EXPERIMENTAL STUDY OF SUPER-CRITICAL FLOW THROUGH CHANNEL CONTRACTION

A DISSERTATION

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CANDIDATE'S DECLARATION

I, Shashank Shekhar, 2K16/HFE/17 student of M.Tech Hydraulic and Water Resources Engineering, hereby certify that theproject Dissertation titled "**Experimental study of super-critical flow through channel contraction**" which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in the partial fulfilment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously fored the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar tite or recognition.

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CERTIFICATE

I hereby certify that the Project Dissertation titled "EXPERIMENTAL STUDY OF SUPER-CRITICAL FLOW THROUGH CHANNEL CONTRACTION" which is submitted by Shashank Shekhar, Roll No 2K16/HFE/17, Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology is record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

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ABSTRACT

The transitions in a channel serve as a connection between the original and the new channel. These channel transitions are a necessity in artificial or natural channels at bridges, barrages, weirs, siphons, falls, aqueducts etc. Transitions are also provided in water drains and sewage systems. The energy losses and determination of the surface profile to provide the required velocity distribution at the end of the transition are few problems areas that the hydraulic engineers need to consider. In this study, experiments were performed on a rectangular channel. The transition was contraction and expansion of the channel. It was found that for super-critical flow, till the contraction width is greater than the choking width, as the contraction width decreases the rise in water level increases and the velocity decreases. When the contraction width is reduced beyond the choking width, the water flow changes from super critical to sub critical at some distance upstream from the contraction through a small hydraulic jump. An afflux is developed, specific energy increases so that the flow can be maintained; velocity decreases abruptly some distance before the contraction. It continues to decrease till it reaches contraction.

CONTENTS

List of Abbreviations and Symbols

b	Width of the channel
b_2	Width contraction
b_0	Width of channel at contraction
v	Depth averaged velocity
F_r	Froude Number
g	Acceleration due to gravity
h	Piezometric head difference
y	Depth of flow
x	Horizontal distance
Q	Discharge
q	Unit discharge

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CHAPTER 1

INTRODUCTION

Introduction of transitions in a channel is a common necessity for economical as well as practical reasons. The transitions serve as a connection between the original and the new channel. The transitions can be in the form of contracting channel to reduce the width of the channel, expanding channel to increase the width of the channel, humps and depression in the channel bed, increasing or decreasing the grade of the channel etc. . These channel transitions are a necessity in artificial or natural channels at bridges, barrages, weirs, siphons, falls, aqueducts etc. Transitions are also provided in water drains and sewage systems. Designing and performance of these transitions are critically dependent on subcritical and supercritical flow states. The energy losses and determination of the surface profile to provide the required velocity distribution at the end of the transition are few problems areas that the hydraulic engineers need to consider.

There are different types of transitions that can be applied as per the requirement. The transition can be gradual or sudden, vertical (fall or rise in bed) or horizontal (contracting or expanding) or it may be a combination of above. Sudden transitions introduce the change in a relatively short distance and it will give rise to rapidly varied flow. Constriction is the reach of sudden reduction in the cross section of the channel. Gradual transitions introduce the change in a relatively longer distance and it will give rise to gradually varied flow varied flow.

1.1 Specific Energy

Energy head of an open channel with respect to the channel bed, expressed in terms of depth of flow and velocity head is called Specific Energy. B.A. Bakmeteff was the first one to introduce the concept of specific energy in 1912 and since then it has helped to get solutions and physical interpretation of complex problems of open channel flow. For a constant given discharge, the specific energy varies with depth of flow.

1.2 Critical Flow

The flow with minimum specific energy is called critical flow. The flow depth at which the flow has minimum specific energy is called critical depth. At critical depth, for a given discharge, the specific force is also minimum. For a given specific energy the discharge is maximum. The value of Froude number is unity.

If the flow depth is more than critical depth, then this type of flow is termed as sub critical flow. If the flow depth is smaller than critical depth, then this type of flow is termed as super critical flow. In sub critical flow the wave velocity is greater than flow velocity. Therefore wave expands and appears upstream. In super critical flow flow velocity is greater than wave velocity. Therefore wave is transmitted downstream and no wave appears on the upstream.

1.3 Velocity Distribution In Open Channels

Generally, open channel flows are complicated. The prediction of depth of flow velocity of free surface flow, discharge and bed slope are inter dependent. Velocity in a channel flow continuously fluctuates due to the friction generated from the side slope and channel bed. The velocity distributions in open channels are generally unsymmetrical because of the bed surface and free surface. The measured maximum velocity occurs at about 0.05 to 0.25 times the depth of flow from the free surface. In a wide, fast flowing and shallow water channel or in very smooth channel, the maximum velocity may occur very near to the free surface. The distribution of velocity in a channel section depends on factors like roughness of the boundary of the channel, shape of the cross-section and presence of bends and curve in the channel layout. . Velocity component in transverse direction is generally small and insignificant compared to the longitudinal velocity components. In this study, the flow in smooth rectangular channel with smooth boundaries has been studied.

