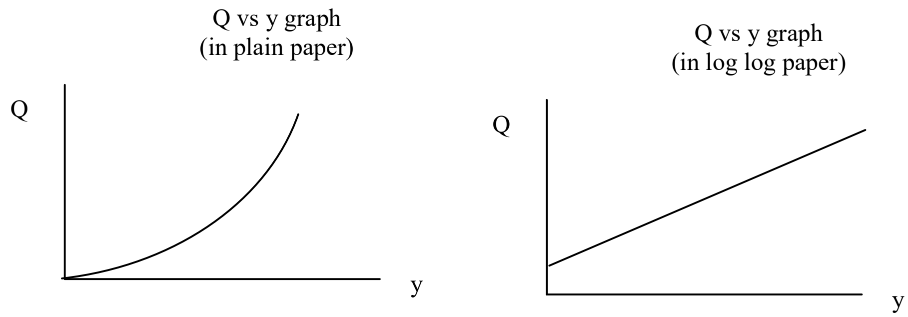


Fig. 2.3: Q (actual discharge) vs y(upstream depth of water above weir) graph

2.7 Assignment

1. What are the advantage, disadvantage and use of a broad-crested weir?
2. Why is it necessary to calibrate a broad-crested weir?
3. A broad-crested weir is designed so that $0.07 \leq H_1/L \leq 0.50$. What do the upper and lower limits of H_1/L signify?

DATA SHEET

Experiment Name :
Experiment Date :

Student's Name :
Student's ID :
Year/ Semester :
Section/ Group :

Length of the weir, L = cm Width of the weir (or flume), B = cm

Depth of water over weir crest (cm)		Theoretical discharge Q_t (cm^3/s)	Actual discharge Q_a (cm^3/s)	Coefficient of discharge C_d

Calibration of the weir

i) By eye estimation (should be done by students having odd student number)

Actual discharge ,Q_a (cm^3/s)	Depth of water above weir crest, y_1 (cm)

ii) By regression (should be done by students having even student number)

y_1	Q_a	$X=\log y_1$	$Y=\log Q$	XY	X^2	Y^2
		$\sum X=$	$\sum Y=$	$\sum XY=$	$\sum X^2=$	$\sum Y^2=$

Course Teacher :
Designation :

Signature

FLOW THROUGH A VENTURI FLUME

Week 10

Experiment No. 7

FLOW THROUGH A VENTURI FLUME

3.1 General

Although weirs are an effective method of artificially creating a critical section at which the flow rate can be determined, a weir installation has at least two disadvantages. First, the use of weirs results in relatively high head loss. Second, most weirs create a dead water zone upstream of it which can serve as a settling basin for sediment and other debris present in the flow. Both of these disadvantages can be overcome with an open flume having a contraction in width which is sufficient to cause the flow to pass through a critical depth. Venturi flume is an open flume used widely in irrigation canals for measuring discharge But Venturi flumes have a disadvantage that there is relatively small head difference between the upstream section and the critical section, especially at low Froude numbers. This experiment deals with measurement of discharge using a Venturi flume and also calibration of the flume.

3.2 Theory

3.2.1 Description of the flume

Venturi flume has a converging section, a throat section and a diverging section. The bed level is kept horizontal. The streamlines run parallel to each other at least over a short distance upstream of the flume.

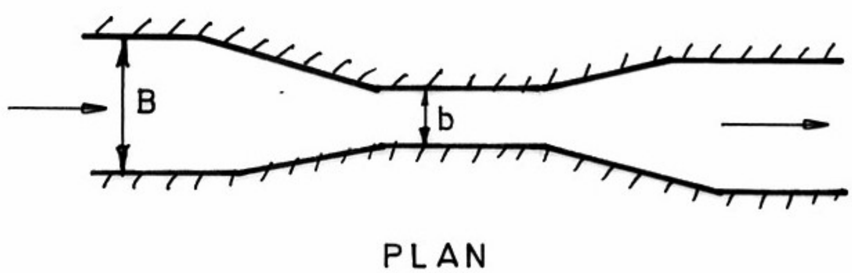


Fig. 3.1 Flow through a Venturi flume

3.2.2 Theoretical discharge at free flow condition

Considering that critical flow occurs at the throat section of the flume, the theoretical discharge at free flow is given by

