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“Comparison of experimental and theoretical study of hydraulic jump in rectangular channel”

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

MASTER OF TECHNOLOGY

IN

HYDRAULICS AND FLOOD ENGINEERING

By

SAHIL DAYAL

ROLL NO. 2K13/HFE/04

Under the guidance of

T.VIJAY KUMAR

(Assistant Professor)

Department of Civil Engineering

Delhi Technological University

(Formerly Delhi College of Engineering)

DECEMBER 2015

CANDIDATE'S DECLARATION

I do hereby certify that the work presented is the report titled "**Comparison of experimental and theoretical study of hydraulic jump in rectangular channel**" in the partial fulfilment 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 work carried out from January 2015 to Dec 2015 under the supervision of T.Vijay Kumar (Assistant Professor), Department of Civil Engineering.

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

Sahil Dayal

Date: 30.12.2015 (2K13/HFE/04)

CERTIFICATE

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

30/12/15

T.VIJAY KUMAR
(Assistant Professor)
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I take this opportunity to express my gratitude and deep regards to T.Vijay Kumar (Assistant Professor, Civil Engineering Department, DTU) for his guidance, monitoring and constant encouragement throughout the course of this project work. The help and guidance given by him from time to time shall carry me a long way in life on which I am going to embark.

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SAHIL DAYAL

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ABSTRACT

Hydraulic jump is a phenomenon caused by change in stream regime from supercritical to sub – critical flow with considerable energy dissipation and rise in depth of flow. Hydraulic jump primarily serves as energy dissipater to dissipate excess energy of flowing water downstream of hydraulic structures,such as spillway, sluice gates etc. This excess energy,if left unchecked, will have adverse effect on the banks and the bed. The reason for carrying out this study is the application of hydraulic jump in various fields. The main reason for using hydraulic jump as energy dissipater is to reduce the scouring. Hydraulic jump can be used to prevent the scouring action on the downstream side of the dam structure**.** In the present study change in the hydraulic jump characteristics are studied for various slopes experimentally and theoretically using and CFD simulation of the flow carried out using the ANSYS CFX software. The result of experimental and theoretical work has been compared .The experiments were carried out in the rectangular flume installed in the hydraulic laboratory of the Delhi Technological University.

Characteristic features like efficiency, relative height of the jump, energy loss, sequent depth ratio, height of the jump are calculated for different slopes experimentally and by using ANSYS CFX software and found experimental results were fairly matched with theoretical results

List of figures

list of graphs

List of Table

List of symbols

1. $E_{1:}$ Specific Energy before Jump
2. E_2: Specific Energy after Jump
3. ΔE: Energy Loss
4. $\Delta E/E_{1:}$ Relative Energy Loss
5. F_r: Froude number
6. g: Gravitational Acceleration
7. Hj: Height of Jump
8. Lj: Length of the Jump
9. y_{tw} : Tail water depth
10. V_1: mean velocity of flow before jump
11. V_2: mean velocity of flow after jump
12. Y_1 :Depth of flow before the jump
13. Y_2:Depth of flow after the jump
14. E_2/E_1: Efficiency of jump
15. Δh_1 :Pressure difference at pre jump location
16. Δh_2 :Pressure difference at post jump location
17. Gk represents the generation of turbulence kinetic energy
18. $C1\varepsilon$, $C2\varepsilon$ And $C3\varepsilon$ are constants.
19. σk and $\sigma\varepsilon$ are the turbulent Prandtl numbers for k and ε respectively.
20. Sk and $S\varepsilon$ are user-defined source terms.
21. $C\mu$ is a constant

Table of Contents

Chapter 1 Introduction

1.1 General description

Hydraulic jump can be defined as the rise in the level of water when the water transform its super critical form into sub critical one i.e. from unstable state to the stable state. A hydraulic jump occurs when a super critical stream meets a sub critical stream of sufficient depths the super critical streams jumps up to meet its alternate depth, while doing so it generates considerable disturbances in the form of large scale eddies and a reverse flow roller with the results that the jump falls short of its alternate depth.

The place where hydraulic jump takes place a lot of energy is dissipated in the form of heat energy. Hydraulic jump serves as an energy dissipater to dissipate the excess energy of flowing water downstream of hydraulic structure such as rivers spillway and sluice gates. This property is used in spillway of dam to reduce the erosive power of super critical flow otherwise it will harm the structure.

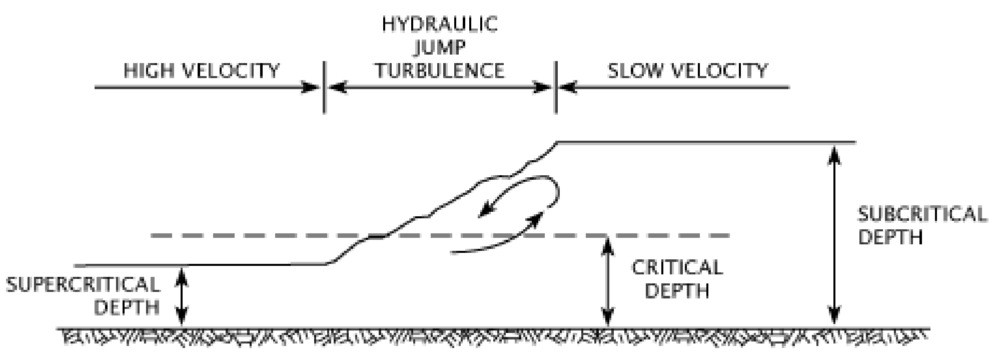


Figure 1: Hydraulic Jump

Hydraulic jump is generally classified on the basis of Froude number,it is a dimensionless quantity which is used to indicate the influence of gravity on the motion of fluid. It is denoted by Fr. a jump can occur in different forms depending upon the approach Froude number. These different forms have different flow patterns and flow like the strength and roller formation. All these characteristic help in determining the amount of energy dissipation that occurs in the jump.

1.2 Application of Hydraulic jump

1. Hydraulic jump can be used as an energy dissipater, dissipate energy in water flowing over dams, weirs and other hydraulic structure. The main reason for using hydraulic jump as energy dissipater is to reduce the scouring.
2. Hydraulic jump reverse the flow of water so it can be used for mixing of chemicals during water purification.
3. Hydraulic jump usually maintains the high water level on the downstream side. This high water level can be used for the irrigation purposes.
4. Hydraulic jump can be used to remove the air from water supply and sewage lines to prevent the air locking.
5. Hydraulic jump can be used to prevent the scouring action on the downstream side of the dam structure.

1.3 Classification of jump

Hydraulic jump in a rectangular channel are classified into 5 classes depending upon the Froude number of the super critical flow.

1. **Undular jump**

Figure 2: Undular Jump

When the water surface shows a very small ripple on the surface. The sequent depth ratio is very small and energy loss is practically zero. Froude number value for undulating jump lies between 0 – 1.7

2. **Weak jump**

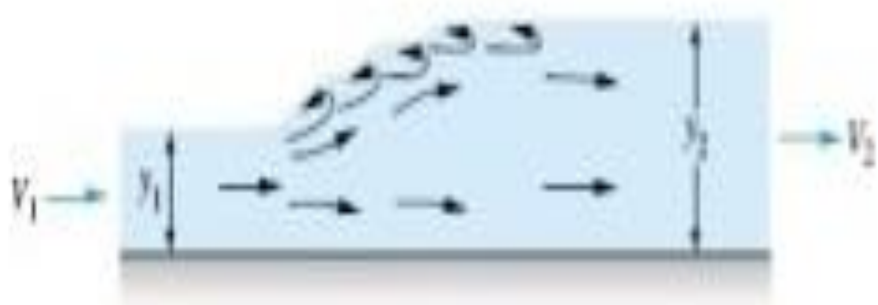


Figure 3: weak Jump

In weak jump the water surface shows more ripple than the Undular jump and the roller starts appearing in this jump at Froude no 1.7 and roller intensity increases as the value of Froude number increases to 2.5. Energy dissipation in this jump varies from 5 % to 18% with respect to increase in the Froude no. and the surface of water becomes smooth after the jump. Froude number value from 1.7 to 2.5

3. **Oscillating jump:** -

Figure 4: Oscillating Jump

Jump under this category shows instability of the high velocity flow which oscillates in a random manner between the bed of the channel and surface. Oscillation in these produce large surface waves which travel considerable distance downstream. moderate energy dissipation takes place in this range of jump and varies from 18% to 45% depending upon the Froude number of the jump .Froude number for this jump varies from 2.5 to 4.5 .

4. **Steady jump: -**

Figure 5: steady Jump

Jump under this category is well established, the roller and jump action is fully developed which can cause appreciable energy loss .the relative energy loss in this jump varies from 45% to70% depending upon the Froude number. This jump is least sensitive in terms of toe positions to showing small fluctuations in the tail water elevation. Froude number for this jump varies from 4.5 to 9

5. **Strong or choppy jump: -**

Figure 6: Strong Jump

Jump under these categories shows the surface of water as very rough and choppy and shows the same condition in the downstream water surface. Sequent depth ratio is large for this jump and large energy dissipation occurs in strong jump. More than 70% of energy loss can be recorded. The value of the Froude number for strong jump is greater than 9.