1.4 Froude Number

In continuum mechanics, the Froude number (represented by F_r) is defined as ration of inertia force to force due to gravity. It is a dimensionless number. The flow can be classified as sub-critical flow, critical flow and super-critical on the basis of value of Froude Number. For sub critical flow $F_r<1$, for critical flow $F_r=1$ and for super critical flow $F_r>1$.

In this paper, water flowing through a rectangular channel has been analysed. The water flows through transition in the rectangular channel. The transition is that the channel first contracts to a certain width and then expands. Sketch of the contraction can be seen Fig 3.2 later in chapter 3. A complete description of the transition is available in the chapter 3. Transitions in a channel are a common necessity for economical as well as practical reasons. The transitions serve as a connection between the original and the new channel. The transitions can be in the form of contracting channel to reduce the width of the channel, expanding channel to increase the width of the channel, humps and depression in the channel bed, increasing or decreasing the grade of the channel etc. These transitions are often required in natural and artificial channels at siphons, aqueducts, weirs, falls, bridges, barrages etc. transitions are also provided in water drains and sewage drains. In this study supercritical flows through a rectangular channel with a contraction and subsequent expansion by experimental means has been studied. Experimentally, with the help of the data, the free surface profile has been plotted. Also the average velocity variation and specific energy graphs for the test length of the flume have been represented graphically.

1.5 Surface Profile

Surface profile is the shape of water surface that the water makes. It is a straight line when the water is flowing uniformly. But any introduction of change in its flow condition changes its profile. The surface profile gives an idea by how much the water will rise/fall due to the transition and to what distance the depth of flow will be influenced. It helps in determining the free board of the water channel. It also helps in determining the position of lateral drains in sewage system so that the water does not flow back into the lateral drains for certain degree of chocking.

1.6 Objective of Present Study

Transitions in a channel are a common necessity for economical as well as practical reasons. The transitions serve as a connection between the original and the new channel. The transitions can be in the form of contracting channel to reduce the width of the channel, expanding channel to increase the width of the channel, humps and depression in the channel bed, increasing or decreasing the grade of the channel etc. These transitions are often required in natural and artificial channels at siphons, weirs, aqueducts, falls, barrages, bridges etc. transitions are also provided in water drains and sewage systems. Designing and performance of these transitions are critically dependent on subcritical and supercritical flow states. The energy losses and determination of the surface profile to provide the required velocity distribution at the end of the transition are few problems areas that the hydraulic engineers need to consider.

In this project how the upstream and downstream get affected when a contraction and expansion is introduced in a rectangular channel has been studied. The project deals with the study of supercritical flow. This type of condition can arise in sewage system. So it becomes important to study the effect of transition to prevent choking of the system.

The main objective of the study are-

- Check the effect of contraction and subsequent expansion on the water surface profile of the super critical flow.
- Longitudinal velocity distribution along the channel with contraction and expansion.
- Effect of contraction and expansion on specific energy.
- Check the effect of contraction and subsequent expansion on the water surface profile of the super critical flow when the contraction is reduced beyond choking width.
- Longitudinal velocity distribution and changes in specific energy along the channel when the contraction is larger than choking width.

1.7 Scope of The Study

For this study, the experiments were performed on rectangular flume/channel of 8m length. The contraction and expansion was made with the help of aluminium sheets. The study of effect of contraction and subsequent expansion on the water surface profile, energy loss and longitudinal velocity distribution will be helpful in determining the behaviour of channel flow, thus aiding engineers to design better performing and more efficient channels for water flow. Studying the effect of contraction and subsequent expansion on the water surface profile of the super critical flow when the contraction is reduced beyond choking width, longitudinal velocity distribution and changes in specific energy along the channel when the contraction is larger than choking width will be helpful in determining the changes that could happen when such conditions become unavoidable due to natural conditions present at the site, thus aiding engineers to design a better performing and more efficient channels for water flow.

1.8 Organisation Of The Thesis

The basic focus of this thesis is to study the effect of the effect of contraction and subsequent expansion on the water surface profile of the super critical flow. The thesis comprises of 6 chapters.

Chapter 1 gives an introduction to the topic with this thesis's objective and scope of this study.

Chapter 2 includes all literature review which was studied related to open channel flow, specific energy etc to develop a hypothesis about the experiment.

Chapter 3 has an extensive detail of the the experimental procedure and experimental setup that is used in this study.

Chapter 4 deals with the theory of all concepts that are needed to understand the behaviour of the flow when contraction and expansion is introduced in the channel.

Chapter 5 includes all the data organised in tables, calculations, results and discussion of the study. Results for all the contracted width are how in these chapter.

Chapter 6 contains the synopsis and conclusion of this thesis. This chapter also includes future recommendation.

CHAPTER 2

LITERATURE REVIEW

Terry W. Sturm (1985) In this study its been established that minimization of standing waves in supercritical flow in a contraction is equivalent to simultaneous satisfaction of the continuity equation across the wave front, the momentum equation parallel to and perpendicular to the wave front and also continuity through the contraction. Simultaneous solution of all these four governing equations has been graphically presented which removes the need of trial and error in the design procedure. Choking criteria has also been defined which can assist the designer in maintaining supercritical flow throughout the transition.