$Q_{tf} = AV = A_c V_c$

Where, A_c and V_c are the area and velocity at the critical flow section of the flume. At the critical state of flow

$$Fr = 1$$

or

$$\frac{V_c^2}{gD_c} = 1$$

or

$$V_c = \sqrt{gD_c}$$

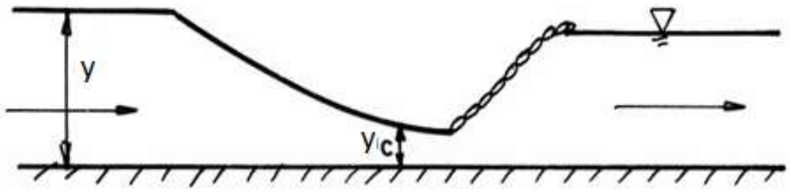


Fig. 3.2 Free flow condition

Now, for a rectangular flume, $A_c = by_c$ and $D_c = y_c$, where b is the width of the Venturi flume at the throat section. Hence, the theoretical discharge at free flow given by

$$Q_{tf} = A_c V_c = b y_c \sqrt{g y_c} \qquad (3.1)$$

For a rectangular channel at critical condition there exists a relationship between total head and the critical depth as

$$H = \frac{3}{2} y_c$$

Hence, putting

$$y_c = \frac{2}{3} H$$

in Eq.(3.1), we obtain

$$Q_{tf} = (2/3)^{1.5} \sqrt{g}\, bH^{1.5} \qquad (3.2)$$

Where, H is the head measured sufficiently upstream of the flume.

3.2.3 Theoretical discharge at submerged flow condition

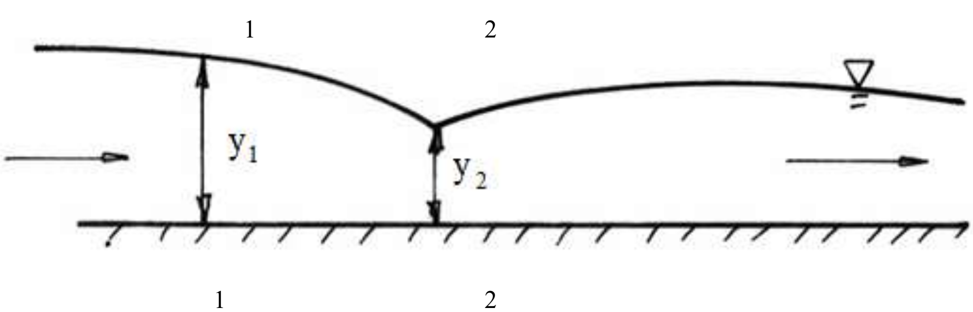


Fig. 3.3 Submerged flow condition

No critical flow section exists at submerged flow condition. Considering Fig 3.3, applying the energy equation between sections 1and 2 neglecting frictional losses, we obtain

$$y_1 + \frac{V_1^2}{2g} = y_2 + \frac{V_2^2}{2g}$$

which gives

$$V_2^2 (1 - \frac{V_1^2}{V_2^2}) = 2g(y_1 - y_2)$$

If A and a are the wetted areas at sections 1 and 2, respectively, then using the continuity equation

$AV_1 = aV_2$

we obtain

$$\frac{V_1}{V_2} = \frac{a}{A}$$

If we assume

$$M = \frac{V_1}{V_2} = \frac{a}{A}$$

Then

$$V_2^2 (1 - M^2) = 2g(y_1 - y_2)$$

so that

$$V_2 = \sqrt{\frac{2g(y_1 - y_2)}{1 - M^2}}$$

Hence, the theoretical discharge at submerged flow condition

$$Q_{ts} = aV_2 = a\sqrt{\frac{2g(y_1 - y_2)}{1 - M^2}} \qquad (3.3)$$

3.2.4 Coefficient of discharge

Due to the assumptions made in the derivation of the governing equation, the theoretical discharge and the actual discharge always vary from each other. So, the coefficient of discharge C_d is introduced. If Q_a is the actual discharge, then the coefficient of discharge at free flow condition, C_{df}, is given by

