"CHARACTERISTICS OF HYDRAULIC JUMP IN RECTANGULAR CHANNEL FOR DIFFERENT SLOPES"

A Thesis Submitted In Partial Fulfilment of the Requirement for the Award Of

MASTER OF TECHNOLOGY

IN

HYDRAULICS AND FLOOD ENGINEERING

By

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JULY 2015

CANDIDATE'S DECLARATION

I do hereby certify that the work presented is the report entitled "**CHARACTERISTICS OF HYDRAULIC JUMP IN RECTANGULAR CHANNEL FOR DIFFERENT SLOPES**" in the partial fulfillment of the requirements for the award of the degree of "Master of Technology" in Hydraulics & Flood engineering submitted in the Department of Civil Engineering, Delhi Technological University, is an authentic record of our own work carried out from January 2015 to July 2015 under the supervision of Dr. Munender Kumar (Associate Professor), Department of Civil Engineering.

I have not submitted the matter embodied in the report for the award of any other degree or diploma.

Vikas Baliya

Date:31/7/15 (2K13/HFE/07)

CERTIFICATE

This is to certify that above statement made by the candidate is correct to best of my knowledge.

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ABSTRACT

Study of the characteristics of hydraulic jump in a rectangular channel at different slope has been carried out in the present work. The study involves both experimental investigation and analytical computation. In the end comparisons are made between analytical and experimental results. The experiments have been carried out in the rectangular horizontal channel in the hydraulics laboratory of the department of Civil Engineering, Delhi Technological University. The necessary related instrumentations have been designed and installed as part of the present work. The efficiency, relative height of jump, relative energy loss, sequent depth ratio, and height of the jump have been obtained and compared. Fairly reasonable result has been obtained between experimental and analytical results. Some discrepancies are attributed to the unsteadiness of the flow, roughness of the channel bed and inherent assumptions in the derivation of the equations for theoretical computations. Future works are possible with improved instrumentations, and complete CFD simulation for the flow.

List of symbols

E1 Specific Energy before Jump

E2 Specific Energy after Jump

ΔE Energy Loss

$\Delta E/E_1$ Relative Energy Loss

Fr_1 incoming Froude number

Fr_2 outgoing Froude no

g Gravitational Acceleration

Hj Height of Jump

Lj Length of the Jump

y_{tw} tail water depth

V_1 mean velocity of flow before jump

V_2 mean velocity of flow after jump

Y1 Depth of flow before the jump

Y2 Depth of flow after the jump

E_2/E_1 Efficiency of jump

Δh_1 pressure difference at pre jump location

Δh_2 pressure difference at post jump location

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CHAPTER 1

INTRODUCTION

1.1 General description and practical applications of hydraulic jump

When the water depth is smaller than the critical depth, the flow is called a tranquil or subcritical flow. But when the depth is greater than the critical depth, the flow is called a rapid or supercritical flow. It has been experimentally found, that the rapid flow is an unstable type of flow, and does not continue on the downstream side. The transformation from rapid flow into tranquil flow occurs by means of a so-called hydraulic jump. A counterclockwise roller rides continously up the surface of the jump, entraining air and contributing to the general complexity of the internal flow patterns. Hence a hydraulic jump is an abrupt change in the flow i.e. from supercritical flow to subcritical flow of sufficient depth. At the place, where the hydraulic jump occurs, a lot of energy of the flowing liquid is dissipated and hence hydraulic jump is said to be a dissipator of the surplus energy of the water. Beyond the hydraulic jump, the water flows with a greater depth, and therefore with a lesser velocity.

At hydraulic jump formation of surface rollers is taking place due to which a high turbulence is created. This turbulence is created at the boundary between the incoming jet and rollers. (Chow 1959). A simple sketch of hydraulic jump is shown in following figure 1.1 which shows the two sections 1-1 and 2-2. Between these two sections formation of hydraulic jump is taking place.

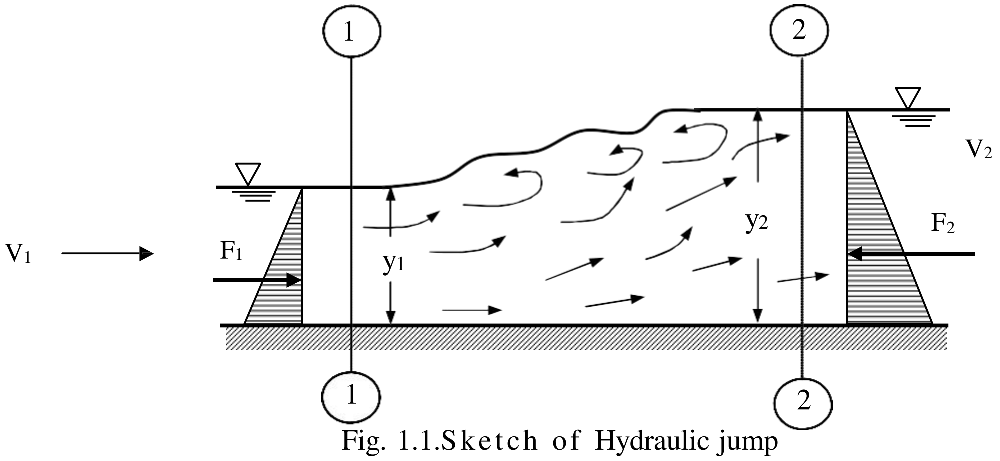

Fig. 1.1.Sketch of Hydraulic jump

Where 1 – 1 = upstream section of the hydraulic jump,

2– 2 = downstream section of the hydraulic jump,

y_1 = depth of flow at section 1 - 1,

V_1 = flow velocity at section 1 - 1,

y_2, V_2 = corresponding values at section 2 – 2

Before we go further concept of specific energy is discussed.

Specific energy

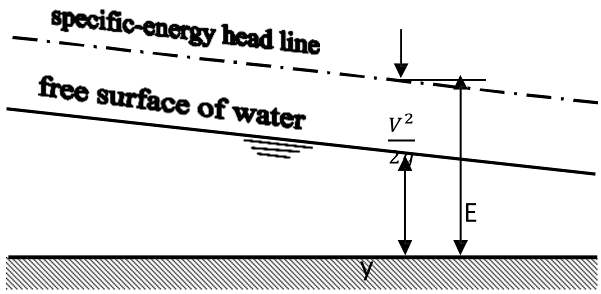

Fig.1.2 Specific-energy head of flowing liquid

For a flowing liquid the specific energy head is defined as the energy head with respect to the datum plane and passing through the channel bottom. See fig 1.2. It is given as

$$E = y + \frac{V^2}{2g} \qquad (1)$$

Where, y is the depth of flow
V is the mean velocity of flow

Also, $E = y + \frac{V^2}{2g} = E_k + E_p$

Where, E_p = y is potential energy head

$E_k = \frac{V^2}{2g} = \frac{q^2}{2gh}$ is kinetic energy head and q is the discharge per unit width

Plotting the specific-energy diagram for a channel (water depth y along the Y axis), which can be done by first drawing the two curves for potential energy and kinetic energy independently and then adding the respective ordinates. Obtaining result is the required *specific-energy head curve*.

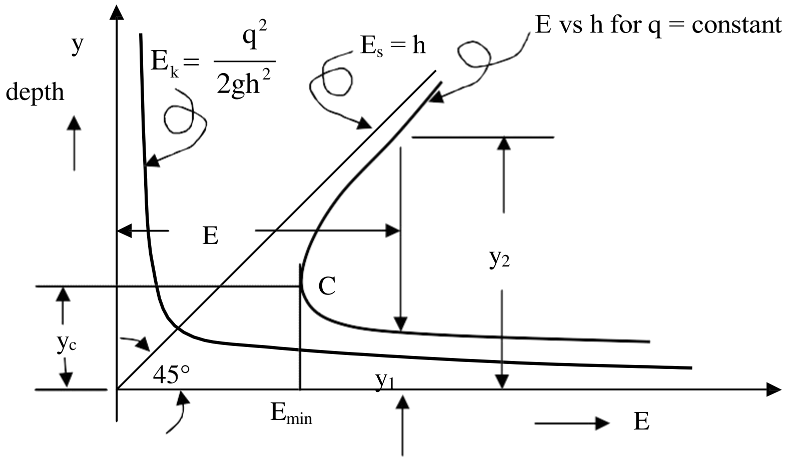

Fig 1.3 Specific-energy head curve

It is found that the curve for potential energy head (E_p) is a straight line through the origin at 45° with horizontal and for kinetic energy head (E_k) it is parabola. See fig 1.3.

By adding these two curves namely potential energy curve and kinetic energy curve at all the ordinates, specific energy head curve is obtained. See fig 1.3.

There are various practical applications of hydraulic jump in day by day life. Some of them are as follows:

1- The main practical application of hydraulic jump is in the form of energy dissipater. Its aim is to perform as an energy-dissipating device to reduce the excess energy of flowing water and hence reduce possible erosion and scouring due to high velocities.
2- Considerable amount of air is entrained during the jump formation which helps in aeration of streams which is polluted by bio-degradable wastes.
3- In canals raising of water level takes place due to hydraulic jump which in turn enhance irrigation practices and reduce pumping heads.
4- It enables efficient operation of flow measuring devices like flume.
5- Hydraulic jump creates a huge and significant amount of turbulence in the form of reverse flow rollers and eddies. This turbulence facilitates the efficient and effective mixing of chemicals.
6- Hydraulic jump is also plays an important role in reducing uplift pressure beneath foundation of hydraulic structures.

1.2 Classification of hydraulic jump

On the basis of Froude no. hydraulic jump may be classified as follows:

For Fr1 =1, the flow is critical and hence no jump can form.

For Fr1 = 1 to 1.7, the water surface shows undulations, and the jump is called undular jump. Fig 1.2(a).