Abdulrahman (2008) in this study a new analytical method to find the solution to specific energy equation has been developed. He has discussed some other methods and with the help of real world examples showed that his method to find the solution to the specific energy equation is closer to the actual value. He showed that the proposed method gives direct solution to the equation which is more accurate less time consuming.

Benjamin Akers and Onno Bokhove (2008) have investigated water flows having less depth flowing in a channel with a contraction by experimental as well as theoretical means. Experimentally, they observed upstream steady and surges and oblique waves in the contraction, as multiple and single steady states, as well as a steady reservoir with a complex hydraulic jump in the contraction occurring in the contraction. Different observations were made for different contraction and represented for different ratios of original and contracted width. A numerical and analytical analysis for two-dimensional supercritical shallow water flows is also given.

Vittal, Nandana. (1978) in this paper an alternate method to find the solution of the specific energy eqution has been derived. This proposed solution is free from the error which was present in the generally used trial and error method to solve the equation. This paper demonstrate unique dimensionless discharge-depth relationships for exponential, trapezoidal and circular channels that gives direct solutions to various problems on vertical, horizontal, and combined horizontal vertical transitions and also including change in cross-sectional shape.

Wilkerson et al. (2005) two models were developed to predict velocity distribution based on depth averaged velocity. When the velocity data for the depth-averaged velocity is available then the 1st model is used and when only depth-averaged velocities, which are predicted, are within the range of 20% of actual velocities the 2^{nd} model is used. He used data of past studies related to straight trapezoidal channels having small width which made form drag on the fluid exerted by the bank dominant and thereby the depth averaged velocity distribution is controlled. The effect of secondary current is ignored to collect the data they used for building up the model are free from.

A. W. Vreman and O. Bokhove (2006) investigated about the hydraulic behaviour of dry granular matter spread over an inclined flume with a linear contraction. They observe upstream moving surge and stationary hydraulic jumps, a deep reservoir with a structure akin to a Mach stem in the contraction, and oblique hydraulic jumps or shocks in the contraction for one value of the Froude number and increasing values of the scaled nozzle. The observations are studied in detail for different contraction width. All the results are plotted on graph and can be easily compared for different contraction. This study was an extension of the study made by Baines and Whitehead.

Baines and Whitehead (2003) considered flows up an inclined plane in a uniform channel and over an obstacle uniform across the channel. They found that the flow regime consists of three stable simultaneously existing steady states for certain Froude numbers and certain contraction widths. The Froude number considered is the upstream Froude number based on the constant depth just downstream of the sluice gate. In addition, to the two states, which are, the upstream moving surge and supercritical flows with frail oblique waves, they found a stable reservoir state with a jump structure similar to a Mach stem in gas dynamics in the contraction. The observations are studied in detail for different contraction width. All the results were plotted on graph and could be easily compared for different contraction.

Nandana Vittal and V. V. Chiranjeevi (1983) some of the existing methods at that time for designing an open channel transition between a rectangular channel and a trapezoidal channel under sub-critical flow have been examined. A Suggestion has been made to make some of the transition design a direct method. Basically from the fluid mechanics point of view the problem of flow through open channel transitions has been viewed and suitable functions for the boundaries of transition such as bed width, bed elevation, and side slope have been identified partly experimentally and partly analytically. Based on the results, a new and rational method of design is suggested. Boundary conditions for transitions having different shapes has been derived. Also a new method of design of the transitions has been developed and verified by taking real world problems.

Prabhata K. Swamee and Bharat C (1994) in this research paper they applied optimal-control theory to develop a methodology for design of contraction transition for a subcritical flow. They have analyzed a large number of optimally designed transitions and then they have obtained empirical equations for bed width, side slope, and bed-elevation profiles. These equations may find use in the design of contacting channels. It was analytically found that the transition design produce less head loss than the existing methods by using the derived equation.

Vicente L. Lopes and Edward D. Shirley (1993) in this paper they have developed a numerical procedure for accurately finding the location and flow transition (also called critical control section) in open channels with gradually varying discharge along the channel length. They have considered triangular, rectangular and trapezoidal cross section of the channel

Francis F. Escoffier (1958) in the journal paper transitional profile in a non uniform channel has been studied. Nature of transition depth and transition profile has been studied. Graphical method to construct transition profiles and its use in practical world has been described. It was found that point of transition or critical point is a singular point and solution to differential equation for steady flow does not give traditional vertical water surface profile at that point

James Cullen (1989) in this thesis paper comparisons have been made between computed and experimental values of water surface profiles in side channel spillways. This thesis investigated the Hinds method with specific reference to the water surface slope equation. Experimental methods used during that time are also discussed. A computer program created to calculate the water surface profile within a side channel spillways is also proposed.

Bejamin Akers (2006) in this work shallow water flows has been studied. Data has been collected from River Severn (England) and Amazon River (Brazil). The have considered different geometry and flow rate to study the effect they have on formation and stability of hydraulic jump.