$$C_{df} = Q_a/Q_{tf} \qquad (3.4)$$

Normally, in a field installation it is not possible to measure the energy head H directly and therefore the discharge is related to the upstream depth of flow y_1 by the equation

$$Q_a = C_v C_{df} (2/3)^{1.5} \sqrt{g}\, b y_1^{1.5} \qquad (3.5)$$

Where, C_v is the correction coefficient for neglecting the velocity head in the approach channel. Generally the effect of C_v is considered in C_d and finally the governing equations become

$$Q_a = C_{df} (2/3)^{1.5} \sqrt{g}\, b y_1^{1.5} \qquad (3.6)$$

and

$$Q_{tf} = (2/3)^{1.5} \sqrt{g}\, b y_1^{1.5} \qquad (3.7)$$

The coefficient of discharge at submerged flow condition, C_{ds} is given by

$$C_{ds} = Q_a/Q_{ts} \qquad (3.8)$$

3.2.5 Calibration

Calibration is the act of obtaining a definite relationship for the measuring device using the sets of known data. For a broad-crested weir there is a definite relationship between the upstream depth and the discharge, i.e. $Q = ky_1^n$. This relation is known as the calibration equation for the device. So calibration deals with determination of k and n and develop the equation $Q = ky_1^n$. The plotting of the calibration equation is known as calibration curve. There are two different ways to develop a calibration equation. These are

i) Plotting best fit line by eye estimation.
ii) Developing best fit line by regression.

By eye estimation

As $\log Q = \log k + n \log y_1$, so if Q and y_1 are plotted in a log log paper, the line will represent a straight line. Different sets of Q and y_1 are plotted in a log log paper keeping y_1 along the x axis and Q along the y axis. The best fit line is drawn by eye estimation. The slope of the line gives the value of n. Then for any value of y the corresponding value of Q is found from the best fit line. Using these values of y, Q and n, the value of k can be found form the equation $Q = ky_1^n$.

By regression

From $Q = ky_1^n$, we have

$$\log Q = \log k + n \log y_1$$

Putting $\log Q = Y$, $\log k = K$ and $\log y_1 = X$, we obtain

$$Y = K + nX$$

Then

$$n = \frac{N(\sum XY) - (\sum X)(\sum Y)}{N(\sum X^2) - (\sum X)^2}$$

$$K = \frac{\sum Y - n\sum X}{N}$$

$$k = \text{antilog } K$$

Where, N is the number of sets of Q and y_1 plotted. The correlation coefficient r is given by

$$r = \frac{N\left(\sum XY\right) - \left(\sum X\right)\left(\sum Y\right)}{\left(\sqrt{N\left(\sum X^2\right) - \left(\sum X\right)^2}\right)\left(\sqrt{N\left(\sum Y^2\right) - \left(\sum Y\right)^2}\right)}$$

For a perfect correlation, r = 1.0. If r is between 0.6 and 1.0, it is generally taken as a good correlation.

3.3 Objectives of the experiment

i) To determine the theoretical discharge of the flume at free flow and submerged flow conditions.

ii) To measure the actual discharge and hence to find out the coefficient of discharge at free flow and submerged flow conditions.

iii) To calibrate the flume.

3.4 Experimental setup

The experimental setup for this experiment is given below.

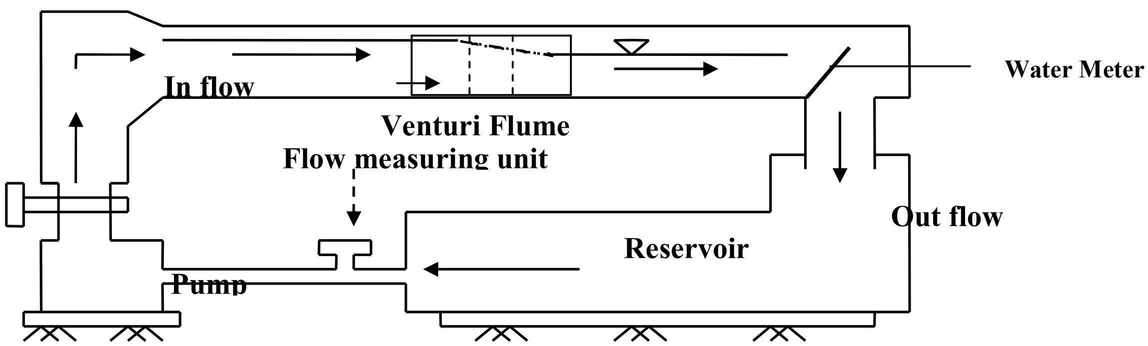


Fig. 3.4 Setup for flow through a Venturi flume

3.5 Procedure

To determine the theoretical and the actual discharges and the coefficient of discharge at free flow condition

i) Measure the depth of flow sufficiently upstream of the flume and determine the theoretical discharge using Eq.(3.7).