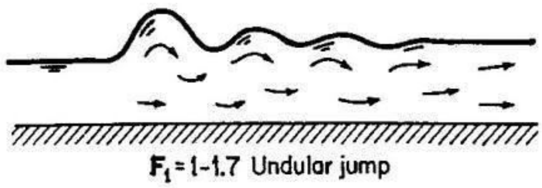

Fig.1.2 (a) Undular Jump

For Fr1 = 1.7 to 2.5, for this type, on the surface of the jump a series of small roller develop, but the downstream water surface remains smooth. The velocity is uniform throughout, and energy loss is low. Such jump is called a weak jump. Fig 1.2(b).

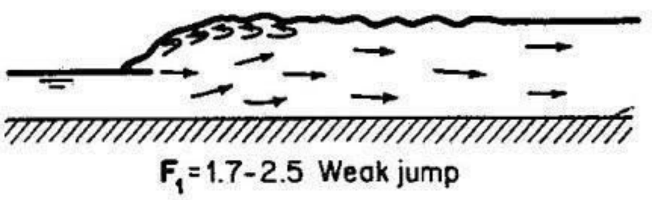

Fig. 1.2(b) Weak Jump

For Fr1 = 2.5 to 4.5, there is an oscillating jet entering the bottom to surface and back again with no periodicity. This jump may be called a oscillating jump. Fig 1.2(c).

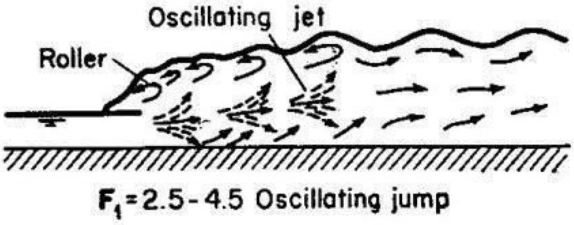

Fig.1.2(c) Oscillating Jump

For Fr1 = 4.5 to 9.0 the downstream extremity of the surface roller and the point at which the high velocity jet tends to leave the flow occur at practically the same vertical section. For such type of jumps there is least sensitivity of position and action by the variation of tail water depth. The jump is well balanced and the performance is at its best. The range of energy dissipation is from 45 to 70%. Such jumps are known as steady jumps. fig 1.2(d).

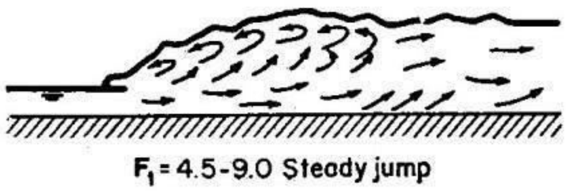

Fig. 1.2(d) Steady Jump

For Fr1 = 9.0 and larger, the high velocity jet grabs intermittent slugs of water rolling down the front face of the jump, generating waves downstream, and rough surface can prevail. The jump action is rough but effective since the energy dissipation is large. In such jumps energy dissipation may reach to 85%. Such jumps are known as strong jumps. See fig 1.2(e).

Fig. 1.2(e) Strong Jump

The classification of hydraulic jump based on hydraulic jump position is as follows.

Case I represents the pattern in which the tail water depth h_{tw} is equal to the sequent depth y_2 corresponding to initial depth y_1. In this case the values of Fr_1, y_1 and y_2 will satisfy the Belanger equation and hence jump forms smoothly . This jump is known as free jump. See Figure 1.2(f).

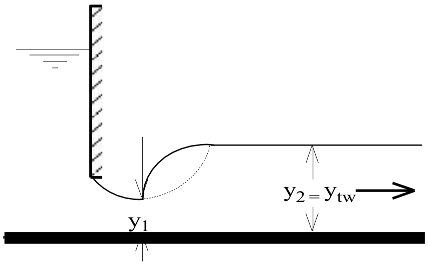

Fig. 1.2(f) Free Jump

Case II represents the pattern in which the tail water depth y_{tw} is less than sequent depth y_2. This meant that the tail water depth in case 1 is decreased. As a result, the jump will recduces downstream to a point where the equation (1) is again satisfied. Such type of jump is called Repelled jump. See Figure 1.2(g)

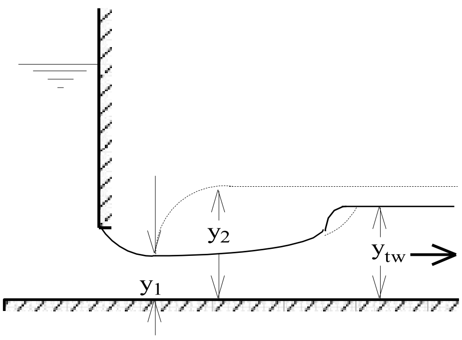

Fig. 1.2(g) Repelled Jump

Case III represents the pattern in which the tail water depth y_{tw} is greater than y_2. This meant that the tail water depth in case 1 is increased. As a result, the jump will be forced upstream and may finally be drowned out of the source, becoming submerged jump. Such a jump is known as Drowned jump or submerged jump. See Figure 1.2(h).

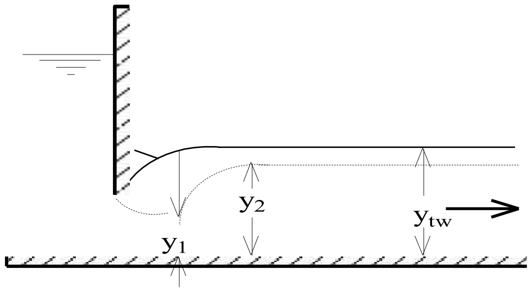

Fig. 1.2(h) Submerged Jump

1.3 BASIC CHARACTERISTICS OF HYDRAULIC JUMP

The basic characteristics of a Hydraulic Jump, such as (i) the conjugate depths, ii) the energy loss in the jump, iii) height of the jump iv) length of the jump will be explained briefly in the following sections.

1.3.1 Conjugate Depths

For a given unit discharge these two depths whose momentum function is equal are known as conjugate depths. For a simple Hydraulic Jump on a smooth rectangular channel, as shown in Figure 1.3.4, the momentum equation along the flow direction is known as Belanger equation and is given as follows (Chow 1959).

Belanger equation $\frac{y_2}{y_1} = \frac{1}{2}\left(-1 + \sqrt{1 + 8\,Fr_1^2}\right)$ (2)

Where $Fr_1 = \frac{u_1}{\sqrt{g y_1}}$ is Froude no of supercritical flow where

y_1 is upstream depth

u_1 is velocity of supercritical flow

g is the acceleration due to gravity

y_2 is downstream depth

According to Chow (1959) if Froude no is greater than 8 then the equation (2) can be used for quick estimation purpose of sequent depth as

$$\frac{y_2}{y_1} \approx 1.41\ Fr_1 \qquad (3)$$

Hager and Bremen indicated that, for flow in which the incoming flow depth y_1 is small, there exists a significant scale effect on sequent depth ratio.

1.3.2 Energy loss in the Jump.

Due to the occurrence of hydraulic jump there is a loss of energy head which is defined as the difference in specific energies before and after the jump (between sections 1-1 and 2-2 see figure 1.2). It can be shown that the loss is

$$\Delta E = E_1 - E_2 = (y_2 - y_1)^3 / \sqrt{4y_1}y_2 \qquad (4)$$

Where

E1 is Specific Energy of Supercritical flow E2 is Specific Energy of Subcritical flow

y_1 is depth of Supercritical flow y_2 is depth of Subcritical flow

1.3.3 Height of the Jump (Hj)

The Height of the jump is equal to the difference between the depths before and after the jump as figure. It can be shown that the height of the jump is

$$h_j = y_2 - y_1 \qquad (5)$$

1.3.4 Length of the jump (Lj)

Length of hydraulic jump may be defined as the distance measured from the front face of the jump (toe) to a point on the surface immediately downstream from the roller at which water surface is fairly level. It can be seen in figure.1.3.4.

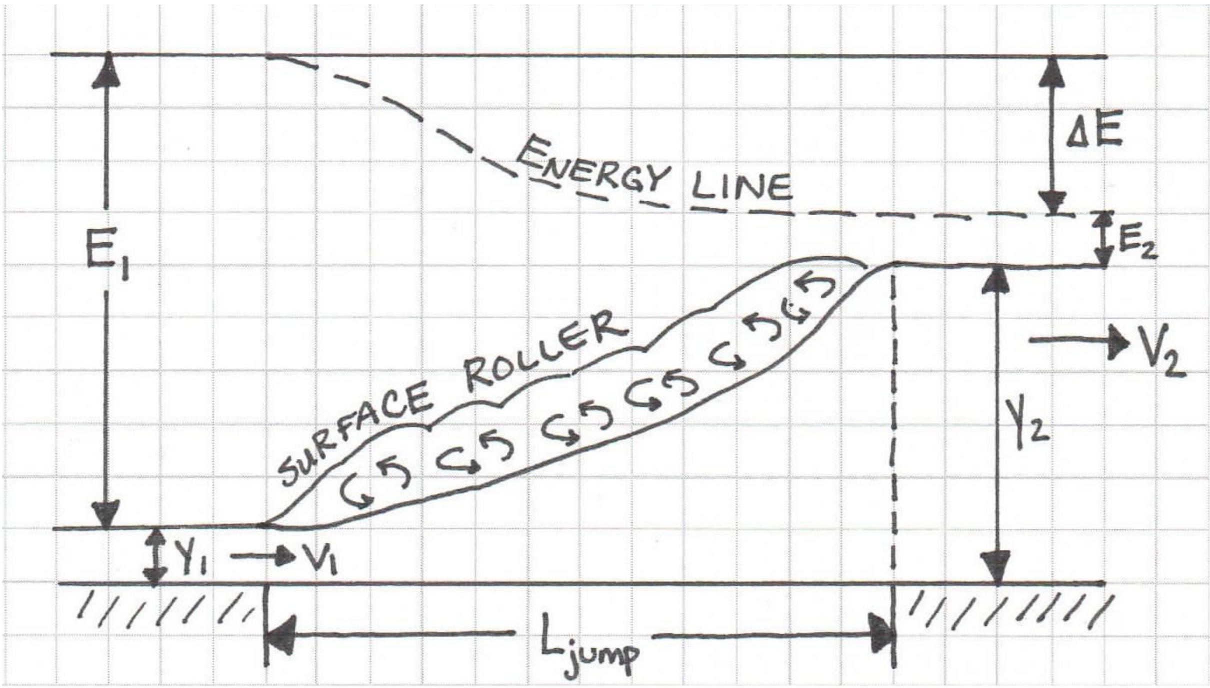

Fig 1.3.4 Hydraulic jump and its characteristics

1.3.5 Location of jump (Lx)

Whenever the equation of momentum is satisfied between the supercritical and subcritical parts of the stream formation of hydraulic jump is takes place. In other words, if the initial depth y_1, the sequent depth y_2 and the approaching Froude number Fr_1 satisfies equation (2) in a smooth rectangular channel, the hydraulic jump will occur.