1.4 Characteristic of hydraulic jump

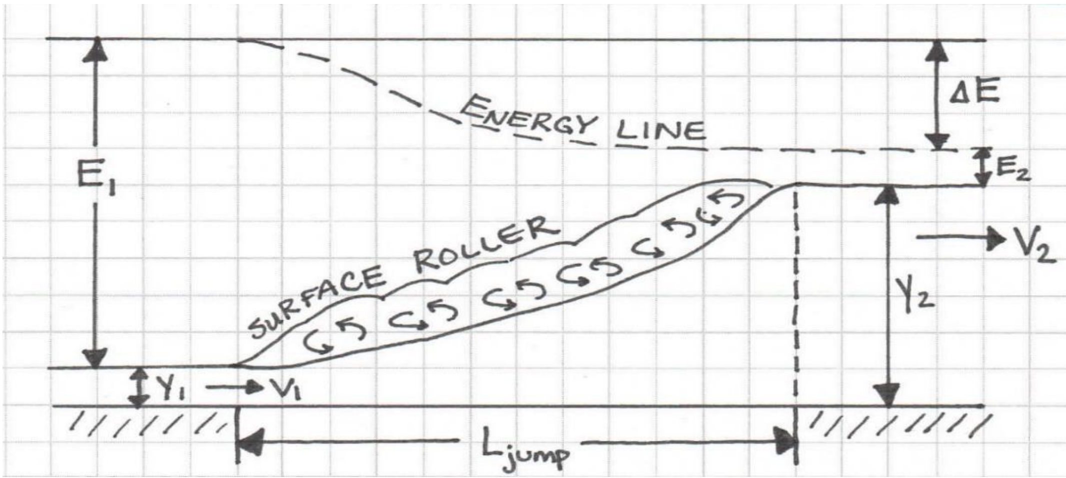


Figure 7: characteristic of hydraulic jump

1.Sequent depth ratio:- it is the ratio of the depth upstream and the depth downstream of the hydraulic jump whose momentum function are equal for a given discharge . The equation which relates the sequent depth **(y_2 \ y_1)** to the initial Froude number is known as Belanger momentum equation.

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

Fr_1 =Froude number of the approach flow=$V_1/(gy_1)^{1/2}$

$y_{2=}$ depth of flow after the jump

y_1 = depth of flow before the jump

V_1= initial velocity

For, higher value of Froude number sequent depth can be calculated by using

y_2/y_1= 1.41F_1

2. Energy loss: - the energy loss **E_L** in the jump is obtained by applying the energy equation to section.

$$E_L = E_1 - E_2$$

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

E_L= energy loss

E_1 = specific energy at supercritical flow

E_2= specific energy at subcritical flow

3. Height of jump: - denoted by $\mathbf{H_j}$, it is the difference in the height of the flow before the jump and after the jump as shown in the figure

$$H_j = Y_2 - Y_1$$

4. Length of the jump: - as shown in the above figure $\mathbf{L_{jump}}$ is an important parameter which affects the size of the stilling basin in which the jump is used. It is the horizontal distance between the toe of the jump to a section where the water surface level becomes stable after reaching the maximum depth.

1.5 Objective of the study

The objective of the study is to study the variation in characteristic of the hydraulic jump on changing the slope of the jump in rectangular channel experimentally in the lab and by using the software Ansys CFX and comparing software work with the experimental work performed in the laboratory for the validation of the results.

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 (L_j/h_2),relative height of jump (h_j/E_1),relative length of jump (L_j/h_2), and efficiency of jump(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 b2 = 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. Analysed 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 he 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, Y1 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.

8. E. Mignot and R. Cienfuegos Energy Dissipation and Turbulent Production in Weak Hydraulic Jumps experimental investigation focuses on energy dissipation and turbulence production in two undeveloped and a partially developed inflow weak hydraulic jumps, measured with micro-ADVs. For the undeveloped inflow jumps, the turbulence production is mostly confined in the shear layer located in the upper part of the water column. For the partially developed inflow jump, two peak turbulence production regions are observed, one in the upper shear layer and the second in the near-wall region. Moreover, the measured energy dissipation distribution in the jumps reveals a similar longitudinal decay of energy dissipation integrated over the flow sections and of maximum turbulence production values from the intermediate jump region toward its downstream section.

9. H. K. Zare and J. C. Doering Forced Hydraulic Jumps below Abrupt Expansions
A new approach for studying forced hydraulic jumps below abrupt symmetric and asymmetric expansions is introduced. Intensive experiments for two expansion ratios, one asymmetry ratio, and different solid sill heights and locations were conducted specifically for the spatial jump case as a critical design case. A new parameter correlating sill height and sill location is presented and found to play an important role in the basin's design, scour, and flow patterns. Using this parameter gives distinguished relationships for predicting sequent depth, energy dissipation, and basin length for the preliminary or operating design in expected or unexpected flow conditions. Empirical equations and experimental regression curves are introduced to predict the sequent depth and the basin length at any sill height and sill location. Scour and flow patterns are intensively studied experimentally and qualitatively described for the symmetric and asymmetric basins with or without sills for the spatial jump. A numerical example is presented to illustrate the applicability of the study in preliminary and operating designs.

10. Esmaeil Kordi and Ismail Abustan, Transitional Expanding Hydraulic Jump This note presents the general features of velocity and variation in length scales of the transition expanding jump, free jump, and wall jet in the rectangular horizontal open channel. The experiments were performed for a range of Froude numbers from 2 to 6 and at an abrupt expansion ratio of 2. The results indicate that the post depth y2 required to form an expanding jump is distinctly smaller than that for the corresponding classical jumps. The expanding jump length was 1.25 times the corresponding free jump length. The velocity profiles for the transition jumps were similar to those for the wall jet. For the transitional expanding jumps, the boundary layer thickness δ, normalized by the supercritical flow depth y1, grows more rapidly relative to the free jumps. The normalized boundary layer thickness δ in terms of the length scale of b equal to the flow depth y, where the velocity u is equal to half of the maximum velocity um, against the longitudinal direction x normalized by y1, which was stabilized at 0.31 for expanding jumps. The length scale L, equal to x where the maximum velocity is equal to half of the initial velocity u0, of the free jump was approximately 0.75 that of the corresponding transitional expanding jump. The growth rate of the length scale (b=y1) for the expanding jumps was approximately 2.4 times that of the corresponding wall jet and free jumps

11. Numerical simulation and laboratory measurement in hydraulic jump by Luis G. Castillo, Jose M. Carrillo, Juan C Garcia

Hydraulic jump is one of the most extended and effective mechanism for hydraulic energy dissipation. Usually, hydraulic jump characteristics have been studied through physical models. Nowadays, computational fluid dynamics (CFD) are an important tool that can help to analyse and to understand complex phenomena that involve high turbulence and air entrainment cases. Free and submerged hydraulic jumps are studied in a rectangular channel downstream a sluice gate. Velocity measurements are carried out by using an Acoustic Doppler Velocimetry (ADV) and a Particle Image velocimetry (PIV). The CFD models boundary conditions are based on laboratory measurements. Air-water two-phase flows are considered in the simulations. The closure problem is solved by using a two-equation turbulence model. Water depths, hydraulic jumps lengths and velocity profiles are compared with laboratory measurements.

Chapter 3 Methodology

In this chapter detail of the experimental work and the theoretical work is provided.

3.1 Experimental work

3.1.1. Aim of the experiment is to create hydraulic jump in the rectangular flume and then to study the characteristic of the hydraulic jump for various slope and analysing the change in the characteristic of the jump due to variation of the slope.

3.1.2 Instruments used in the experiment are as follows:-

1. Working flume

Figure 8: working flume

The flume used in the experiment is 4 m long having a height of 0.40m and width of the flume is 0.30m.

2. Point gauge

It is the instrument which is used to measure the depth of the flow. It is generally fitted on rails over the flume so that it can slide from one point to another for easy measurement

Figure 9: Point Gauge

Figure 10: Point Gauge Fitted on the Flume

3. Pitot static tube

Figure 11: Pitot Static tube

Figure 12: Pitot Static Tube Fitted with Manometer

Pitot tube is an instrument which is used to measure the velocity of flow. In our experiment Pitot tube is fixed with the manometer to measure the velocity of the flow at different points. Pressure difference is noted at various interval in the flume at specific length and then velocity is calculated for the points. For the calibration of the Pitot tube initially pitot tube is placed in the bucket filled with water not having any flow in it , and if the manometer does not show any difference in the pressure and the meniscus in the meter are at the same level than the instrument is considered to be correct , but if the instrument show the variation in the manometric reading or they are not at the same level , than the instrument is not correct for that we have to remove the pressure from the tube and bring the reading to equal level .