Gregory V. Wilkerson and Jessica L. McGahan (2005) In this study it is stated that equations used commonly for the prediction of depth averaged velocities in wide channels do not give accurate results in predicting depth averaged velocities in trapezoidal channels. They have considered three other previous studies to develop two models for predicting depth averaged velocity distributions in straight trapezoidal channels. The first model needed measured velocity data from experiments for calibrating the model coefficients, whereas the second model used prescribed coefficients.

Ioannis K. Tsanis And Hans J. Leutheusser (1986) In this research paper the concepts of quasi-uniform flow and one dimensional flow are used to derive the fundamental differential equation of gradually varied laminar flow in open channels. The equation derived is solved for a particular case of rectangular flume and the analytically predicted surface profiles in channels of zero, mild and adverse slopes are compared with experimental observations.

Mizanur Rahman and M. Hanif Chaudhry (2010) In this study many problems related to supercritical flow are acknowledged like depending on the shape, size and kind of channels, the flow can produce normal or oblique surges, expansion waves, hydraulic jumps and sometimes complex wave patterns due to multiple reflections of these waves at the boundary and also due to their interactions with one another. So a new procedure has been established in this paper to analyze the flow analytically. Instead of fixed grid system, in this study an adaptive grid system is used which adjusts itself as the solution evolves.

Willi H. Hager (1989) In this study a theoretical and an experimental approach has been used to study the main flow features at junctions of a channel transition having supercritical flows. The junctions are characterized by rectangular channels having equal width of branch and the corner edges are kept smooth. Two different angle of junction 22.5° and 45° are considered. Equations have been derived for the wave angles in both the lateral branches and upstream along with the direction of the main wave front. The prediction has been made based on a conventional crosswave analysis. In this analysis streamline curvature effect is not considered. Predictions and observations regarding the maximum wave height, and its position in the junction are agreeable. Furthermore, the flow surface and velocity field are. The limits of supercritical flow conditions are verified by the momentum equation, establishing that the flow contraction generated at the inflow to the downstream branch are included.

CHAPTER 3

EXPERIMENTAL PROGRAM

3.1 General

The experiment was performed under controlled laboratory conditions in the Fluid Mechanics Laboratory of the Civil Engineering Department of Delhi Technological University, Delhi, India in order to plot the surface profile, velocity distribution along the length of the flume and to know how the specific energy varies along the length of the channel transition (contraction and expansion). Experiments were also conducted to plot the surface profile, velocity distribution along the length of the flume and to know how the specific energy varies along the length of the channel transition (contraction and expansion) when the contraction is reduced beyond the choking width. The flow characteristics such as discharge, velocity of flow at different points, specific energy and depth of flow were studied. Other readings which were considered are slope of tilting flume, width of contraction, angle of convergence and angle of divergence. This chapter describes the experimental channel design and construction of contraction. Details of various instruments used in this experiment are also discussed.

3.2 Experimental Apparatus

3.2.1. Tilting Flume

For the current experiment, the 8m tilting rectangular flume present at Fluid Mechanics laboratory of Civil Engineering Department of Delhi Technological University was used. The tilting flume having a dimension of 8m length, width 0.3m and depth 0.5m is used. The tilting flume has metal frame with glass panels forming the boundary of the rectangular flume. The bed of the flume is painted to make it smooth. The water from the pump drops into a tank attached at the upstream side of the flume, from there the water passes through 2 screens which have mesh with circular holes in it to stabilize the turbulence of flow. It reduces the waves if formed in the water body before it passes over the channel. Then comes the head gate which is opened to allow the water to flow through the channel. The channel ends with a tail gate and a provision to drain off the water into the sump tank. To measure the slope of the tilting flume a scale is attached at the upstream end of the flume which measures the relative height of the upstream end with respect to the downstream end. The plan view of the setup is shown in Fig 3.1.