ii) Take the reading of actual discharge and hence find the coefficient of discharge using Eq. (3.4).

To determine the theoretical and the actual discharges and the coefficient of discharge in submerged flow condition

i) Measure the flow depths at sections 1 and 2 shown in Fig. 3.3 and determine the theoretical discharge using Eq.(3.3).

ii) Take the reading of actual discharge and hence find the coefficient of discharge using Eq. (3.8).

To calibrate the flume (for free flow condition only) by eye estimation (should be done by students having even student number)

i) Plot the actual discharge against the corresponding upstream depth in a log log paper and find the values of n and k as discussed in Art. 3.2.5.

ii) Develop the relationship $Q = ky_1^n$.

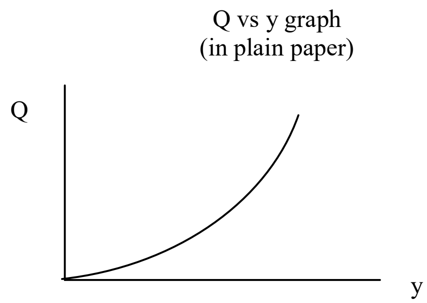
To calibrate the flume (for free flow condition only) by regression (should be done by students having odd student number)

i) Form a table having columns for Q, y_1, X, Y, XY, X^2, Y^2 as discussed in Art.3.2.5 and find the values of n, k and r.

ii) Compare the equation with that obtained by the eye estimation method.

3.6 Shape of Q vs y graph

In a plain graph paper the plot of $Q = ky^n$ is non-linear. But in a log log paper $Q = ky^n$ plots as a straight line since $\log Q = \log k + n \log y$ which is an equation of a straight line (of the form $y = mx + c$).



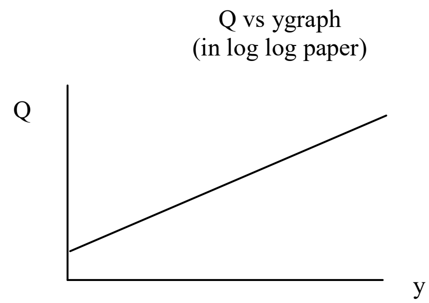


Fig. 3.5: Q (actual discharge) vs y(upstream depth of water) graph

3.7 Assignment

1. What are the advantage, disadvantage and use of a Venturi flume?
2. What is the difference between free and submerged flows? How can you produce submerged flow in a laboratory flume? What is the effect of submergence on the flow?

DATA SHEET

Experiment Name :
Experiment Date :

Student's Name :
Student's ID :
Year/ Semester :
Section/ Group :

Channel width, B = cm Throat width, b = cm

Actual discharge Q_a (cm^3/s)	Free flow condition			Submerged flow condition				
	y_1 (cm)	Q_{tf} (cm^3/s)	C_{df}	y_1 (cm)	y_2 (cm)	M	Q_{ts} (cm^3/s)	C_{ds}

Calibration of the flume:

i) By eye estimation (should be done by students having odd student number)

Actual discharge ,Q_a (cm^3/s)	Depth of water at upstream, y_1 (cm)

ii) By regression (should be done by students having odd student number)

y_1	Q_a	$X=\log y_1$	$Y=\log Q$	XY	X^2	Y^2
		$\sum X=$	$\sum Y=$	$\sum XY=$	$\sum X^2=$	$\sum Y^2=$

Course Teacher :
Designation :