4. Inlet valve: it used to control the rate of flow during the experiment, increase or decrease in the flow is controlled by the inlet valve.

5. Sluice gate at both the ends of the flume: sluice gate are present at the start and at the end of the rectangular flume, by maintaining the opening of these gate hydraulic jump is formed in the channel.

6. Water pump: it is necessary for the flow of water through the flume.

3.1.3 Measurements taken in the experiments

In the experiment inlet pressure is measured , slope of the rectangular channel is measured ,height before the jump and height after the jump is measured and velocity of the flow is measured at various interval length of the flume , and length of the jump is measured .

3.1.4 Experimental set up

The experiment is carried out in the hydraulics lab of the Delhi technological university, the flume used in the experiment is 4 m long rectangular flume having width 0.30m and height 0.40m and the two sluice gate are 3m apart. The slope of the flume is maintained with the help of the rotating screw which is situated at the base of the flume. The flume is made of steel structure and the transparent glass so that the jump can be easily seen.

Figure 13: Flume Showing Hydraulic Jump

In this experiment a rectangular working flume is used which is connected with the supply tank for the flow of water, there is an inlet and outlet pipe through which the water from the tank goes to the flume and from the flume goes into the tank again. Inlet pipes are fitted with the orifice meter which shoes the pressure at which the water is flowing in the pipe by the pump. The flume have a rail fitted to in the upper section on which point gauge is fitted , rails helps the movement of point gauge throughout the flume for measurement of depth of the flow . flume have two sluice gate fitted in at one at the inlet and other at the tail end both of them can be regulated with the help of screw fitted on the side of the sluice gate . Jump formation is controlled with the help of these sluice gate. Other than that Pitot tube is used here to measure the velocity of the flow at specific length along the flume. Flume is checked for any leakage of water for the correct reading there should not be any leakage from it.

3.1.5 Experimental procedure

Figure 15:Hydraulic Jump from outside the flume

Figure 14: Hydraulic Jump from the Sluice Gate

This experiment is carried out for the different slopes

1. Initially 0 degree slope is maintained of the rectangular channel, for the first case channel should be horizontal
2. Pump is turned on and water is allowed to flow through the pipes.

3. The flow of water through the inlet pipe is controlled by the screw presents at the inlet pipe. We have maintained the same pressure throughout the experiments for all the different slopes.
4. After the flow through the flume has taken place than flow is regulated with the help of the sluice gate presents.
5. opening of the sluice gate is controlled at both the ends, so that the jump can be formed
6. Jump formed should be stable so that the readings can be taken.
7. after the jump has reached the stable state in the flume than readings are taken
8. Initially bed depth is measured, after that the height of the surface of the water flowing after the jump is measured with the help of the point gauge. The difference in the height of the bed and the height of the flowing water gives the height of the jump of the condition.
9. Marking on the flume along the length are made at the 1.5 m, 2m, 2.5m from the starting sluice gate. so that the reading can be taken at these fixed length in all the cases
10. we divide the 0.30m wide flume from right side to left and have taken readings at 5 cm,10 cm,15cm,20cm,25 cm
11. Pitot tube connected with the manometer is than placed into the flume carefully and fixed at 3cm height above the bed of the flume and along with point gauge so that velocity can be measured at 5cm, 10cm, 15cm, 20cm, 25cm.
12. The same procedure is repeated for 1°, 2°, 3°by changing the slope of the flume and reading are taken similarly at different point along the length and width.

3.1.6 CALCULATIONS

For 0° slope
Y_1= height before the jump = 0.12 m
Y_2= height after the jump = 0.748 m
Velocity are calculated by using the formula $v = \sqrt{(2g\Delta h)}$
Here g= 9.8, Δh = change in the pressure shown by the pitot tube
V_1 = velocity of the flow before the jump = 7.13m/s
V_2 = velocity of the flow after the jump 3.13m/s

Froude number = $V_1 \div \sqrt{gy_1}$= 6.57

Specific energy at supercritical zone i.e.

$E_1 = y_1 + \frac{V_1^2}{2g}$ =0.012+7.132/ 2x9.8= 2.60

Specific energy at sub critical zone i.e.

$E_2 = y_2 + \frac{V_2^2}{2g}$= 1.23

Energy loss = ΔE= E_1- E_2=1.37

Relative energy loss = $\Delta E/E_1$=1.37/2.60=0.52
Efficiency of jump = E_2/E_1=0.47

Height of jump =Y_2-Y_1=0.748-0.12=0.62m

Sequent depth ratio= Y_2/ Y_1=0.748/0.12=6.23
And similarly the calculation for all the other reading for different slope is completed, which is latter used in plotting the graphs

3.2 Numerical Method

3.2.1 Introduction to CFD

Branch of fluid mechanics that uses numerical methods and algorithms to solve and analyses problems that involve fluid flows is known as Computational fluid dynamics (CFD). In this Computers are used to perform the calculations required to simulate the interaction of liquids and gases with surfaces defined by boundary conditions. By using high-speed supercomputers, better results can be achieved.

It constitutes a new third approach in the philosophical study and development of the whole discipline of Fluid Dynamics. The use of high speed digital computer combined with a development of accurate numerical algorithms for solving physical problems on these computers has revolutionized the way we study and practice Fluid Dynamics today. CFD is today an equal partner with theory and experiment in the analysis and solution of Fluid Dynamics problem.
This technique based on simulation by the use of computers is very powerful and have wide range of industrial and non-industrial application areas.

3.2.2 Advantages of CFD

1. Reduction of times and costs of new design can be achieved
2. Ability to study models where controlled experiments are difficult or impossible to perform (e.g. very large models) can be achieved
3. Ability to study systems under hazardous condition at and beyond their normal performance limits (e.g. safety and accident scenarios) can be achieved
4. Practically unlimited level of detail of results can be achieved
5. Cost-Effective Innovation can be achieved

So for solving our CFD problem we are using ANSYS CFX software

The experimental procedure explained above is carried out in the ANSYS CFX software the software work is divided into 3 steps basically

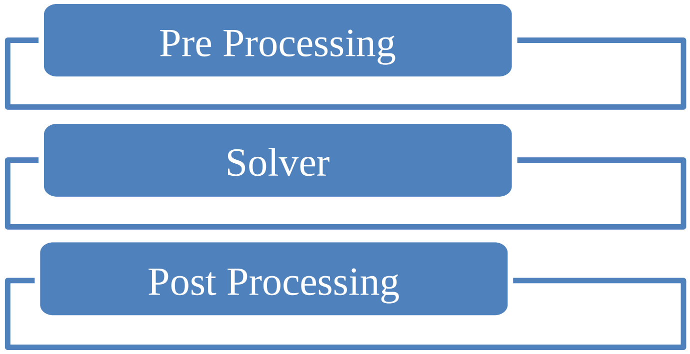


Figure 16: Software Process

3.2.3 Detail of the software process

(A) Pre-Processing

1. Geometry set-up
2. Defining the flow condition (e.g. laminar, turbulent etc.)
3. Defining the boundary condition and initial condition

1. **Geometry set up**:-
   Making the 3D model of the rectangular flume, it is complex to make a 3D model in the ansys so for that we have made our model in AutoCAD software and then imported that model to ansys for the working. The dimension considered in the 3D model are the same that we have considered in the our laboratory experiment of 3m X 0.30m X 0.40m