Location of Hydraulic jump is measured from the weir or inlet sluice gate to the point where the flow fluctuates or roller starts.

1.4 Objective of study

The main objective of present study is to analyze and study the different characteristics of hydraulic jump for different slopes and compare them with analytical results. Also the analysis and comparison for the same characteristics for horizontal channel and the sloping channel is takes place in this study.

1.5 Scope of study

The present study aimed at quantifying and comparing experimental data for various slopes of the horizontal rectangular channel with theoretically predicted profile of hydraulic jump. The incoming Froude no. and depth of jumps were controlled by controlling the flow rate through the variation of openings of valve. This study enables us to show the variations with slope and how it differs from the horizontal one.

CHAPTER 2

LITERATURE REVIEW

1. **Gandhi and Yadav (2013)** – In October 2013 Gandhi and Yadav perform their work on "CHARACTERISTICS OF SUPERCRITICAL FLOW IN RECTANGULAR CHANNEL". Their work is to verify analytical and empirical relations for various flow characteristics namely sequent depth ratio (Y_2/Y_1), relative length of jump ($\frac{L_j}{h_2}$), relative height of jump ($\frac{h_j}{E_1}$), relative length of jump ($\frac{L_j}{h_2}$), and efficiency of jump ($\frac{E_2}{E_1}$). They also validate the models proposed by other authors. They plot curve between sequent depth ratio and Froude no, relative height of jump and Froude no, relative length of jump and Froude no and efficiency of jump and Froude no and compare the same with analytical formula and also with other different universities results. Their findings are as follows:

(i) Linear variation of sequent depth ratio with Froude no.

(ii) For Froude no 1 to 7 efficiency decreases non-linearly and this is found highly satisfactory when compared to Chow results.

(iii) Up to Froude no 3 relative height of jump increases and then decreases non linearly as Froude no increases up to 7.

(iv) Relative length of jump shows typical increasing non-linear variation against Froude no. Maximum value is observed at Froude no. 6.

From their study they conclude that the error is considerably less in the equations of supercritical jump and subcritical jump given by Khosla et al. (1993). Except h_j/E1 results obtained for h2/h1, E2/E1 and L_j/h2 are fairly good with the existing result and can be used for field analysis. It can also be concluded from the present study and the existing result that it is equally applicable to non-prismatic channel (with little modification in Froude no.).

2. **Md. Rezaul Hasan and Md. Abdul Matin (2008) –** Md. Rezaul Hasan and Md. Abdul Martin both are from Bangladesh and did their study on the topic named "Experimental study for sequent depth ratio of hydraulic jump in horizontal expanding channel". They conduct the experiment for different expansion ratios of the channel with different gate openings and results are used to evaluate the prediction equations whose format is similar to Belanger equation. They carried out experiment in laboratory flume of dimensions 12.2 m ×0.3048 × 0.3048 m. For maintaining the exact expansion ratio, they installed several constriction elements in the flume and just downstream of the sluice gate, they inserted two constriction elements along the direction of flow to make a reduced a channel in the middle of the chamber. In their study, they basically used three different expansion ratios i.e. 0.50, 0.67 and 0.83 to keep the constant downstream width b_2 = 0.3048 m. No lateral movement of water between the constriction elements and the sidewalls is taking place. The length of the constriction element is based on the range of jump formed on the flume. The location of jump is controlled by tail gate and discharge. Their findings are as follows:

(i) Incoming Froude no. increases with increase of discharge and also Froude no. increases with reduction of sluice gate opening.
(ii) The value of 'k' (a parameter accounts for the effect of abrupt channel expansion on jump depth) for different expansion ratios decreases with increasing expansion ratio.
(iii) Sequent depth ratio increases with increase in Froude no.

From the study they concluded that the magnitude of parameter k is dependent on inflow Froude no. for cases of expansion ratio (b1/b2) less than 0.677 but it is more or less dependent on inflow Froude no. for higher values of expansion ratio.

3. On sequent depth ratio of hydraulic jump the effect of wall friction, both theoretically and experimentally is investigated by **Hager and Bremen** . Their findings are as follows:

They stated that laboratory studies of hydraulic jump's sequent depth have always shows slight disagreement with Belanger equation. They proposed that a 5 % deviation from the Belanger equation in model studies seems to reflect the accuracy on which a design might be based. However, they also state that for deviations greater than 5 %, viscosity effect must be taken into account.

4. **Celik** et al. analyzed the effect of prismatic roughness elements on properties of hydraulic jump.

According to him both length and sequent depth of a hydraulic jump in a rough channel when compared to the length and sequent depth of a jump on a smooth channel is found to be smaller.

5. **Ayanlar** : On the properties of hydraulic jump he investigated the effects of corrugated bed. Corrugated aluminium sheets of different incoming Froude no and length was used by him in experiment and the ranges of Froude no is more than 4 but less than 12. His findings are as follows:

The tail water depth required for Fr_1 , Y_1 and for upstream flow conditions are reduced by corrugations as compared to the results of Hydraulic Jumps on smooth beds.

He states that for tail water depth the average reduction factor is about 35%.

6. **Farhoudi and Narayanan** (1991) investigated the characteristics of the fluctuation. They concluded that the intensity of force fluctuations on an area of slab beneath a jump vary with respect to the jump area's length, the channel width, and the distance from the toe of the jump.

7. **Toso and Bowers** (1988) studied the large pressure fluctuation in hydraulic jump stilling basins. The fluctuation pressures are the pressures that act on the hydraulic structures or water channels caused by oscillating flow waves .The study indicated the fluctuation pressures are a function of the Froude number, the distance from the toe of the jump, and the boundary layer development. Their findings are as follows:

1. The maximum pressure fluctuations on the floor usually happen at about one-third of the distance through the jump.
2. The fluctuation pressure head in the jump tend to approach 80%- 100% of the entering velocity head.
3. Whether or not the inflow is fully developed has little effect on the fluctuation pressure.
4. Whether the channel bottom has blocks, sills or neither does not make much difference in fluctuation pressure.
5. The sidewall fluctuation pressure head's peak is about one to two inflow depths above the floor.

CHAPTER 3

EXPERIMENTAL SET UP AND PROCEDURE

In this chapter detailed discussion about the experimental set up, procedure and methodology used is given.

3.1 **APPARATUS USED**

During the experiment the apparatus used are as follows:

3.1.1 Flume

Flume is a device which is basically used to determine the definite relationship between depth of flow and discharge at critical depth. They are designed so that flow achieves the critical depth within the structure. For present study the flume and other apparatus is provided by Delhi technological university, Delhi. The flume used is of the dimensions 4m × 0.30m × 0.40m. See fig. 3.1.1 (a)

Fig. 3.1.1(a) WORKING FLUME

Flumes are of the following types:

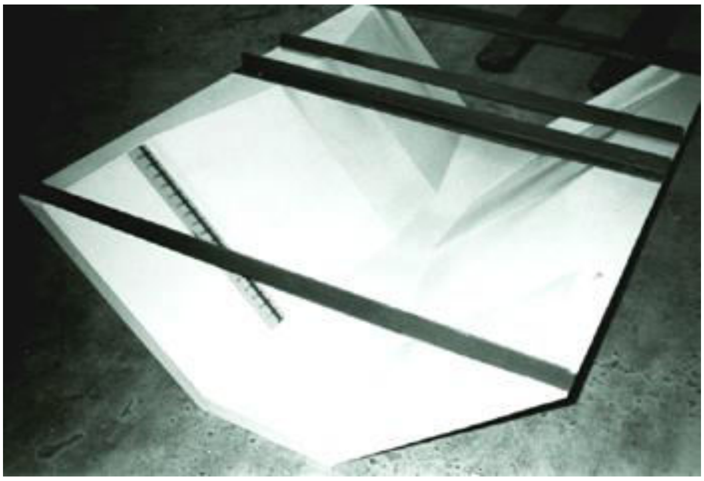

FIGURE 3.1.1 (b) TREPAZODIAL FLUME

FIGURE 3.1.1 (c) H-TYPE FLUME

FIGURE 3.1.1 (d) MONTANA FLUME

FIGURE 3.1.1 (e) CUTTHROAT FLUME

3.1.2 Point gauge

It is a device which is used to measure the depth of flow within the channel. It is mounted on the upper rails of the channel over which it slides easily from one point to another. See fig 3.1.2