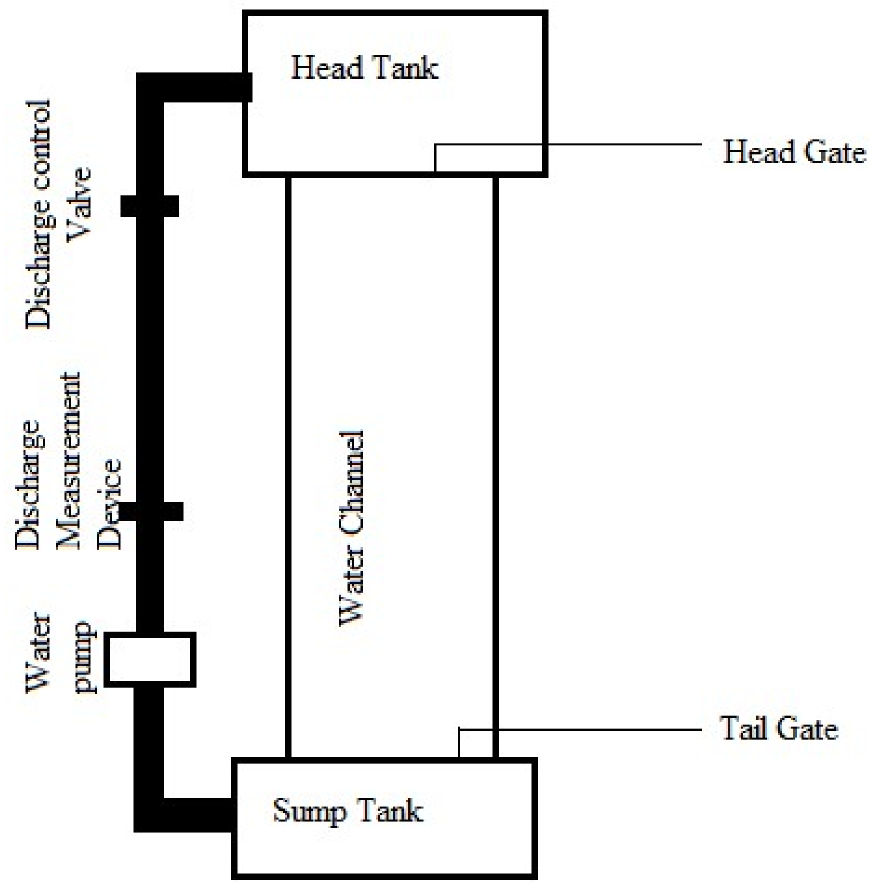

Fig 3.1. Schematic diagram of flume

3.2.2 Channel Contraction

The channel contraction was made up of two aluminium sheets having length of 1.22m and width 0.3m. The contracting length was kept equal to the diverging length. The diverging length was kept at 0.34m and contracting length as 0.34m along the channel. The height of the contraction setup was 0.3 cm. the contraction is maintained for 0.54cm followed by the expansion. The original width of the flow channel was kept as flume width (0.3m) and contracted width was varied. The aluminium sheets were kept at place by using some water proof tape and styrofoam blocks. At the contraction some clay was used in the inner side of the contracting sheets to keep the contraction stable, supports in the form of styrofoam blocks were also used to prevent the sheets from buckling toward the inside which would have made it convex contraction . Fig 3.2 shows the representation of the contraction, Fig 3.3 shows the actual picture of the contraction from upstream side.

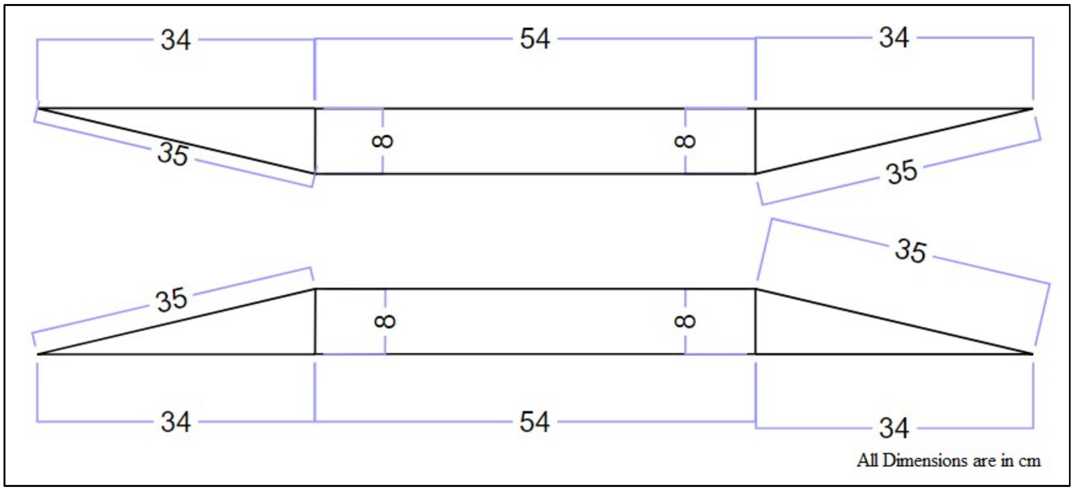

Fig 3.2. Sketch of the contraction setup with contraction width=14cm

Waterproof cellophane tape was used to keep the contraction in position and for not allowing the water to flow outside the contraction. Fig 3.3 shows how the cellophane tapes were used.

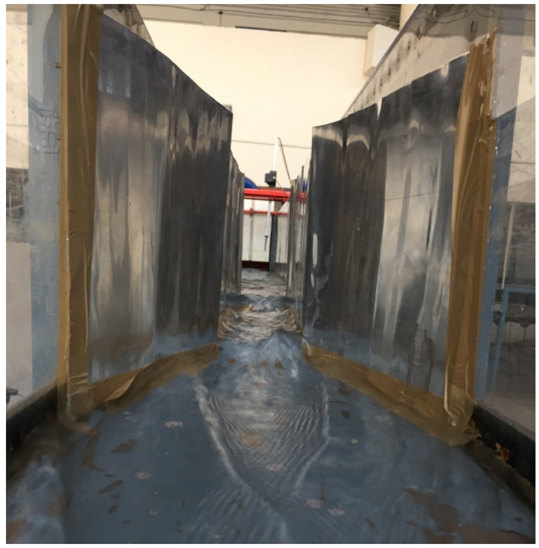

Fig 3.3. Picture of the contraction from upstream side.