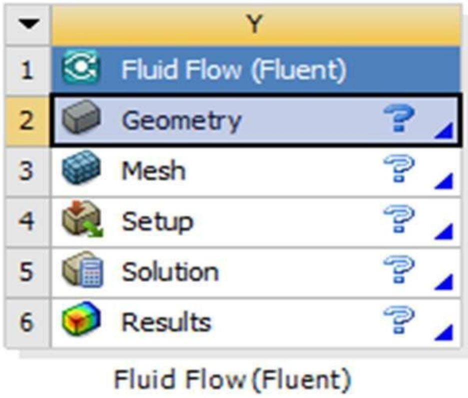


Figure 17: Initial Software Window

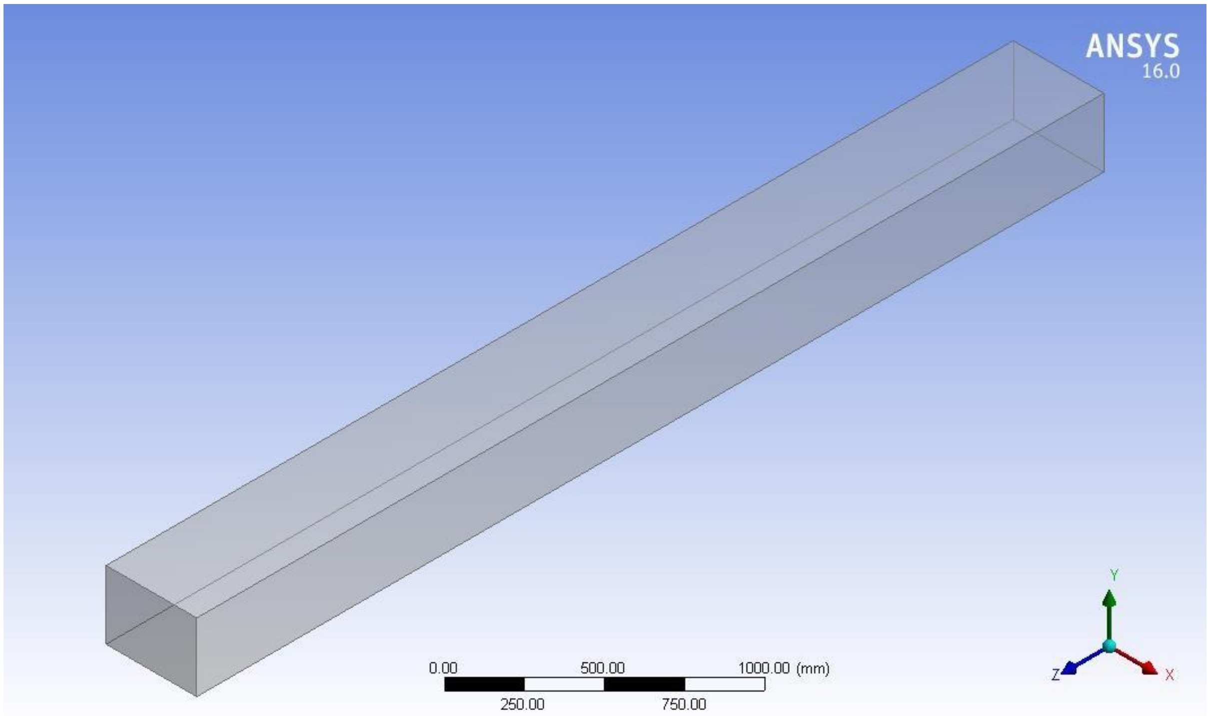


Figure 18: Model Imported From AutoCAD

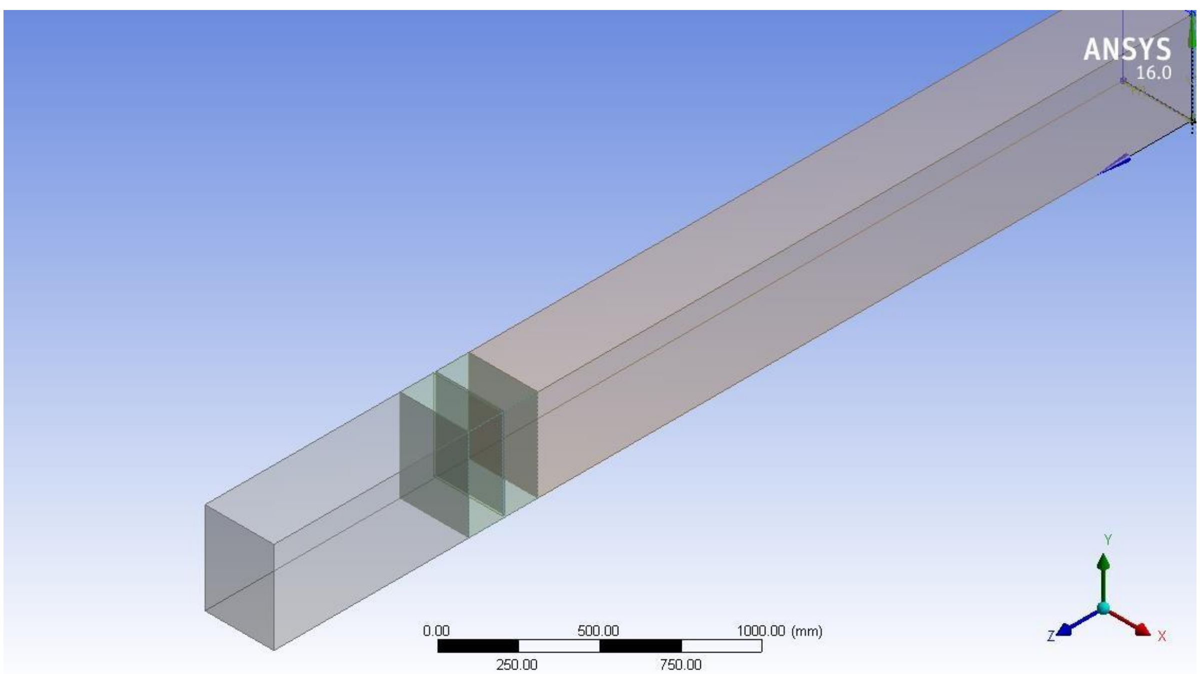


Figure 19: Model of flume

1. (a) Meshing

The basic reason for meshing is to divide the whole model into small sections or small pieces and then study the different sections according to the need and then combine them for the cumulative effect, more the density of meshing more will be its accuracy and more difficult it will become for calculations. The reason for the necessity of the meshing is like in our experiment the velocity of flow will be different in different section so to study the change in the properties of fluid we have to do this process. Ansys has its own meshing software for the use.