Signature

FLOW THROUGH A PARSHALL FLUME

Week 11-12

Experiment No. 8

FLOW THROUGH A PARSHALL FLUME

4.1 General

The problem with a Venturi flume is that there is a relatively small head difference between the upstream section and the critical section. This problem can be overcome by designing a flume which has a contracted throat section in which critical flow occurs followed by a short length of supercritical flow and a hydraulic jump at the exit section. A flume of this type was designed by R.L. Parshall and is widely known as the Parshall flume. Practically this type of flume is used in small irrigation canals for flow measurement purpose. It is better than all other devices discussed before as it is more accurate, can withstand a relatively high degree of submergence over a wide range of backwater condition downstream from the structure and it acts as a self-cleaning device due to the fact that high velocity washes out the debris and sediments present in the flow. However, when a heavy burden of erosion debris is present in the stream, the Parshall flume becomes invalid like weir, because deposition of debris will produce undesirable result. Another problem which arises with this flume is that the fabrication is complicated and also fabrication should be done as per requirement. This experiment deals with the measurement of discharge using a Parshall flume.

4.2 Theory

4.2.1 Description of the flume

A Parshall flume consists of a broad flat converging section, a narrow downward sloping throat section and an upward sloping diverging section. The reason of downward sloping throat section is to increase the head difference between the upstream section and the critical section. The upward slope in the diverging section is given to produce a high tailwater depth which reduces the length of the supercritical flow region.

4.2.2 Theoretical discharge

The Parshall flume is a calibrated device i.e. there exists a definite depth-discharge relationship for the flume. So, analytic determination of theoretical discharge is not required for this flume. Similar to other types of device, the discharge through a Parshall flume is given by

$$Q_t = KH_a^n \qquad (4.1)$$

where K is a constant which depends on the system of units used, n is an exponent and H_a is the upstream depth measured at the location shown in Fig. 4.1.

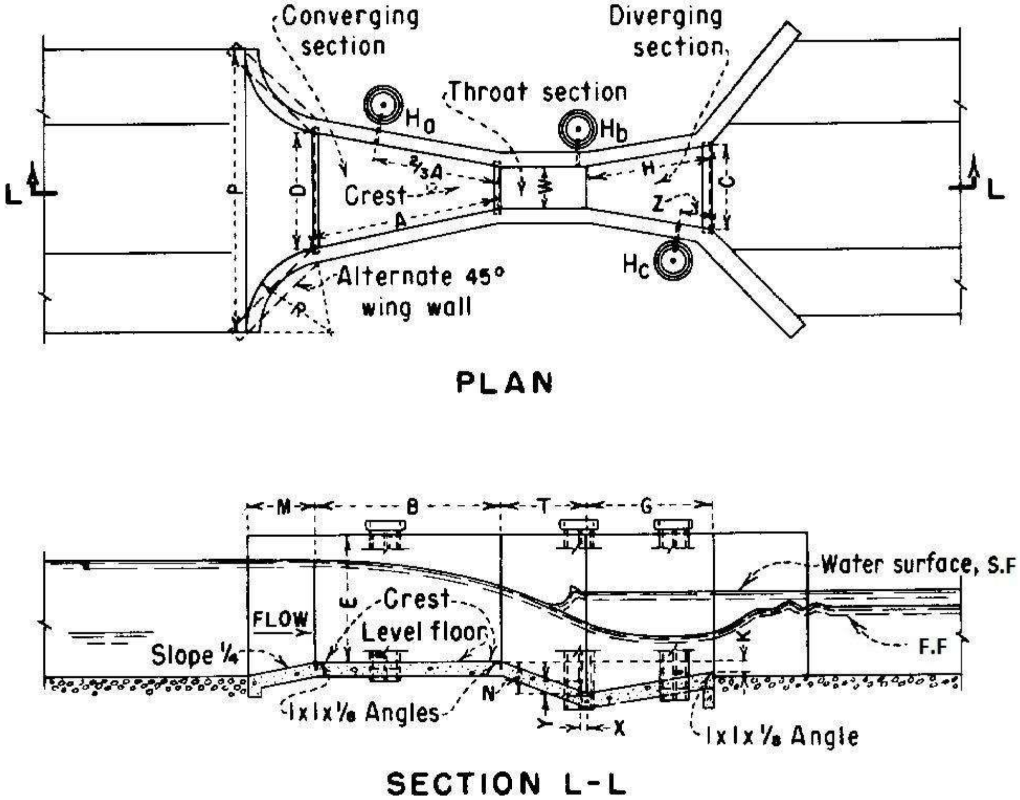


Fig. 4.1 Flow through Parshall flume

The values of K and n depend on the throat width and are given in Table 4.1. According to this table, for free flow condition, the depth-discharge relationship of a Parshall flume of 6″ throat width which is normally used in the laboratory, as calibrated empirically, is given by

$Q_{tf}= 2.06\ H_a^{1.58}$ (4.2)

Where, Q_{tf} is in ft^3/s and H_a is in ft.