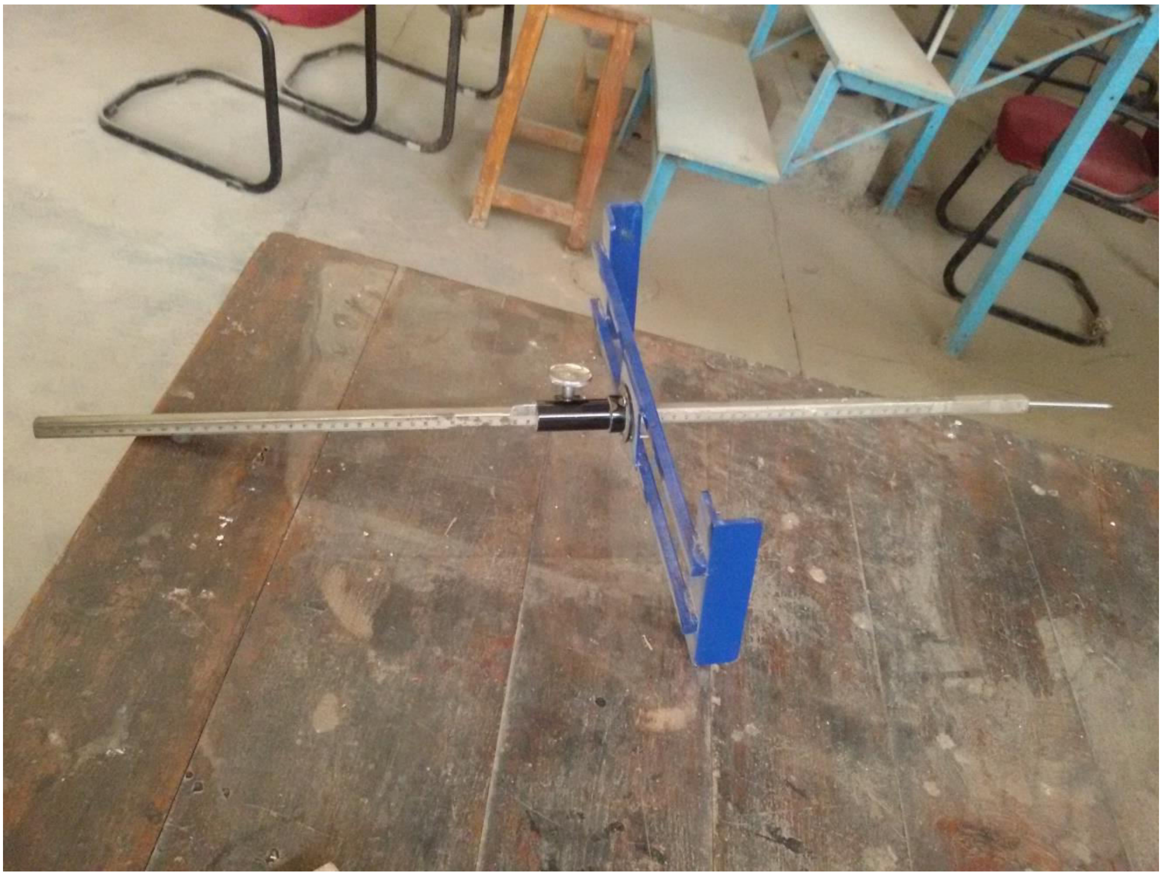

Fig. 3.1.2 POINT GAUGE

3.1.3 Pitot tube

Pitot tube is a device which is used to measure the velocity of flow and pressure of flow. In present study the velocity of flow is determined by using pitot tube which in turn connected to a inverted U-tube manometer from which the readings are taken. The detailed working of pitot tube is given in the section 3.2.1. See fig. 3.1.3

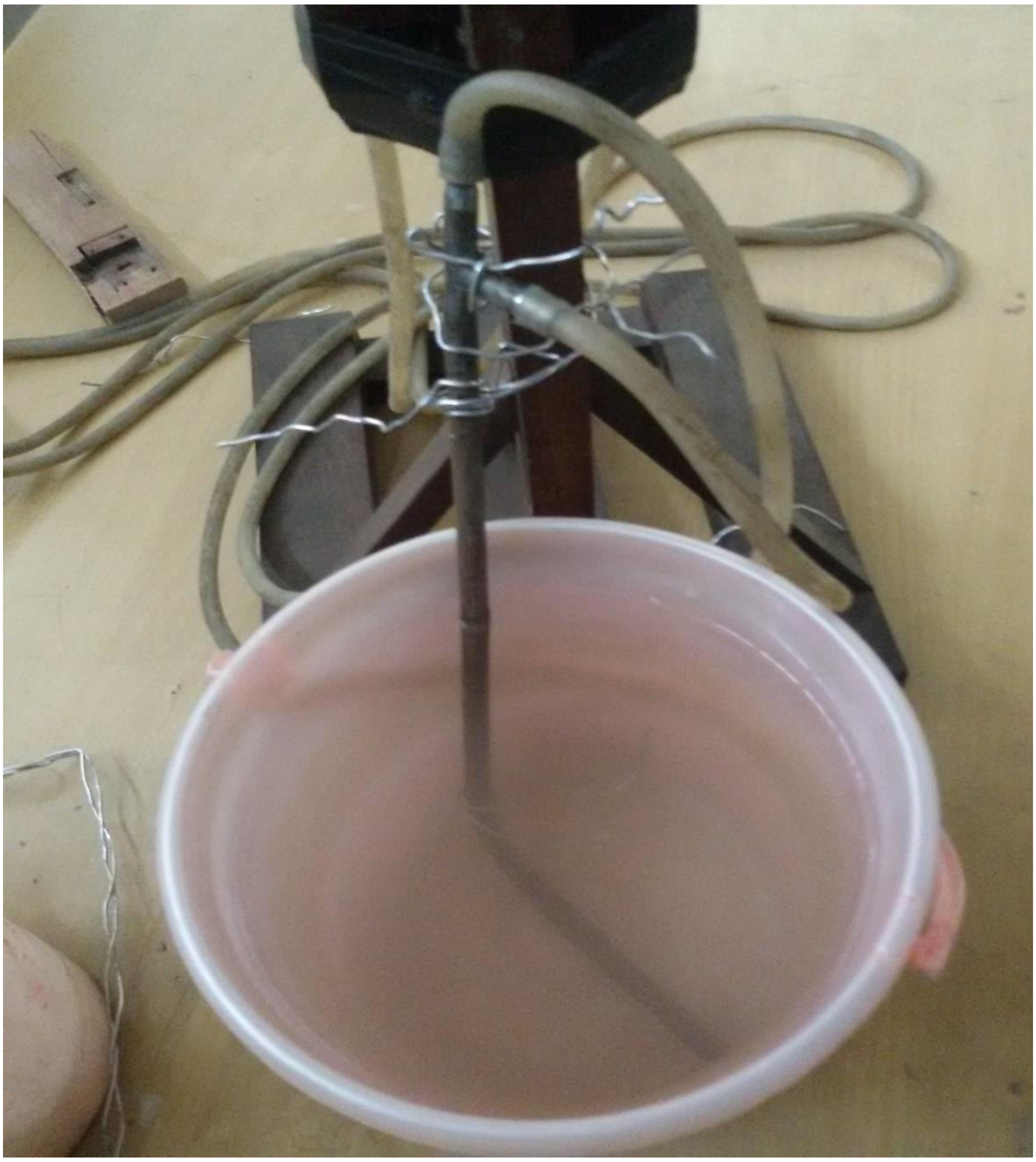

Fig. 3.1.3 PITOT TUBE

3.1.4 Weir

Weir is an obstruction in the path of flow over which flow takes place. It is generally used to measure the discharge through the channel. In present study a rectangular metallic plate is used as weir for creating hydraulic jump over which the flow is taking place. The weir used in present study is given in fig 3.1.4.

Fig. 3.1.4 WEIR

3.2 MEASUREMENT OF DIFFERENT QUANTITIES

3.2.1 Flow velocity and flow rate

The velocity of flow, flow rate and specific energy is measured with the help of pitot tube. The pitot tube which is used during the present study is a L shaped metallic tube of external diameter 3.3 mm (see fig 3.1.3). An inverted U-tube manometer is used which consists of two identical glass tube clamped to a wooden stand (see fig 3.2.1 (a)). The wooden stand is fitted with measuring scale for the facility of measuring and taking the readings easily. The top end of the inverted glass tube is open to atmosphere and the two bottom ends are connected to the pitot tube with the help of two 2m long hard nylon tubes (see fig 3.2.1(b).

First the water level in both the glass tube makes equal. For this the pitot tube is drown in the jug or bucket of still water and the water is sucked up and down slowly from the top end till the level becomes equals. Once it is equal then it is fixed with the help of arrangement provided with the apparatus (see fig 3.2.1 (c)). It is then used to measure the velocity of flow at desired point. For measuring the mean velocity at pre jump and post jump location following formula is used:

$$V_1 = \frac{(v_1 \text{ at } 0.8y_1 + v_1 \text{ at } 0.2y_2)}{2}$$

$$V_2 = \frac{(v_2\ at\ 0.8y_2 + v_2\ at\ 0.2y_2)}{2}$$

Where, V_1 is the mean velocity of flow at pre jump location

V_2 is the mean velocity of flow at post jump location

v_1 at $0.8y_1$ is the pre jump velocity at a distance of $0.8y_1$ from free surface

v_1 at $0.2y_1$ is the pre jump velocity at a distance of $0.2y_1$ from free surface

Subscript 1 and 2 represents the pre jump and post jump locations respectively.

Hence for determining mean velocity we have to determine the velocity at these two values i.e. 0.8 and 0.2 times the depth of flow and on taking the average of these two gives us the mean velocity. Specific energy is then given as

$$E_1 = y_1 + V_1^2/2g \tag{5}$$

Similarly, $E_2 = y_2 + V_2^2/2g$

And energy loss = $\Delta E = E_1 - E_2$

At a given cross section and value of y from channel bed the velocity and specific energy is deduced from the two manometer readings and the corresponding flow rate is obtained using continuity equation as

$$Q = AV$$

Fig. 3.2.1 (a) INVERTED U-TUBE MANOMETER WITH WOODEN STAND

Fig. 3.2.1 (b) LOWER END OF MANOMETER AND NYLON TUBE

Fig 3.2.1(c) TOP END OF MANOMETER WITH FIXING ARRANGEMENT

3.2.2 Measurement of depth of flow and length of jump

For measuring the flow depth point gauge mounted on the rails of the flume is used. It is fitted with a measuring scale for indicating the depth of flow. It can travel over the rails of the flume very smoothly for easy measurement of depth of flow at any point in the flume. Hence sometimes it is also known as travelling point gauge. The subcritical and supercritical depth i.e. y_1 and y_2 are measured with the help of this travelling point gauge.