Various types of meshing is available in the software

1. Hexahedral
2. Tetrahedral
3. Shell And Beam
4. Advanced Size Function
5. Flexible Sizing Control

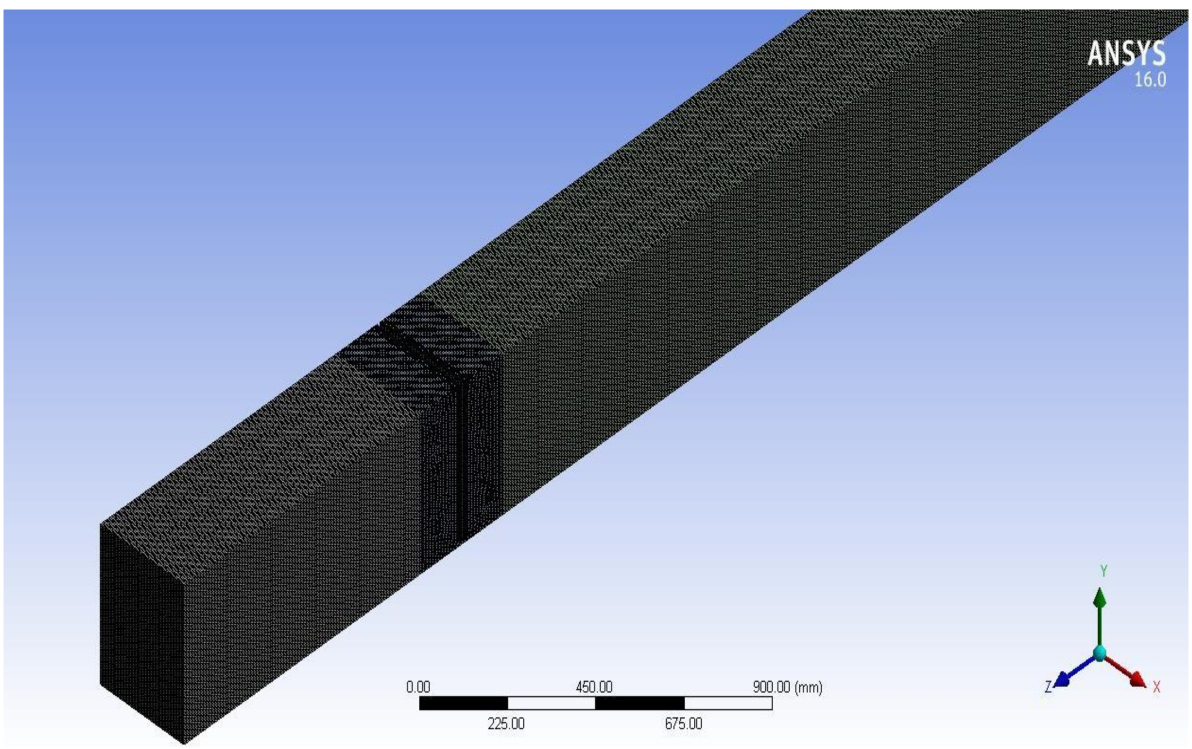


Figure 20: Meshing of the Model

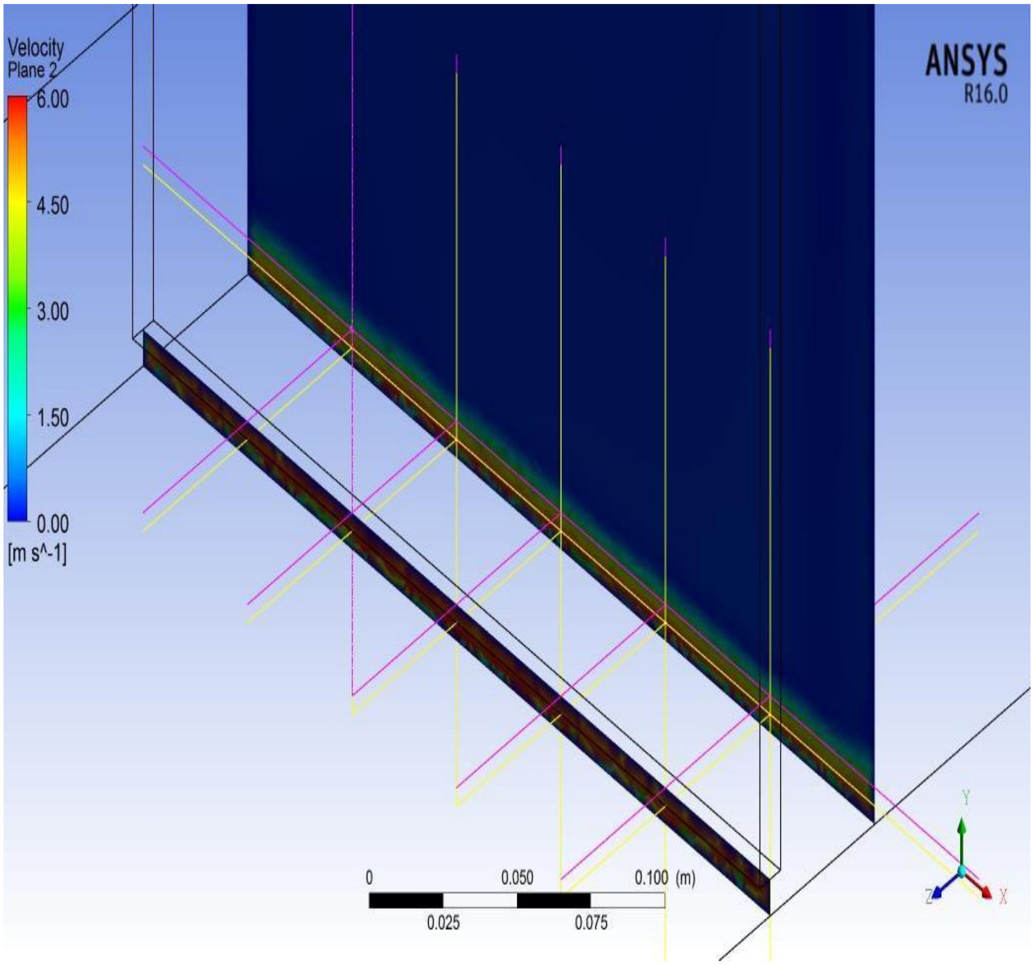


Figure 21: Sections of flume

1. (b) CFX Model: -

First thing to do in setup is to define the gravity action, here in our experiment we have considered the gravity effect and its value is taken as 9.8. So, direction and flow in our experiment is in x direction .after this we have to select the model to be used in the analysis out of the various available models, we have used K-epsilon model. Different available models for the analysis are shown in the figure below

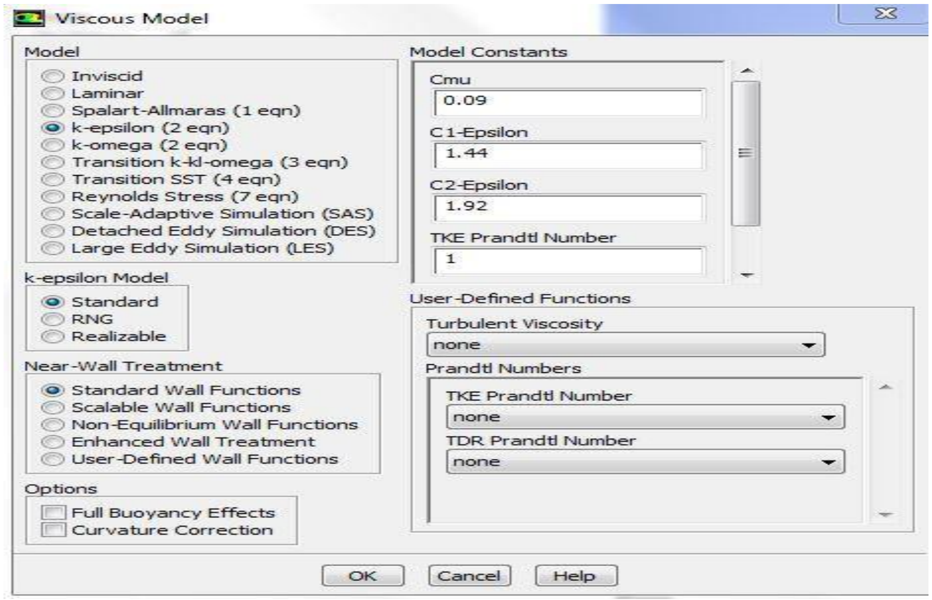


Figure 22: Model Selection Window

Standard k-ε model: this is based on model transport equations for the turbulence kinetic energy (k) and dissipation rate (ε). The assumption made in this model is that there flow is fully turbulent and there is no effect of molecular viscosity on the model . The turbulence kinetic energy (k) and its dissipation rate (ε) are obtained from the following transport equations:

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial t}(\rho k u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + G_k + G_b - \rho\varepsilon - Y_M + S_k \quad \text{.......(i)}$$

And

$$\frac{\partial}{\partial t}(\rho\varepsilon) + \frac{\partial}{\partial t}(\rho\varepsilon u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial k}{\partial x_j}\right] + C_{1\varepsilon}\frac{\varepsilon}{k}(G_k + C_{3\varepsilon}G_b) - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} + S_\varepsilon \quad \text{....(ii)}$$

Here,

Gk represents the generation of turbulence kinetic energy due to the mean velocity gradients, is the generation of turbulence kinetic energy due to buoyancy.

Represents the contribution of the fluctuating dilatation in compressible turbulence to the overall dissipation rate.

$C_1\varepsilon$, $C_2\varepsilon$ And $C_3\varepsilon$ are constants.

σk and $\sigma\varepsilon$ are the turbulent Prandtl numbers for k and ε respectively.

Sk and $S\varepsilon$ are user-defined source terms.

The turbulent (or eddy) viscosity is computed by combining k and ε as:

$$\mu_t = \rho C_\mu \frac{k^2}{\varepsilon}$$

here , $C\mu$ is a constant.

The model constants $C_{1\varepsilon}$, C_2, C_3, σk and $\sigma\varepsilon$ have the following default values

$C_{1\varepsilon} = 1.44$, $C_{2\varepsilon} = 1.92$, $C\mu = 0.09$, $\sigma k = 1.0$, $\sigma\varepsilon = 1.3$
These default values have been determined from experiments for fundamental turbulent flows including frequently encountered shear flows like boundary layers, mixing layers and jets as well as for isotropic grid turbulence. These value have been found to work fairly well for a wide range of wall-bounded and free shear flows.

2. Flow Conditions: - in our experiment the fluid considered is water ,flowing at the temperature of 25 degree Celsius and having a density of 0.997g/ml.

3.Boundary Conditions :- the boundary conditions provided in our experiments are inlet the velocity is 2.6m/s for first case , 2.4m/s for the second case ,2.6m/s for the third case and 3m/s for the last case. Inlet pressure is considered to be 0.9kg/cm^2 and the outlet condition is that water is released at the atmospheric pressure

1. Click the "Create a Boundary Condition" command and enter a name for the boundary. Boundary conditions can be inlets, outlets, openings, walls and symmetry planes.

2. Inlets are used for regions where inflow is expected. Outlets are used for regions where outflow is expected. Define a region as an "opening" when the full prescription of information at that location is not readily available; for example, if the value of pressure is known but the direction of flow is unknown.

3. Walls are solid (impermeable) boundaries to fluid flow. A symmetry boundary condition refers to a planar boundary surface around which the problem is symmetric and the flow on one side of the plane is a mirror image of the flow on the opposite side.