Table 4.1 Values of K and n for different throat widths

Throat width	Equation
3″	$Q= 0.992\ H_a^{1.547}$
6″	$Q= 2.06\ H_a^{1.58}$
9″	$Q= 3.07\ H_a^{1.53}$
12″ to 8′	$Q = 4WH_a^{1.552W^{0.026}}$
10′ to 50′	$Q= (3.6875W + 2.5)\ H_a^{1.6}$

In the above equation, Q is the free discharge in cfs, W is the width of the throat in ft and H_a is the gage reading in ft.

4.2.3 Coefficient of discharge

The actual discharge always varies with the theoretical discharge of the flume. So the introduction of a coefficient of discharge is necessary. If the actual discharge Qa is measured by the water meter, the coefficient of discharge is given by

$C_{df}= Q_a/Q_{tf}$ (at free flow condition) (4.3)

$C_{ds}= Q_a/Q_{ts}$ (at submerged flow condition) (4.4)

4.2.4 Percentage of submergence

The percentage of submergence for the Parshall flume is given by $100H_b/H_a$, where H_b is the downstream depth measured from the invert datum. When the percentage of submergence exceeds 0.6, the discharge through the Parshall flume is reduced. The discharge of Parshall flume then determined from figure 4.3.

4.3 Objectives of the experiment

i. To determine the theoretical discharge at the free flow condition.
ii. To determine the theoretical discharge at the submerged flow condition.
iii. To determine the coefficient of discharge C_d for both the free and submerged flow conditions.
iv. To verify the values of K and n.

4.4 Experiment setup

The experiment setup is given below.