3.2.3 Water Supply System

Water to the channel was supplied by water pump which takes the water from the sump tank and fill up the head tank. The discharge by the pump was controlled with the help of control valve fitted in the supply pipe line. The discharge was measured with the help of orifice meter attached in the supply pipe. The diameter of the supply pipe was 0.1m and diameter of the orifice was 0.05m. The pressure difference upstream and downstream of the orifice was measured automatically by discharge measuring electronic equipment. Fig 3.5 shows the electronic discharge measuring device used which has two probes fitted at each side of the orifice to measure the pressure difference.

To keep the contraction stable, supports in the form of styrofoam blocks were also used to prevent the sheets from buckling toward the inside which would have made it convex contraction. Fig 3.4. shows how the styrofoam blocks were used.

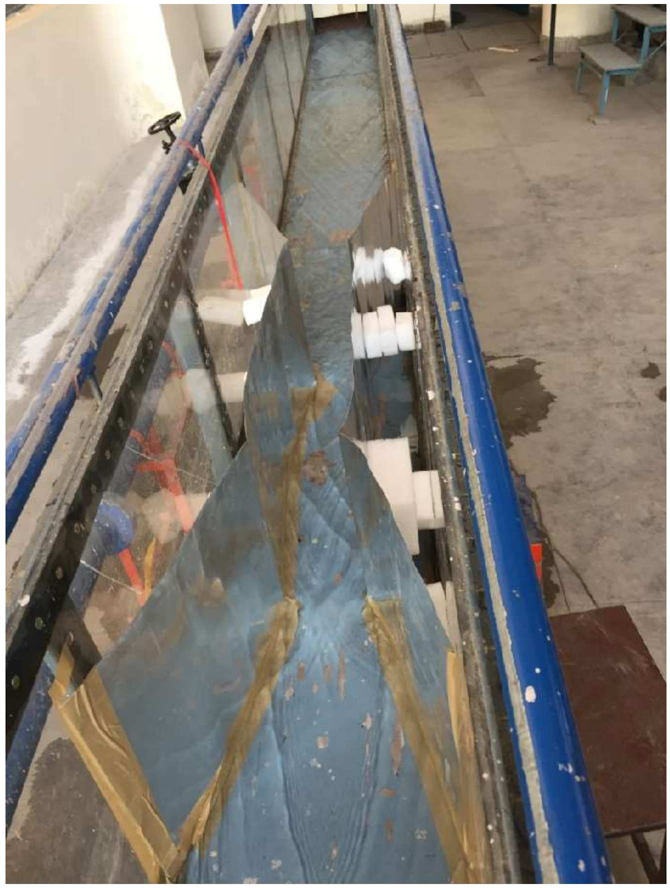

Fig 3.4. Styrofoam blocks were used to give support to the setup.

3.2.4 Water Level Point Gauge

Point gauge is a device used to measure the water surface position as frequently as needed. Generally readings are taken by using a small point or hook which is adjusted manually to just touch the water surface and by using a scale or vernier readings noted. In this experiment digital water level point gauge was used from which readings can be taken directly from the display. Fig 3.6. shows the water level point gauge.

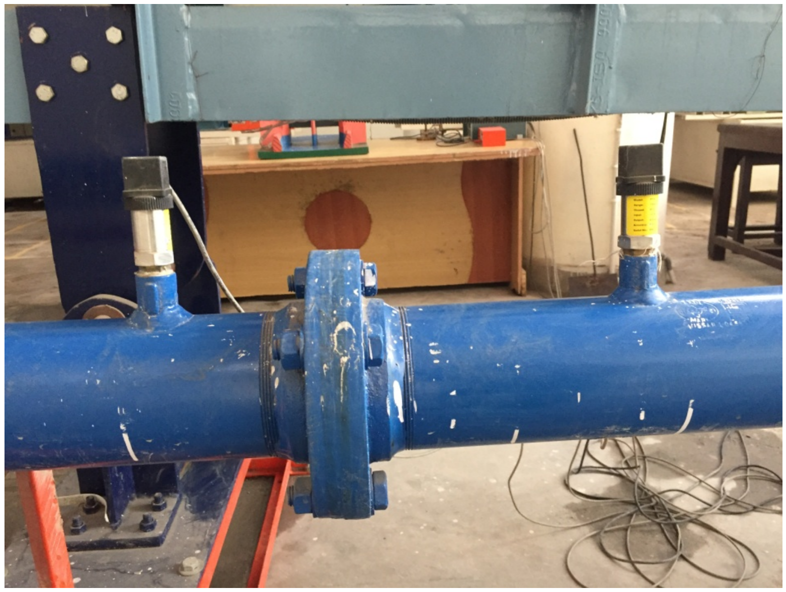

Fig 3.5. Orificemeter

Fig 3.6. Water level point gauge

3.3. Experimental Procedure & Calculations

3.3.1 Apparatus and Methodology

The main parameters which are measured during this experiment are contraction width, depth of flow at different location along the flume length and the distance, from the starting of the transition, to the point where control section is formed and the discharge. The measurement procedure of these parameters is briefly described in this section. Depth of the flow is measured by using a point gauge fixed into the travelling bridge and operated manually. Discharge was measured with the help of Orificemeter and confirmed with volumetric measurement. Details of the measurement of the different parameters taken are described hence forth.