Length of jump is defined as the distance between the weir and the point in the water where fluctuations starts or formation of rollers is taking place and hence length of hydraulic jump is obtained by taking the difference between starting point and the point where rollers start.

3.3 SET UP AND PROCEDURE

The experimental set up is located at hydraulics laboratory of department of Civil Engineering, Delhi Technological University, Delhi. Present study is carried out on a rectangular channel of dimensions 4m long, 0.30m wide and 0.40m deep (fig 3.1.1 a). All the other appropriate instrumentations which are used for flow measurement profile are designed and installed. The fig 3.3(a) shows top view of experimental set up.

All the parts of this channel is made up of steel structure except the wall of the middle portion which is 2.0m long. There is a pump which circulates the water from outlet to inlet (fig 3.3(b)). At inlet a weir (a rectangular metallic plate of dimensions 0.245m by 0.295m fig 3.1.4) is used during the present study for formation of hydraulic jump. A tail gate is installed at the outlet of the channel (fig 3.3(c)). By varying the opening of this tail gate the location of jump is controlled. Also the location of jump, Froude no, and rate of flow is controlled by varying the opening of inlet valve. Fig 3.3(d)

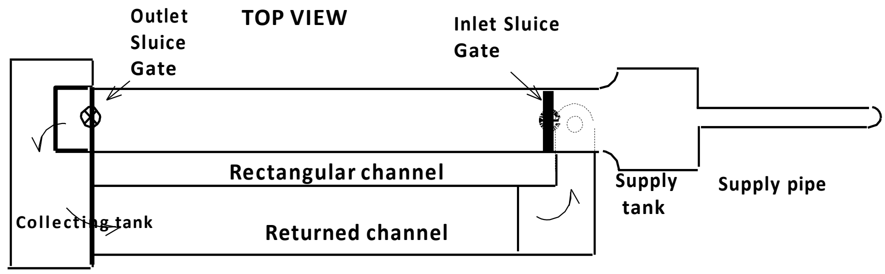

Fig.3.3 (a) A schematic diagram of channel set up

Fig 3.3 (b) PUMP

Fig 3.3(c) TAIL GATE WITH FLUME END

Fig 3.3 (d) INLET VALVE

PROCEDURE

Initially the channel is set at 0° or purely horizontal and Pump is turned ON and by opening the inlet valve water starts flowing in the channel over the weir. By varying the opening of the tail gate formation and location of hydraulic jump is adjusted. After a good hydraulic jump is formed the supercritical depth and subcritical depth is noted with the help of point gauge (fig 3.3(e)). Also at this time the incoming mean velocity (V_1) and outgoing mean velocity (V_2) is measured from pitot tube one by one. Now by using this data incoming Froude no (F_1), outgoing Froude no (F_2), rate of flow (Q), incoming specific energy (E_1), outgoing specific energy (E_2) etc. are obtained.

The above procedure is repeated for a no. of series of runs with different values of Froude no. and slopes (in present study it is limited up to 4°). Variation in Froude no is done by varying the discharge which is done by varying opening of inlet valve and the variation in slope is done by changing the sloping mechanism given below the channel. Fig 3.3 (f)

Fig 3.3 (e) HYDRAULIC JUMP

Fig 3.3 (f) Screw mechanism

Fig 3.3 (g) COLLECTING TANK

Fig 3.3 (h) DELIVERY PIPE

3.4 CALULATIONS

Here calculation for first reading of 0° is shown below.

y_1 = 0.018 m

y_2 = 0.042 m

Mean velocity or average velocity at pre jump location

V_1(Av) or simply V_1 = $\frac{v_1 \text{at } 0.2y_1 \text{from free surface} + v_1 \text{at } 0.8y_1 \text{from free surface}}{2}$

And mean velocity or average velocity at post jump location

V_2(Av) or simply V_2 = $\frac{v_2 \text{at } 0.2y_2 \text{from free surface} + v_2 \text{at } 0.8y_2 \text{from free surface}}{2}$

Where v_1 is the velocity at $0.8y_1$ from free surface and is given as = $\sqrt{2g\Delta h_1(at 0.8y_1\,)}$

$\Delta h_1(at0.8y_1\,)$ is the pressure difference at $0.8y_1$ from free surface

Similarly v_1 is the velocity at $0.2y_1$ from free surface and is given as = $\sqrt{2g\Delta h_1(at\ 0.2y_1)}$

$\Delta h_1(at\ 0.2y_1)$ is the pressure difference at $0.2y_1$ from free surface

Similarly v_2 at $0.8y_2$ from free surface and v_2 at $0.2y_2$ from free surface are the corresponding velocities at corresponding points except Δh_1 is replaced by Δh_2 and y_1 is replaced by y_2.

v_1 at $0.2y_1$ = $\sqrt{2g\Delta h_1}$ = $\sqrt{2 \times 9.81 \times 0.095}$ = 1.365 m/s

v_1 at $0.8y_1$ = $\sqrt{2g\Delta h_1}$ = $\sqrt{2 \times 9.81 \times 0.055}$ = 1.0387 m/s

V_1 (Av) = $\frac{v_1 \text{at } 0.8y_1 \text{from free surface} + v_1 \text{at } 0.2y_1 \text{from free surface}}{2}$

= $\frac{1.365+1.0387}{2}$

= 1.20 m/s

Similarly,

v_2 at $0.2y_2$ = $\sqrt{2g\Delta h_2}$ = $\sqrt{2 \times 9.81 \times 0.025}$ = 0.7003 m/s

v_2 at $0.8y_2$= $\sqrt{2g\Delta h_2}$ = $\sqrt{2 \times 9.81 \times 0.01}$ = 0.4429 m/s

therefore, V_2(Av) = $\frac{0.7003+0.4429}{2}$ = 0.5716 m/s

$Q_1 = A_1V_1(Av) = by_1V_1(Av) = 0.3\times 0.018 \times 1.20 = 0.00648$ m³/s

$Q_2 = A_2V_2(Av) = by_2V_2(Av) = 0.3\times 0.042 \times 0.5716 = 0.00720$ m³/s

There is a slight variation in supercritical discharge and subcritical discharge due to loss of energy during the jump.

$Fr_1 = \frac{V_1}{\sqrt{gy_1}} = \frac{1.20}{\sqrt{9.81\times 0.018}} = 2.85$

Specific energy at supercritical zone, i.e. $E_1 = y_1 + \frac{V_1^2}{2g} = 0.018 + \frac{1.20^2}{2\times9.81} = 0.0913944$ m

And specific energy at subcritical zone, i.e. $E_2 = y_2 + \frac{V_2^2}{2g} = 0.042 + \frac{0.571^2}{2\times9.81} = 0.0586177$ m

Energy loss, i.e. $\Delta E = E_1 - E_2$ = 0.0913944-0.0586177 = 0.032776795 m

Relative energy loss, i.e. $\frac{\Delta E}{E_1}$ = 0.032776795/0.0913944= 0.3586

Efficiency of jump = $\frac{E_2}{E_1}$ = 0.0586177/0.0913944 = 0.6413

Sequent depth ratio = $\frac{y_2}{y_1}$ = 0.042/0.018 = 2.33

Height of jump = $H_j = y_2 - y_1$ = 0.042 – 0.018 = 0.024 m = 2.4 cm

$\frac{H_j}{E_1} = \frac{0.024}{0.0913944} = 0.2625$

And for calculating analytical results Bengler equation is used

$$\frac{y_2}{y_1} = \frac{1}{2}\left(-1 + \sqrt{1 + 8\,Fr_1^2}\right)$$

$= 0.5\ (-1 + \sqrt{1 + 8 \times 2.85^2}\ ) = 3.56$

Error = -1.23

And for efficiency, $\frac{E_2}{E_1} = \frac{(8F_1^2 + 1)\text{^}1.5 + 1 - 4F_1^2}{8F_1^2\,(2+F_1^2)}$ (6)

On substituting the value of F_1 we get, $\frac{E_2}{E_1}$ =0.76

Error = -0.118

Similarly the calculation for all sets of reading is done.

CHAPTER 4

RESULT AND DISCUSSION

In this chapter the findings of the present study is presented in the forms of tables and graphs.

4.1 Froude no v/s Sequent depth ratio

The sequent depth varies with Froude no according to polynomial law for best fit curve as shown by figure 4a and the corresponding value of regression coefficient is shown in fig 4a. It increases with increase in slope and Froude no. When compared to the analytical curve it shows a little deviation which may be due to channel bottom and side roughness. It is also shown from fig 4a that 97%, 98%, 100% experiment data are laying in ± 10% of best fit curve values.