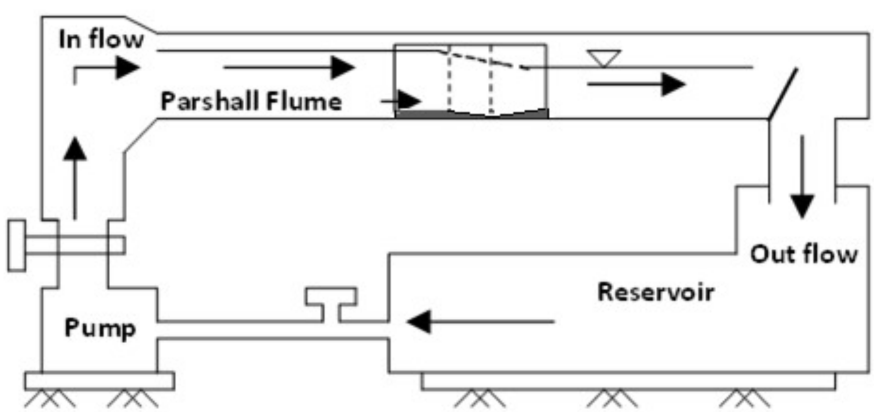
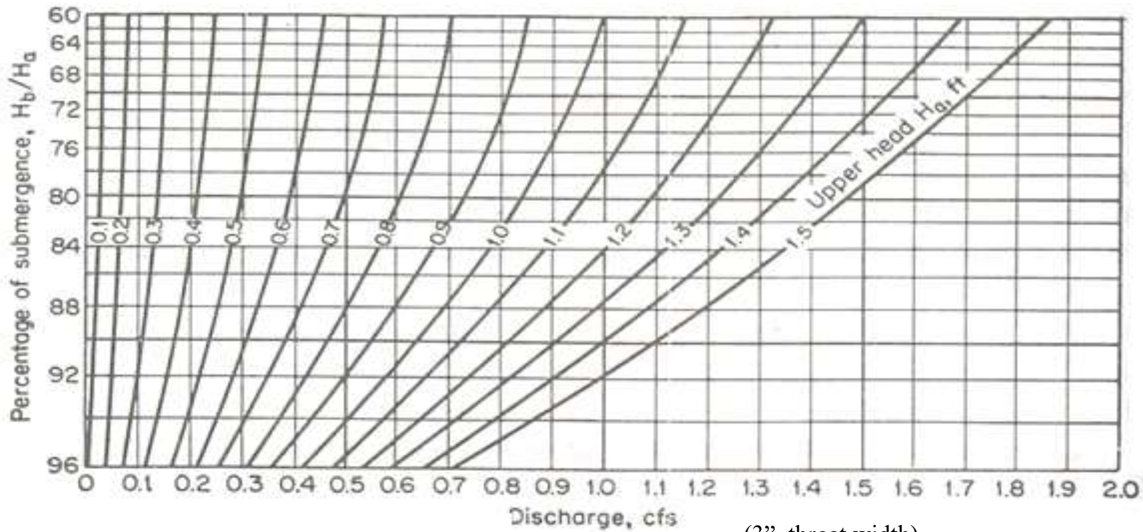
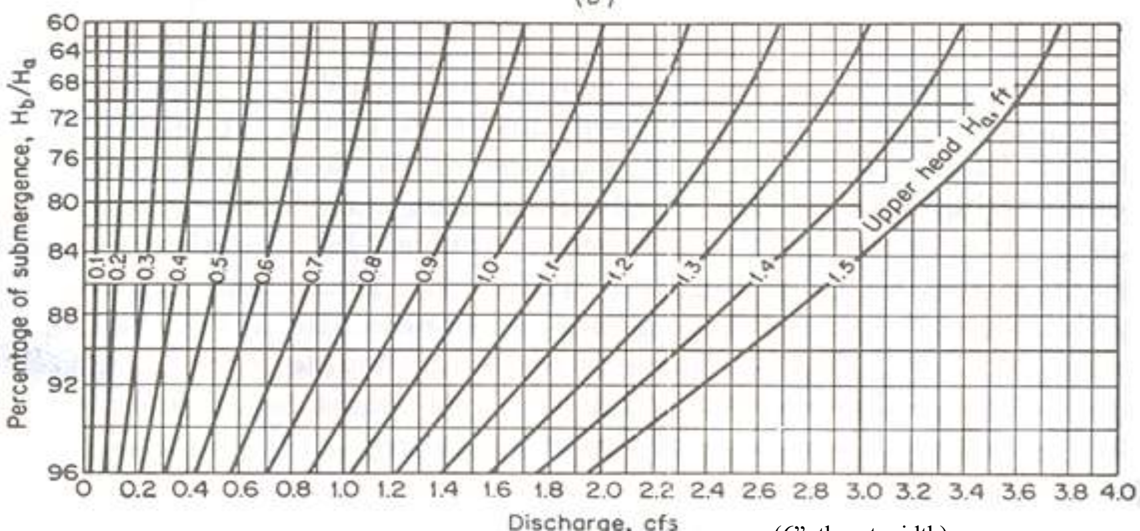


Fig.4.2 Setup for flow through a Parshall flume



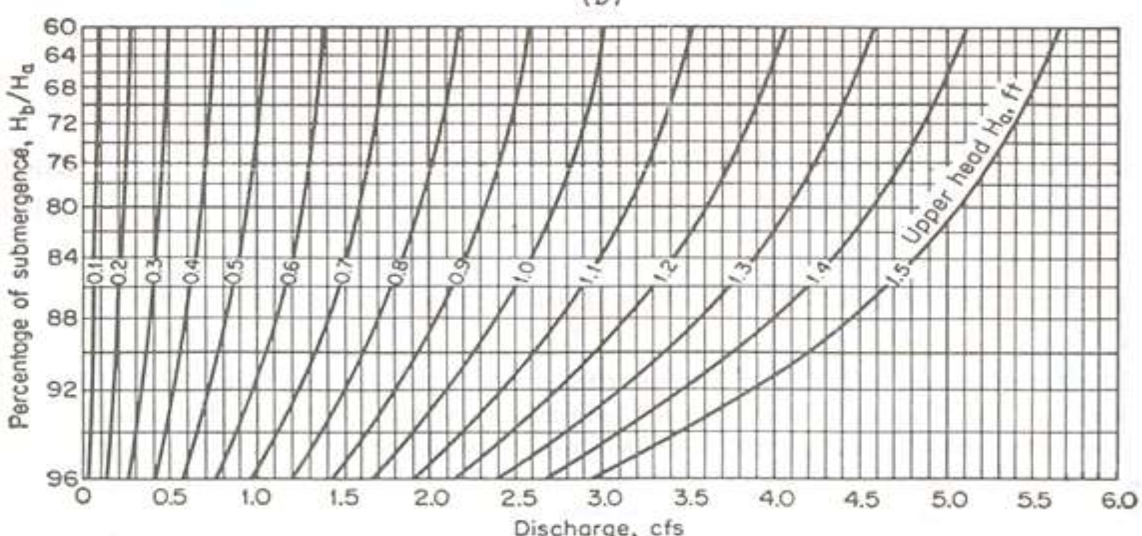
(3" throat width)