(B) Solver: - this include the use of the equation till the desired level of accuracy is not reached in the process

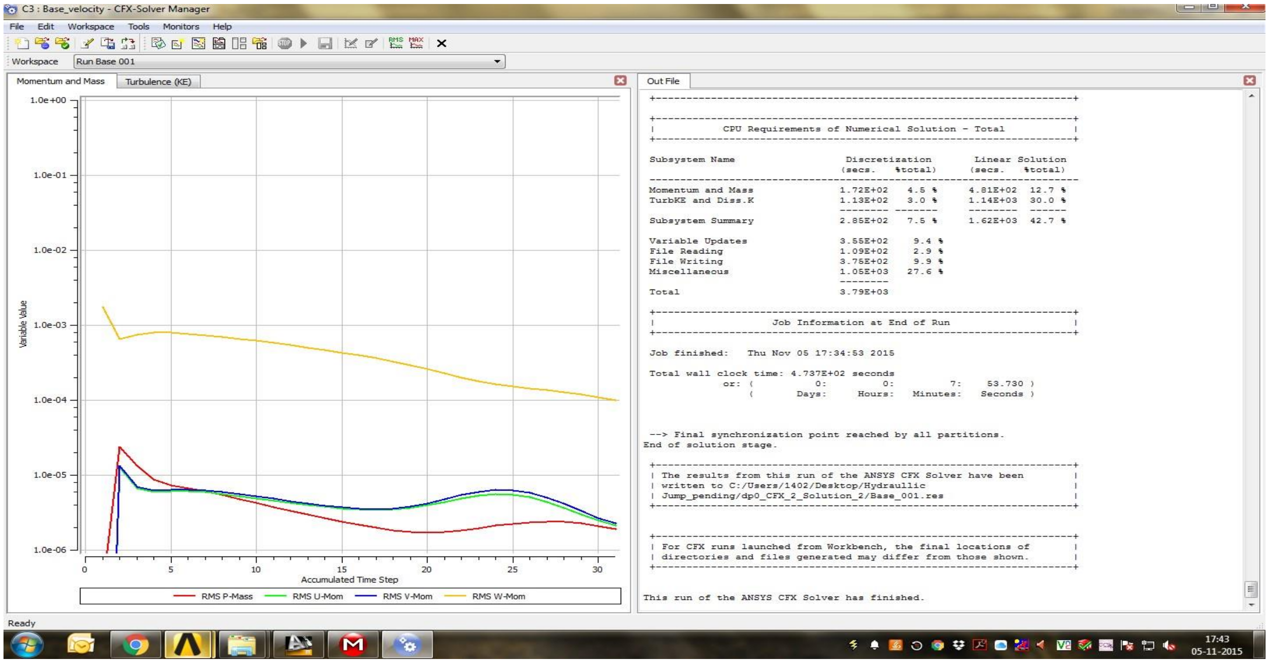


Figure 23: Running Solver Condition

(C) Post Processing: - it include the analysis of the result generated

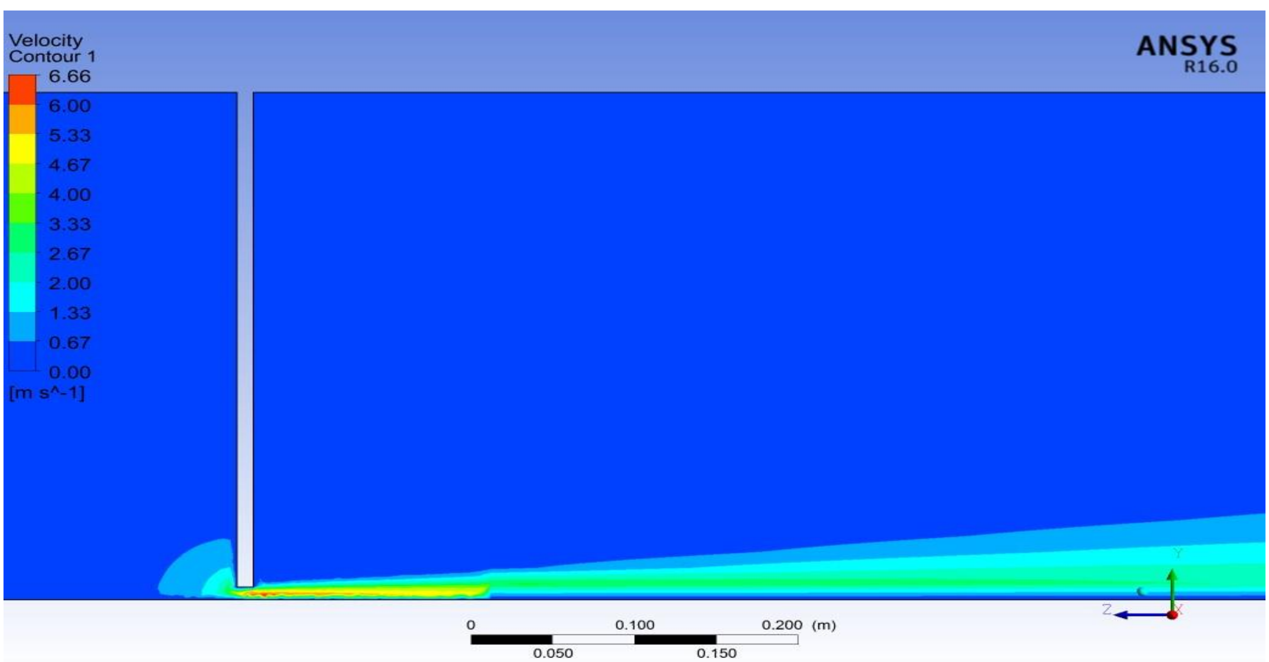


Figure 24: showing the hydraulic jump

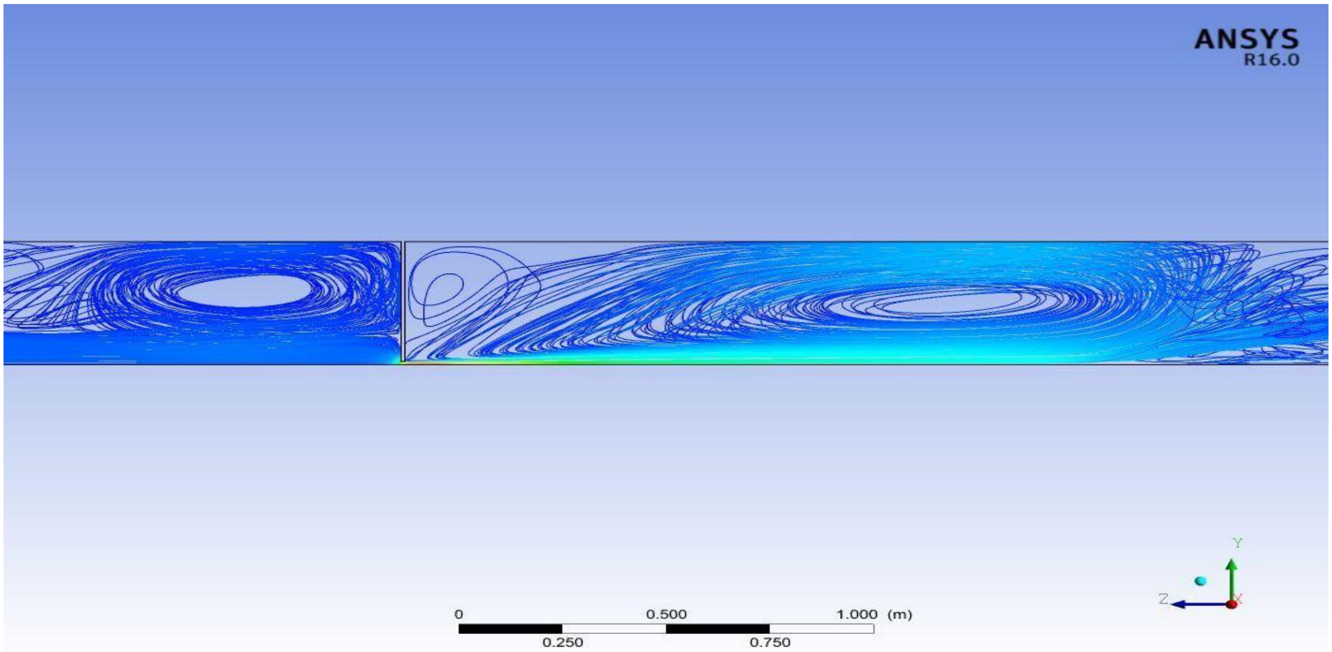


Figure 25: showing the point probe

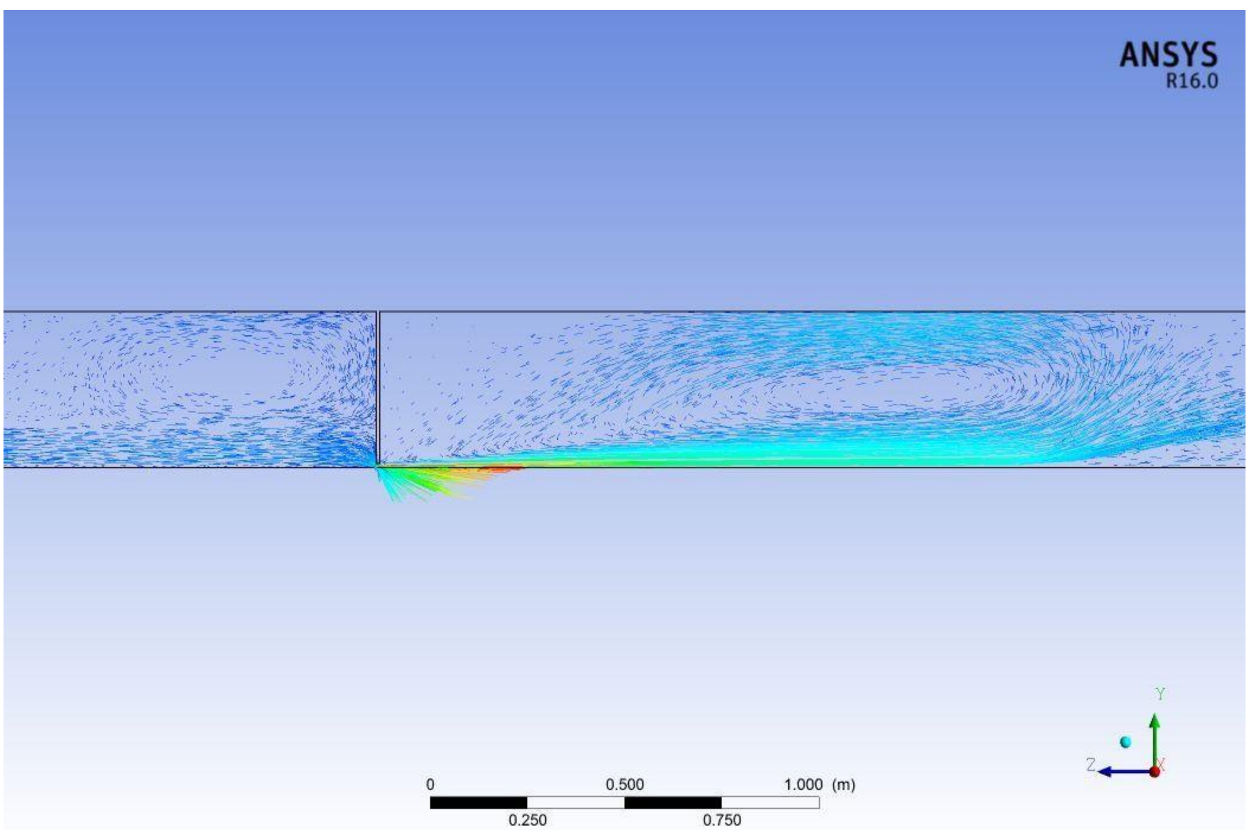


Figure 26: showing the point streamlines

Chapter 4 Results and Discussion

In this chapter all the data generated from the experimental works in the laboratory and the software use are shown

Distance between the sluice gate = 3m

Length of the flume= 4 m

Height of the flume = 0.40m

Width of the flume =0.30m

Pressure P_1= 1.65kg/cm^2, P_2= 0.75kg/cm^2

Case 1:- for 0^0

All the velocities are measured at the 3 cm height from the bed of the flume.

Initial velocity before the jump is 7.13m/s

Height of the jump is 7.58cm

1. Experimental values after the jump for 0°

Table 1: Experimental velocities measured for 0° slope

Velocity at (m/s)	1.5 m length	2 m length	2.5 m length
5 cm width	2.42	2.42	3.13
10 cm	4.84	1.97	2.42
15 cm	7.91	1.97	3.13
20 cm	6.56	2.8	3.42
25 cm	2.42	3.13	3.13

2. Theoretical values after the jump for 0^0

Table 2: Theoretical velocities measured for 0° slope

Velocity at (m/s)	1.5 m length	2 m length	2.5 m length
5 cm width	2.69	2.71	3.85
10 cm	5.56	2.5	2.95
15 cm	8.92	2.23	3.82
20 cm	7.41	3.1	3.97

25 cm	2.71	3.45	3.68

Case 2:- for 1°

Height of the jump is measured 7.68cm

Jump formation at 0.90m from the starting sluice gate

Initial velocity = 6.85m/s

1. Experimental values after the jump