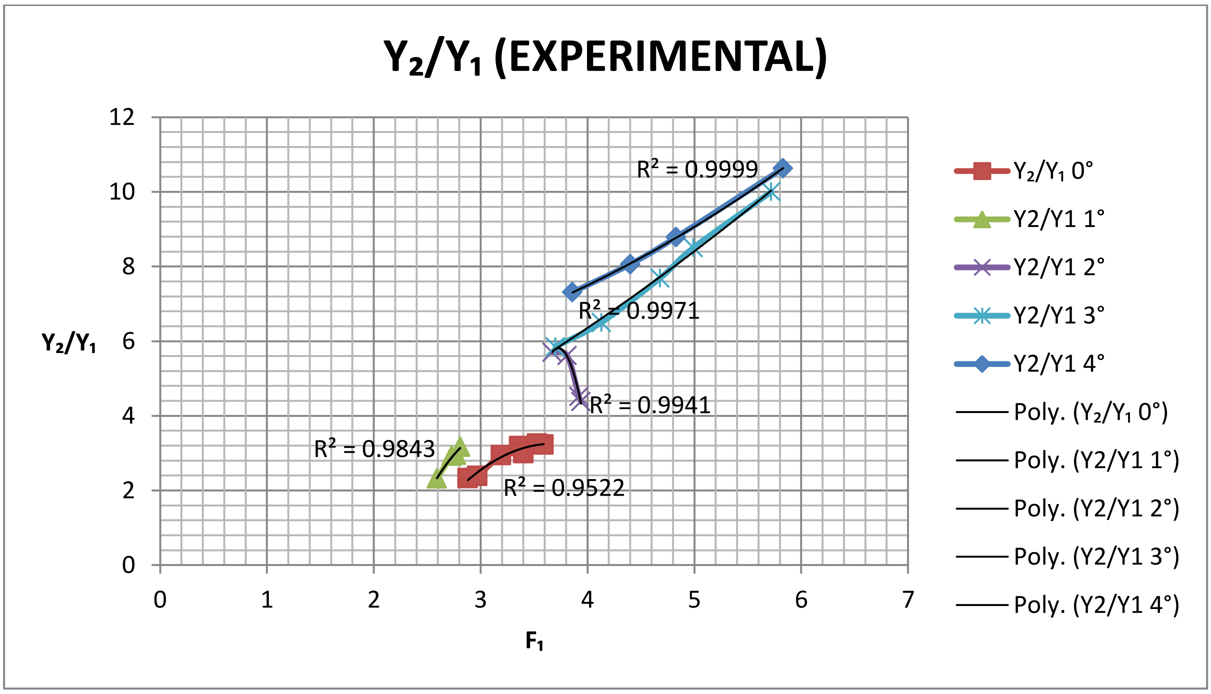

Fig 4a Showing variation of sequent depth with Froude no

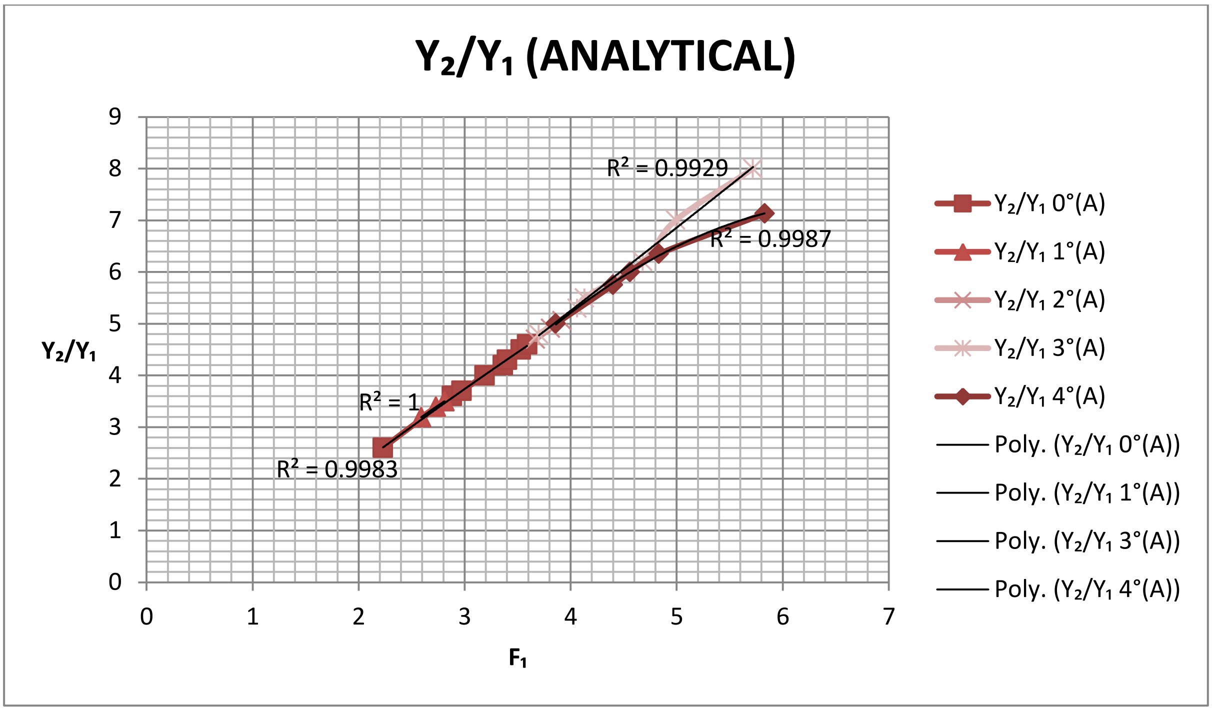

Fig 4b Showing analytical variation of sequent depth with Froude no

4.2 Froude no v/s Efficiency

It is find in the present study that efficiency of the hydraulic jump is decreases with increase in Froude no and with slope the curve is shifting right which shows that Froude no increases with slope. Friction is not included in the present study. This curve also varies according to polynomial law for best fit curve. Fig 4c. It is also seen that 93%, 95%, 96% of experimental data is laying within the range of $\pm$10% of best fit curve.