(a)



(6" throat width)

(b)



(9" throat width)

(c)

Fig.4.3 The submerged flow for Parshall flumes of various sizes

4.5 Procedure

To determine the theoretical discharge at the free flow condition

i) Measure the head H_a.

ii) Compute Q_{tf}using Eq.(4.2).

To determine the theoretical discharge at the submerged flow condition

i) Measure the heads H_a and H_b.

ii) Compute Q_{tf} using Eq.(4.2).

iii) Find the % of submergence, $100H_b/H_a$.

iv) If the % of submergence exceeds 60%, find the discharge from Fig. 4.3.

To determine the coefficient of discharge, measure the actual discharge from the water meter and calculate C_{df} and C_{ds} using Eqs.(4.3) and (4.4).

To verify the values of K and n

i) Plot $Q_a$vs H_a in a log log paper.

ii) Slope of the plotted line gives the value of n.

iii) Using the value of n for any set of values of Q_a and H_a, find K using Eq.(4.1).

4.6 Shape of Q vs H_a graph

In a plain graph paper the plot of $Q = KH_a^n$ is a non-linear. But in a log log paper $Q = KH_a^n$ plots as a straight line since $\log Q = \log K + n \log H_a$ which is the equation of a straight line (of the form $y = mx + c$).

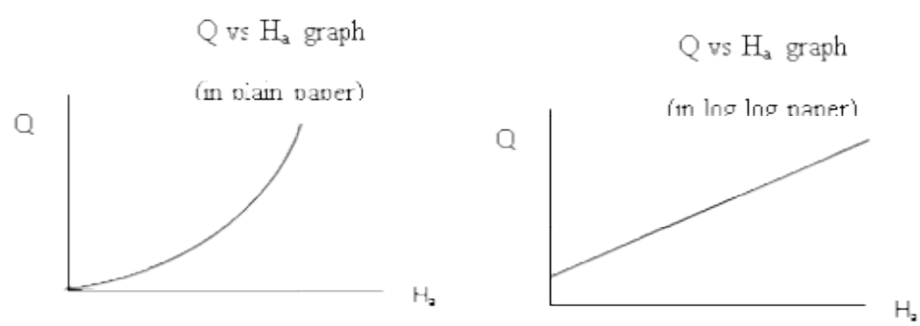


Fig. 4.4 Q (actual discharge) vs H_a (upstream depth of water) graph

4.7 Assignment

1. What are the advantage, disadvantage and use of a Parshall flume?

2. Why a downward narrow section and an upward diverging section are provided in a Parshall flume?

DATA SHEET

Experiment Name :
Experiment Date :

Student's Name :
Student's ID :
Year/ Semester :
Section/ Group :

Throat width, W = in Actual discharge, Q_a = ft^3/s

Free flow condition			Submerged flow condition				
H_a (ft)	Q_{tf} (ft^3/s)	C_{df}	H_a (ft)	H_b (ft)	% Submergence $=(H_b/H_a)*100\%$	Q_{ts} (ft^3/s)	C_{ds}

Verification of K and n

Actual discharge ,Q_a (ft^3/s)	H_a (ft)

Course Teacher :
Designation :

Signature

Practice ,review & Lab Report Assessment,Self study

Week 13-14

Lab Test, Viva, Quiz, Overall Assessment, Skill Development Test (Competency)

Week 15-17