3.3.2 Calculation of Bed slope

To find the bed slope, the scale at the head gate is read. The scale is placed in such a manner that that the pointer shows the relative height of the head gate with respect to the tail gate. The relative height was 8 cm. the position of scale can be seen in Fig 3.7.

Fig 3.7. Scale showing height difference between upstream and downstream end of the flume

3.3.3. Discharge Measurement

Discharge was measured with help of Orificemeter attached in the supply pipe. The diameter of the supply pipe is 0.1m and the orifice diameter is .05m. Coefficient of discharge of the orifice, C_d= 0.67. the discharge can be determined with the help of the formula

$$Q = C_d A_1 A_2 \sqrt{\frac{2gh}{A_1^2 - A_2^2}} \qquad \text{... (3.1)}$$

Where

Q= Dischrage in m^3/s

A_1= Area of Pipe in m^2

A_2=Area of orifice in m^2

g=acceleration due to gravity

h= piezometric head difference at inlet and outlet of orifcemeter.

h= $\frac{P_1 - P_2}{\rho g}$

The Calculation of discharge is shown in Table No. 3.1. P_1 and P_2 are the pressure at sections before and after the orifice (in Kg/cm^2).

Table No 3.1. Showing discharge measurement table.

P1	0.9320
P2	0.8993
ΔP	0.03264
H	0.3202
A1	0.00785
A2	0.00196
Q	0.003432

The calculated discharge was cross checked using volumetric measurement. For this a large bucket was placed under the point where the water was flowing into the sump from the tail gate. Time was noted for the water to rise from a predefined level to a predefined level. Volume between the levels where determined using measuring flasks. The volume so obtained divided by the time taken gives the discharge flowing out of the flume.

3.3.4. Calculation of Velocity

Since a lot of turbulence occurs at the contraction, absolute velocity measurement is a tough task. To simplify this problem average velocity was calculated. The average velocity was calculated by considering continuity equation. The formula used

$$v = \frac{Q}{yb} \qquad \dots (3.2)$$

Where

v= average velocity of flow in m^2/s

Q= discharge in m^3/s

y= depth of flow in m

b= width at that section in m

The value of the velocities after calculations is shown in Table No. 4.1, Table No. 4.2 and Table No. 4.3 in the next chapter. Velocities for all the data set has been calculated using above formula.

3.3.5. Calculation of Froude Number

The calculation of Froude number is done with the help of the formula

$$F_r = \frac{v}{\sqrt{gy}} \qquad \dots (3.3)$$

Where

F_r= Froude Number

v= velocity of flow

g= acceleration due to gravity

CHAPTER 4

THEORETICAL CONSIDERATIONS

Change of bed slope, rise or fall of bed surface, increasing or decreasing of channel width is a common necessity for economical as well as practical reasons. These changes are called channel transition. The transitions serve as a connection between the original and the new channel. These transitions are often required in natural and artificial channels at siphons, aqueducts, weirs, falls, bridges, barrages etc. Transitions are also provided in water drains and sewage systems. Designing and performance of these transitions are critically dependent on subcritical and supercritical flow states.

When the water is flowing through an open channel with a high velocity and has a flow depth which is less than the critical depth, then the flow is called super critical flow. In supercritical flow Froude number is always greater than one. When the flow depth is more than critical depth then the flow is called sub-critical flow. Froude Number for the flow is less than one. Flow velocity is also not as high as supercritical flow. Unlike subcritical flow, in supercritical flow many abnormalities are there like depending on the shape, size and kind of channels, the flow can produce normal or oblique surges, expansion waves, hydraulic jumps and sometimes complex wave patterns due to multiple reflections of these waves at the boundary and also due to their interactions with one another.

The best way to predict the changes that super-critical flow will undergo while flowing through a transition is by using specific energy concept. This concept was given by B.A. Bakmeteff in 1912.

4.1 Specific Energy

Specific energy is the energy at a cross-section of an open channel flow with respect to the channel bed. Study of specific energy is important because in real fluid flow total energy decreases in the direction of flow but specific energy remains constant for uniform flow, since specific energy is defined in terms of bed elevation relative to elevation of energy line. Mathematically specific energy is given by –

$$E = y + \frac{v^2}{2g} = y + \frac{Q^2}{2gA^2} \qquad \ldots (4.1)$$

Where

E= Specific Energy

y= Depth of flow

v= flow velocity

g= acceleration due to gravity

Q= Discharge flowing through the cross-section area A

For rectangular channel, the cross-section area can be written as B×y, where B is the width of the channel y is the depth of flow. So Eq 4.1 can be written as-

$$E = y + \frac{Q^2}{2g(By)^2} = y + \frac{q^2}{2gy^2} \qquad \ldots (4.2)$$

Where

$q = \frac{Q}{B} = \text{Unit Discharge}$

Now the depth of flow can be studied for two different cases, keeping specific energy as constant or keeping discharge constant. Both the cases can be plotted graphically for ease.