Table 3: Experimental velocities measured for 1° slope

Velocity at (m/s)	1.5 m length	2 m length	2.5 m length
5 cm width	7.66	5.4	4.2
10 cm	6.71	4.64	1.97
15 cm	3.13	1.4	2.42
20 cm	2.42	1.4	1.7
25 cm	1.97	2.42	1.97

2. Theoretical values after the jump

Table 4: Theoretical velocities measured for 1° **slope**

Velocity at (m/s)	1.5 m length	2 m length	2.5 m length
5 cm width	9.19	6.26	4.8
10 cm	7.91	5.12	2.56
15 cm	3.85	1.9	3.12
20 cm	3.12	2.1	2.13
25 cm	2.25	2.85	2.51

Case 3:- for 2°

Height of the jump measured is 8cm

Jump formation at 1.10m from the starting sluice gate

Initial velocity = 7.13m/s

1. Experimental values after the jump

Table 5: Experimental velocities measured for 2° slope

Velocity at (m/s)	1.5 m length	2 m length	2.5 m length
5 cm width	1.97	2.42	1.4
10 cm	1.97	2.42	1.97
15 cm	6.26	3.70	2.42
20 cm	9.59	4.8	3.42
25 cm	3.70	6.10	4.42

2. Theoretical values after the jump

Table 6: Theoretical velocities measured for 2° slope

Velocity at (m/s)	1.5 m length	2 m length	2.5 m length
5 cm width	2.12	2.85	1.68
10 cm	2.5	2.98	2.28
15 cm	7.85	4.25	2.86
20 cm	11.1	5.65	3.96
25 cm	4.23	7.18	5.21

Case 4:- for 3 °

Height of the jump measured is 8.7cm

Jump formation at 1.30 m from the starting sluice gate

Initial velocity = 7.66m/s

1. Experimental values after the jump

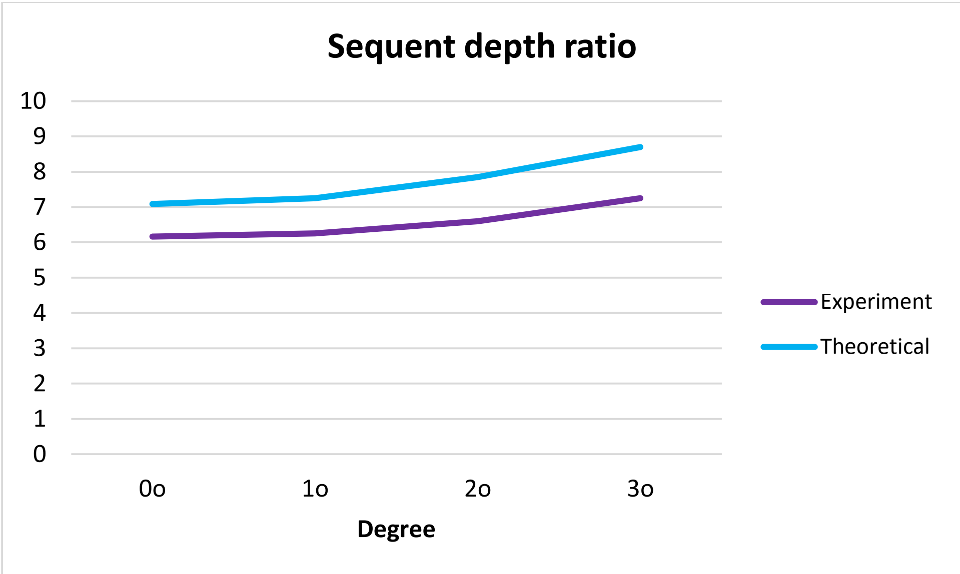
Table 7: Experimental velocities measured for 3° slope

Velocity at (m/s)	1.5 m length	2 m length	2.5 m length
5 cm width	9.66	5.4	4.2
10 cm	6.71	3.70	1.97
15 cm	3.13	1.4	2.42
20 cm	2.42	1.4	1.4
25 cm	1.97	2.42	7

2. Theoretical values after the jump

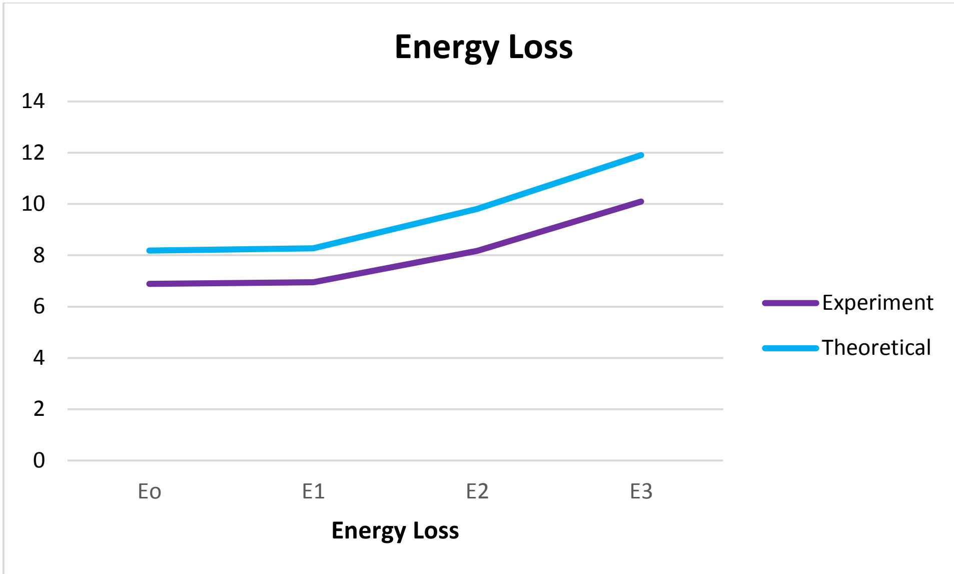
Table 8: Theoretical velocities measured for 3° slope