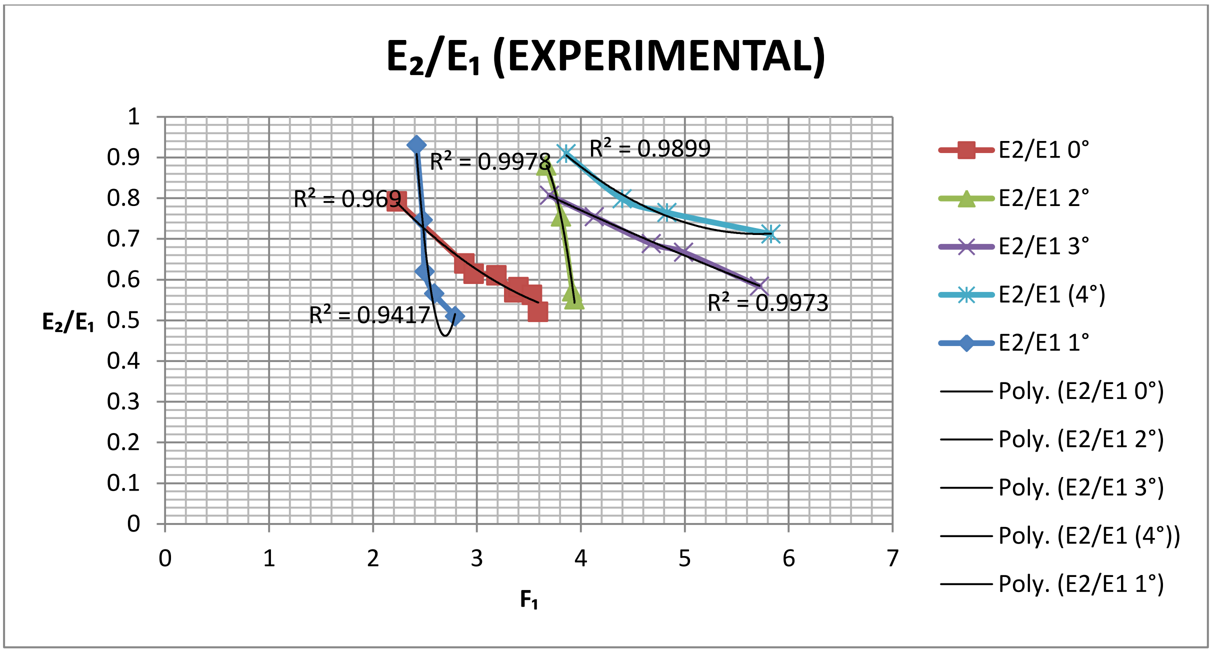

Fig 4c Variation of efficiency of hydraulic jump with Froude no

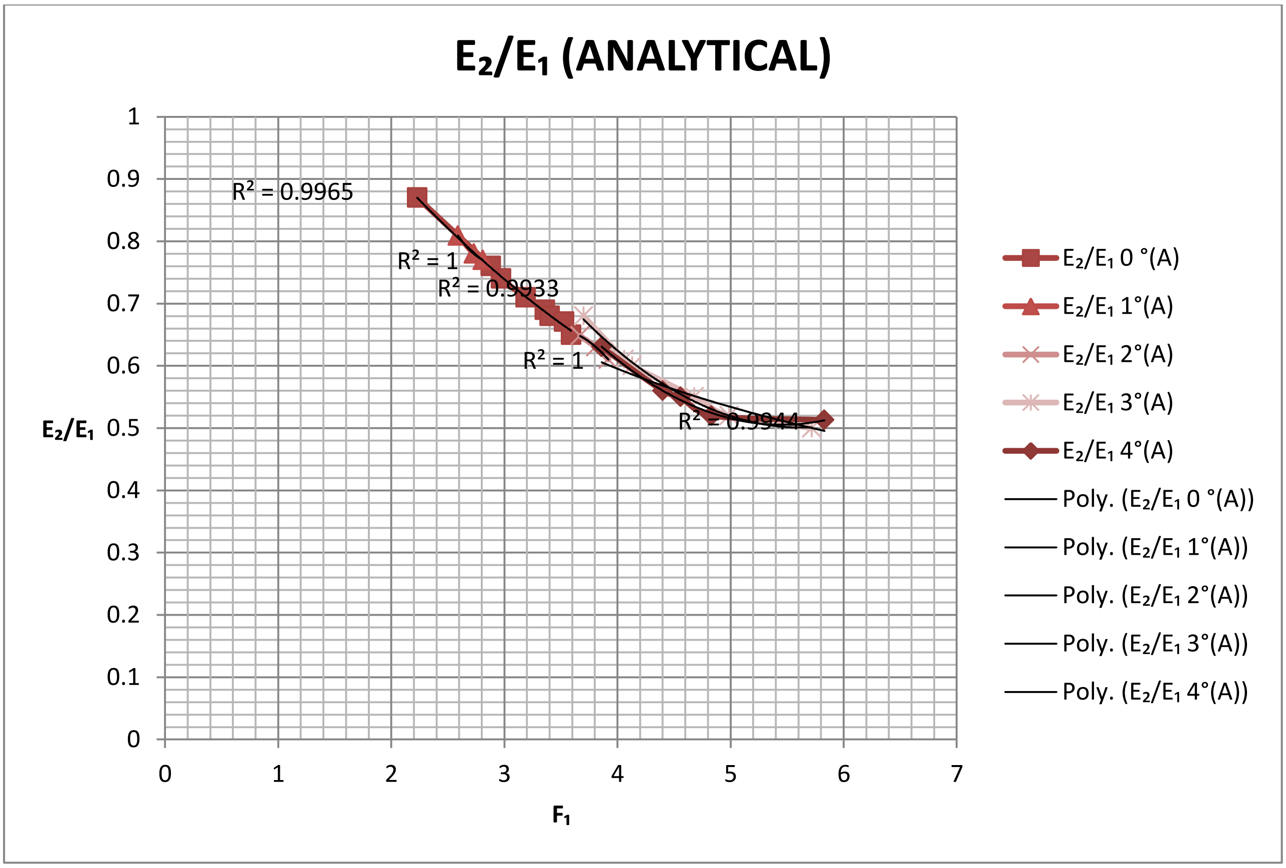

Fig 4d Analytical variation of efficiency of hydraulic jump with Froude no

4.3 Froude no v/s Relative energy loss

It is clearly seen from fig 4e that by increasing the approaching Froude no the magnitude of relative energy loss increases whereas it is also decreasing simultaneously as the slope of channel bed is increases and hence the curve is shifted rightwards and down by following the polynomial law for best fit curve. It is also seen that 88%, 89%, 90% of the experimental data is laying in the range of ±10% of best fit curve.

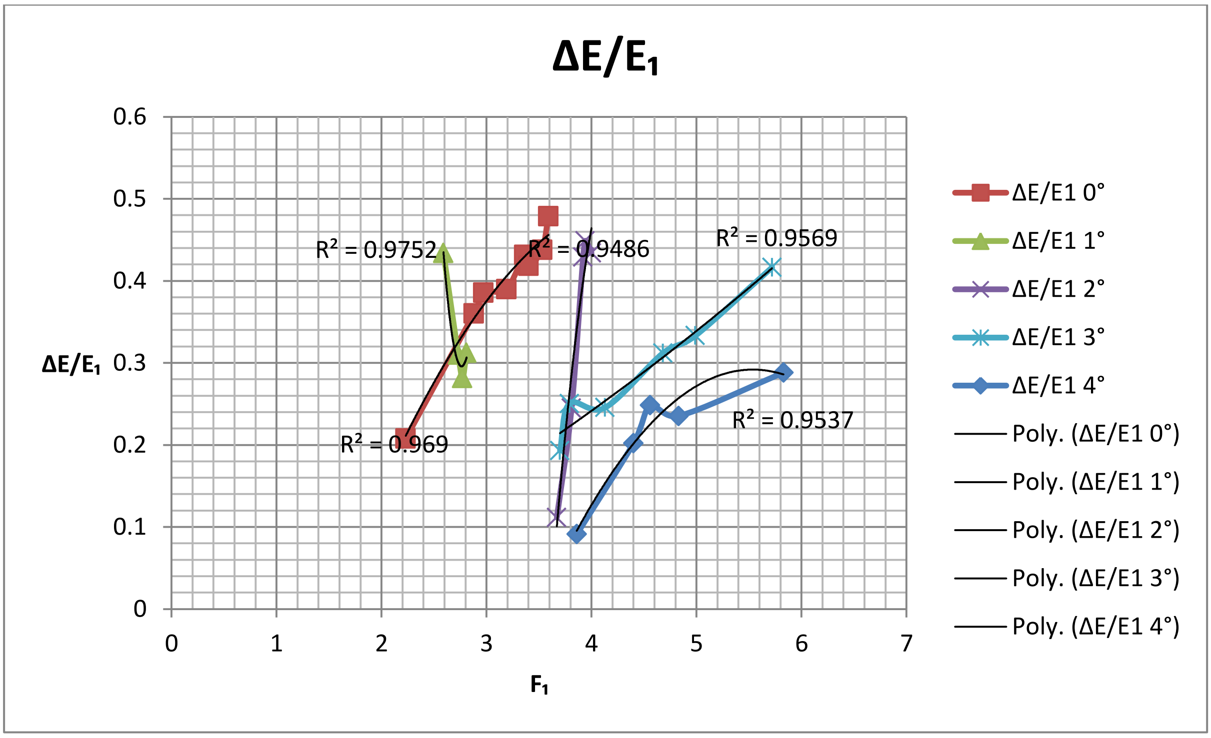

Fig 4e Variation of relative energy loss of hydraulic jump with Froude no

4.4 Froude no v/s Relative height of jump

With increase in Froude no the relative height of jump is decreases and increases alternately and hence vary non linearly and with respect to slope it is increasing with increase in slope and hence the curve is shifted rightwards and upwards in a zig zag or non-linear manner see figure 4g.

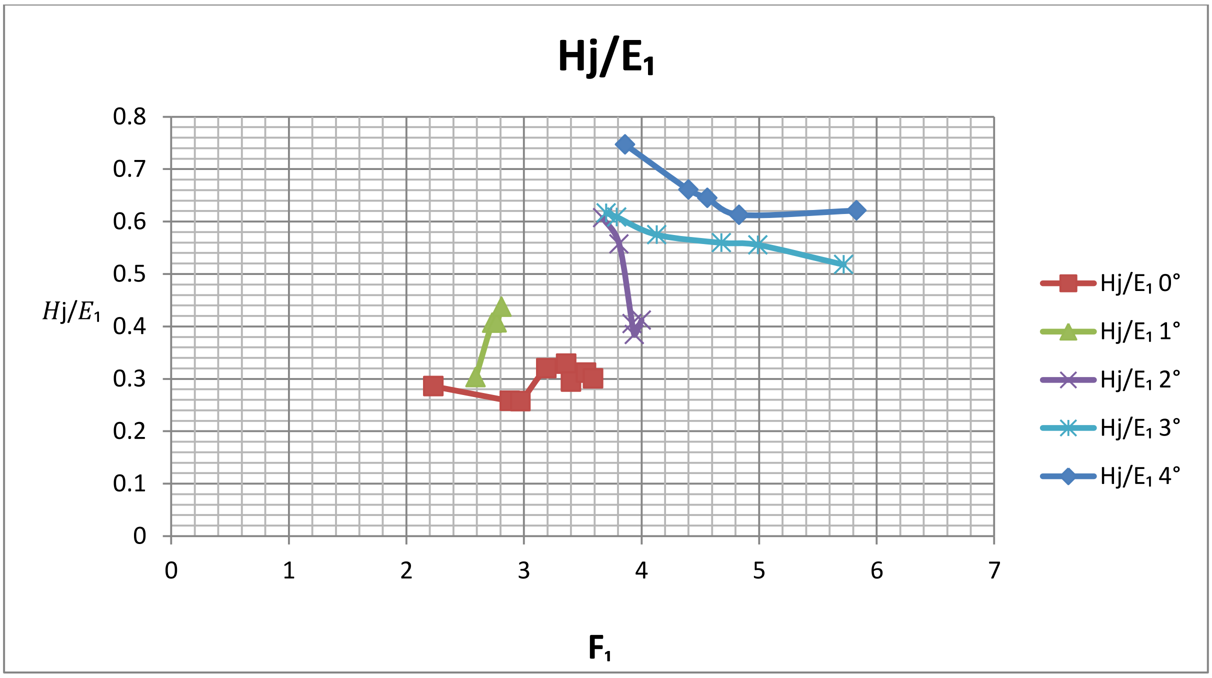

Fig 4g Showing variation of relative height of jump with Froude no

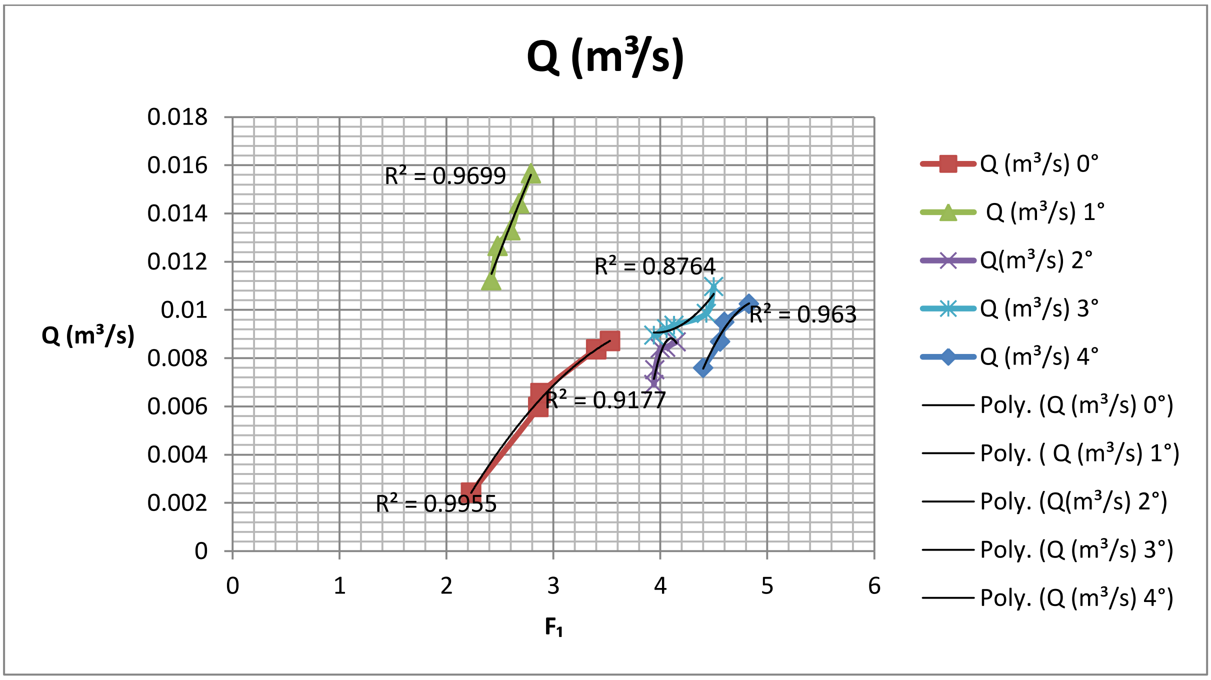

Fig 4f Variation of discharge with Froude no

4.5 CONCLUSION

From the present study it is concluded that sequent depth ratio and relative energy loss increases with increase in incoming Froude no while efficiency of the jump decreases with increase in Froude no.
If we are talking about the variation of these characteristics of hydraulic jump with slope, sequent depth ratio, and relative height of jump increases with increase in slope of channel but relative energy loss decreases with increase in slope of channel. It may be noted that the present study is valid between Froude no 2 to 5. Field results may vary.

Analytical data and graphs have also been shown and plotted side by side to see the variation of experimental data. These variations of experimental data from the analytical ones and from best fit curve may be due to lack of accuracy in measurement of depth of flow, flow velocity. It may also due to friction which is neglected in the present study and may be due to instrumentation errors like roughness, error in sloping mechanism etc.

ANNEXURE

0° READINGS

Table 1: The following table shows experimental data along with analytical data for 0°.

Y_1 (m)	Y_2 (m)	$F_1 = \frac{V_1}{\sqrt{g y_1}}$	Y_2/Y_1 0° (Ex)	$\frac{y_2}{y_1}$ (analytical)	E_2/E_1 0° (Ex)	$\frac{E_2}{E_1}$ (analytical)	$\Delta E/E_1$ 0°	H_j/E_1
0.018	0.042	2.85	2.33	3.56	0.6413	0.76	0.3586	0.2625
0.023	0.055	2.97	2.39	3.7	0.6143	0.74	0.3856	0.257
0.022	0.065	3.19	2.95	4	0.6101	0.71	0.3898	0.3199
0.021	0.067	3.36	3.19	4.2	0.5684	0.69	0.4315	0.3289
0.019	0.057	3.4	3	4.3	0.5814	0.68	0.4185	0.2946
0.004	0.018	3.53	4.5	4.5	0.562	0.66	0.4379	0.3119
0.021	0.068	3.59	3.23	4.6	0.521	0.65	0.4789	0.30047

Table:2 Table comparison between experimental values and analytical values for 0° (by Chow method)

Error in $\frac{y_2}{y_1}$	Error in $\frac{E_2}{E_1}$
-1.23	-0.118
-1.31	-0.125
-1.05	-0.099
-1.01	-0.121
-1.3	-0.0986
0	-0.098
-1.37	-0.129

1° READINGS

Table 3: The following table shows experimental data along with analytical data for 1°.

Y_1 (m)	Y_2 (m)	$F_1 = \frac{V_1}{\sqrt{gy_1}}$	Y_2/Y_1 1° (Ex)	$\frac{y_2}{y_1}$ (analytical)	$\Delta E/E_1$ 1°	H_j/E_1
0.034	0.079	2.59	2.32	3.19	0.4341	0.3028
0.029	0.085	2.73	2.93	3.39	0.3101	0.40685
0.03	0.089	2.77	2.96	3.4	0.28	0.407799
0.029	0.092	2.81	3.17	3.5	0.312	0.43755

Y_1 (m)	Y_2 (m)	$F_1 = \frac{V_1}{\sqrt{gy_1}}$	E_2/E_1 1° (Ex)	$\frac{E_2}{E_1}$ (analytical)
0.029	0.092	2.42	0.9302	0.838
0.031	0.088	2.48	0.7462	0.828
0.034	0.074	2.5	0.6179	0.82
0.034	0.079	2.59	0.5658	0.809
0.032	0.072	2.79	0.5095	0.776
0.017	0.044	3.3	0.45	0.69

Table 4: Table comparison between experimental values and analytical values for 1° by using Chow method

Error in $\frac{y_2}{y_1}$	Error in $\frac{E_2}{E_1}$
-0.87	0.092
-0.46	-0.0818
-0.44	-0.2
-0.33	-0.243
	-0.266
	-0.24

2° READINGS

Table 5: The following table shows experimental data along with analytical data for 2°.

Y_1 (m)	Y_2 (m)	$F_1 = \frac{V_1}{\sqrt{gy_1}}$	Y_2/Y_1 2° (Ex)	$\frac{y_2}{y_1}$ (analytical)	E_2/E_1 2° (Ex)	$\frac{E_2}{E_1}$ (analytical)	$\Delta E/E_1$ 2°	H_j/E_1 2°

0.017	0.097	3.67	5.7	4.7	0.88	0.648	0.1116	0.607
0.018	0.101	3.81	5.61	4.91	0.7551	0.63	0.2448	0.5571
0.017	0.077	3.92	4.52	5.06	0.5712	0.617	0.4287	0.405
0.013	0.057	3.94	4.38	5.1	0.551	0.615	0.4488	0.384

Table 6: comparison between experimental values and analytical values for 2° by using Chow method

Error in $\frac{y_2}{y_1}$	Error in $\frac{E_2}{E_1}$
1	0.232
0.7	0.125
-0.54	-0.045
-0.72	-0.064

3° READINGS

Table 7: The following table shows experimental data along with analytical data for 3°.

Y_1 (m)	Y_2 (m)	$F_1 = \frac{V_1}{\sqrt{g y_1}}$	Y2/Y1 3° (Ex)	$\frac{y_2}{y_1}$ (analytical)	E2/E1 3° (Ex)	$\frac{E_2}{E_1}$ (analytical)	ΔE/E1	H_j/E_1 3°
0.02	0.117	3.7	5.85	4.8	0.8067	0.68	0.1932	0.61618
0.016	0.104	4.13	6.5	5.5	0.7544	0.6	0.2455	0.5748
0.013	0.10	4.68	7.69	6.2	0.6881	0.55	0.3118	0.5595
0.01	0.085	4.99	8.5	7	0.6667	0.52	0.3323	0.5555
0.007	0.07	5.72	10	8	0.5835	0.5	0.4164	0.51775

Table 8: comparison between experimental values and analytical values for 3° by using Chow method

Error in $\frac{y_2}{y_1}$	Error in $\frac{E_2}{E_1}$
1.05	0.126

1	0.154
1.49	0.138
1.5	0.146
2	0.083

4° READINGS

Table: 9 The following table shows the experimental data along with analytical data for 4°.

Y_1 (m)	Y_2 (m)	$F_1 = \frac{V_1}{\sqrt{gy_1}}$	Y_2/Y_1 4° (Ex)	$\frac{y_2}{y_1}$ (analytical)	E_2/E_1 (4°) (Ex)	$\frac{E_2}{E_1}$ (analytical)	$\Delta E/E_1$	Hj/E_1 4°
0.019	0.139	3.86	7.31	4.98	0.9088	0.625	0.0911	0.747
0.015	0.121	4.4	8.06	5.75	0.798	0.57	0.20198	0.6608
0.014	0.123	4.83	8.785	6.35	0.7646	0.5242	0.2353	0.6128
0.011	0.117	5.83	10.63	7.13	0.7118	0.613	0.2881	0.621

Table 10: comparison between experimental values and analytical values for 4° by using Chow method

Error in $\frac{y_2}{y_1}$	Error in $\frac{E_2}{E_1}$
2.32	0.28
2.31	0.22
2.43	0.24
3.5	0.098

Table 11: Showing variation of discharge with Froude no for 0°

Y_1 (m)	Y_2 (m)	$F_1 = \frac{V_1}{\sqrt{gy_1}}$	Q (m^3/s) 0°= A_1V_1
0.011	0.022	2.23	0.002423
0.017	0.051	2.86	0.005976
0.018	0.042	2.85	0.00648
0.019	0.057	3.4	0.008373
0.004	0.018	3.53	0.0008403
0.021	0.068	3.59	0.010291

Table 12: Showing variation of discharge with Froude no for 1°

Y_1 (m)	Y_2 (m)	$F_1 = \frac{V_1}{\sqrt{g y_1}}$	Q (m^3/s) 1°
0.029	0.092	2.42	0.011232
0.031	0.088	2.48	0.012648
0.031	0.094	2.6	0.013299
0.032	0.088	2.68	0.014419
0.032	0.072	2.79	0.01566

Table 13: Showing variation of discharge with Froude no for 2°

Y_1 (m)	Y_2 (m)	$F_1 = \frac{V_1}{\sqrt{g y_1}}$	Q(m^3/s) 2°
0.013	0.057	3.94	0.005499
0.016	0.078	3.95	0.007517
0.017	0.081	4	0.008408
0.017	0.107	4.05	0.008451
0.017	0.104	4.15	0.00867

Table 14: Showing variation of discharge with Froude no for 3°

Y_1 (m)	Y_2 (m)	$F_1 = \frac{V_1}{\sqrt{g y_1}}$	Q (m^3/s) 3°
0.018	0.12	3.94	0.008949
0.018	0.106	4.06	0.009217
0.016	0.104	4.13	0.009362
0.014	0.103	4.43	0.009854
0.022	0.142	4.5	0.01097

Table 15: Showing variation of discharge with Froude no for 4°

Y_1 (m)	Y_2 (m)	$F_1 = \frac{V_1}{\sqrt{g y_1}}$	Q (m^3/s) 4°
0.015	0.121	4.4	0.007603
0.016	0.134	4.56	0.008688
0.014	0.097	4.6	0.009497
0.014	0.125	4.83	0.010255

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