Velocity at (m/s)	1.5 m length	2 m length	2.5 m length
5 cm width	11.40	6.04	4.87
10 cm	7.51	4.36	2.12
15 cm	3.75	1.78	2.69
20 cm	2.78	1.6	1.66
25 cm	2.3	2.85	2.11



Graph 1: showing the variation in sequent depth with the change in the slope

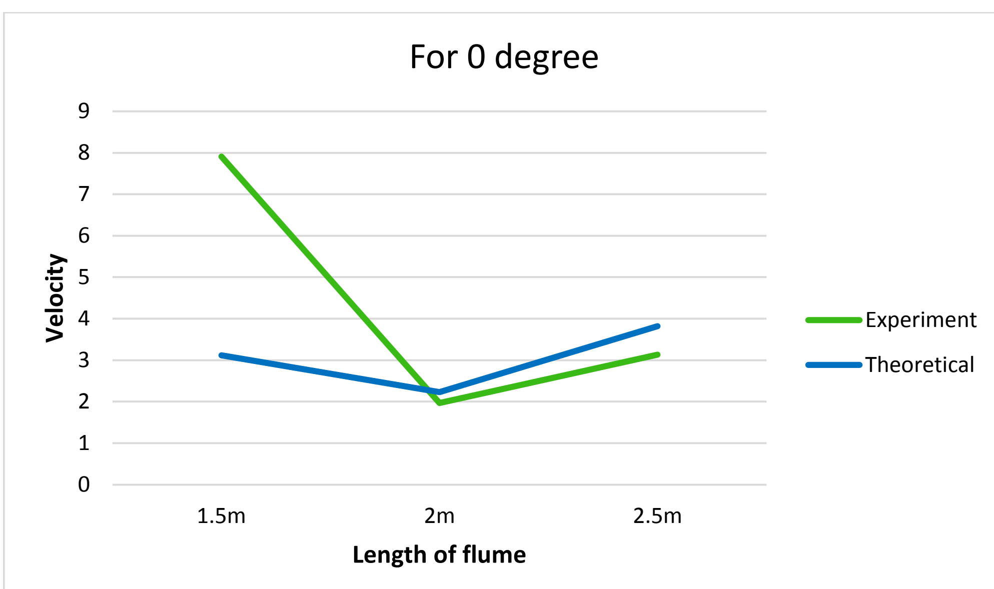
Graph showing the variation in the sequent depth with the change of slope, from the study it was concluded that the by increasing the slope of the channel the sequent depth ratio also increases and the same result is shown in both the works experimental as well as the software the difference in the value of the experimental and software work is may be due to the error in the taking the reading in the experimental works or could be due to error in sloping mechanism.



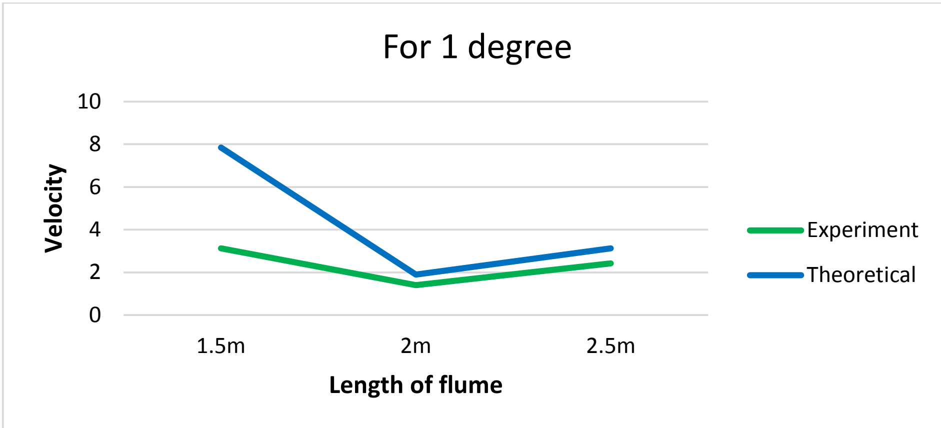
Graph 2: showing the variation in energy loss with the change in the slope

The graph showing the variation in the energy loss with the change of slope, from the study it was concluded that the by increasing the slope of the channel the sequent depth ratio also increases and the same result is shown in both the works experimental as well as the software the difference in the value of the experimental and software work is may be due to the error in the taking the reading in the experimental works or could be due to error in sloping mechanism.

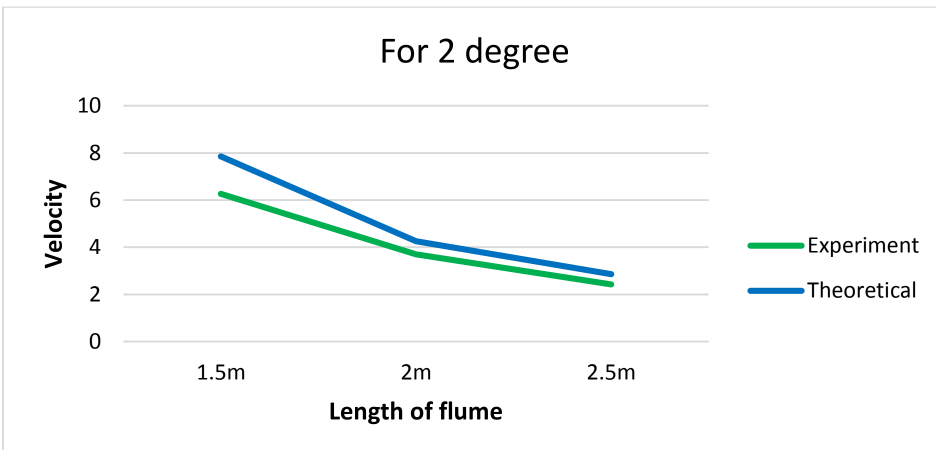
Following graphs are showing the change in the velocity patterns after the jump for different slopes



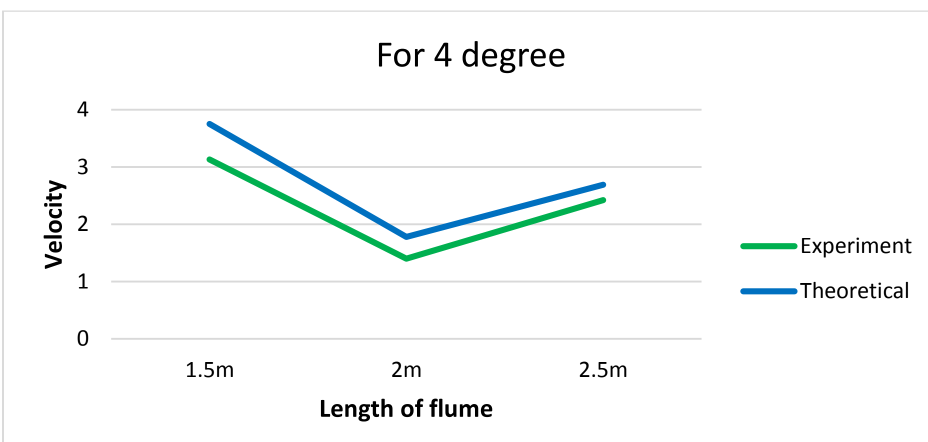
Graph 3: showing the variation in velocity of the flow for 0^0 slope



Graph 4: showing the variation in velocity of the flow for 1^0 slope



Graph 5: showing the variation in velocity of the flow for 2^0 slope



Graph 6: showing the variation in velocity of the flow for 3^0 slope

Chapter 5 Conclusion

Hydraulic jump is a phenomenon caused by change in stream regime from supercritical to sub – critical flow with considerable energy dissipation and rise in depth of flow. Hydraulic jump primarily serves as an energy dissipater to dissipate excess energy of flowing water downstream of hydraulic structures, such as spillway, sluice gates etc. This excess energy, if left unchecked, will have adverse effect on the banks and the bed.in the present study, the experimental and numerical modelling of the flow pattern at rectangular channel has been carried out. On the basis of the investigation concerning flow the properties of the hydraulic jump have been concluded. On the basis of velocity contour it is concluded that there is a good agreement between the results of the CFD analysis with that of the experimental results. The conclusion of the study, the reason for carrying out the study is to analyses the effect of changing slopes bring in the properties of the hydraulic jump, the study resulted in the variation of the properties like with increase in the slope of the channel there is increase in the sequent depth ratio and height of the jump and energy loss also increase as the slope is increased but relative energy loss decrease with the increment in slope. Various graphs showing the change in the pattern of the properties are already shown in the results. These result have been concluded from the experiment performed in the laboratory as well as by the use of the software. On comparing the results from experimental works and software work there is 10-20% difference in the values of the properties considered have been observed. The difference in the result is may be due the instrumental error or due to error in taking the reading during experimental works or it could be due the friction or roughness in the bed of the flume which we have not considered into our study .The result obtained from the study are satisfactory

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