If the specific energy is to be kept constant and a depth versus discharge graph is plotted, it is called Depth-Discharge curve. A typical Depth-Discharge graph can be seen in Fig 4.1.

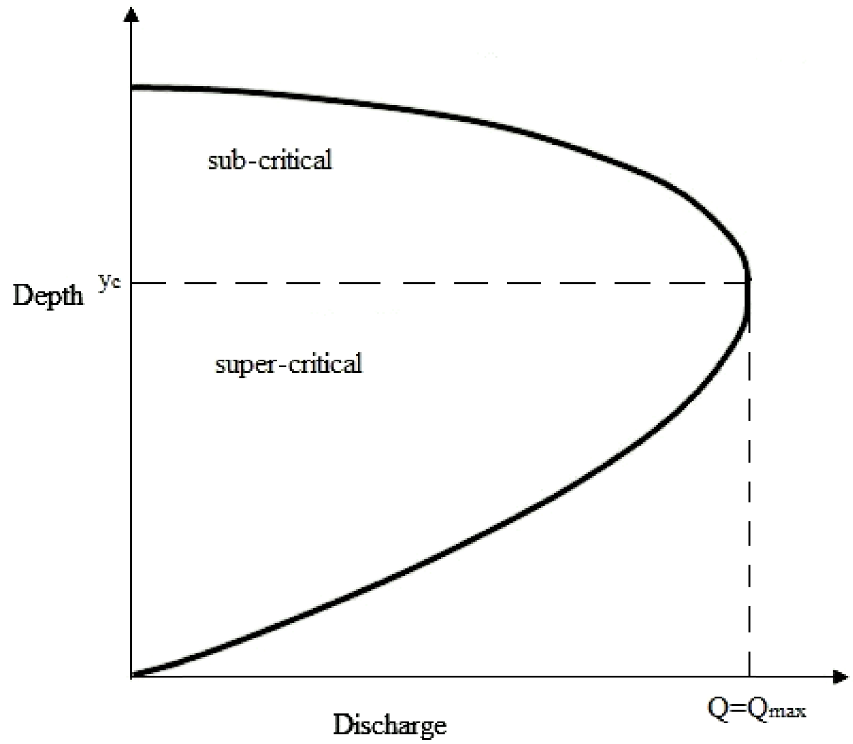

Fig 4.1. Depth Discharge curve

In this curve it can be seen that for a certain specific energy, for super critical flow, as the discharge increases depth of flow increases. For sub critical flow opposite happens, when discharge increases flow depth decreases. For this specific energy the discharge can be increased only to a certain value, after this to maintain the flow, specific energy has to be increased which will change the values on the graph keeping the nature of the graph constant.

For same discharge, depth versus specific energy graph is shown in Fig 4.2.

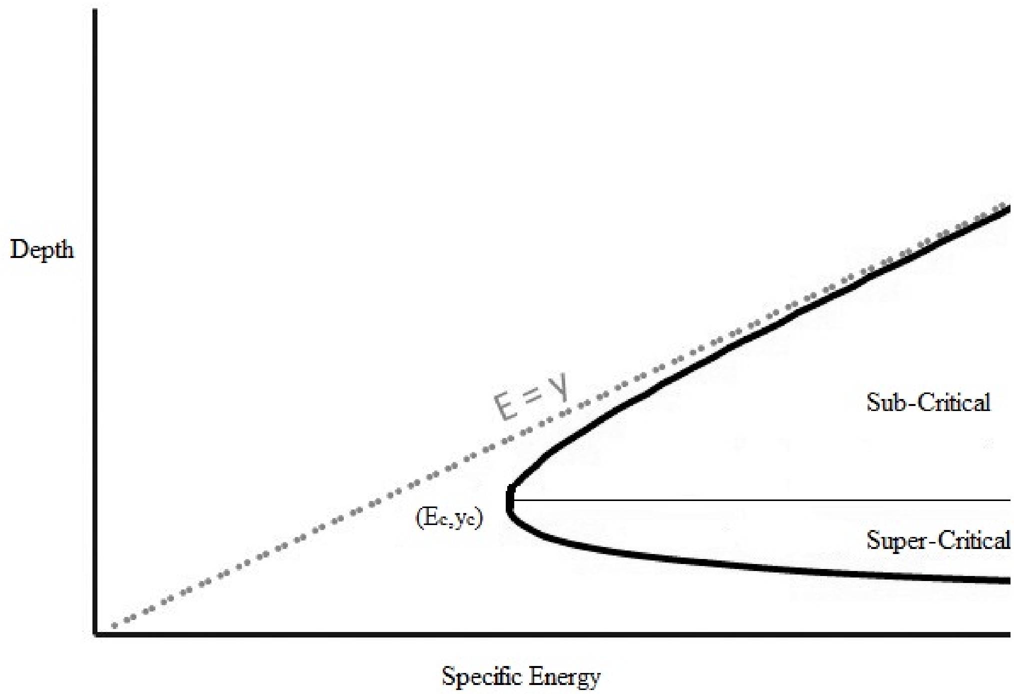

Fig 4.2. Specific Energy curve

Keeping the discharge constant, when the specific energy is plotted against flow depth, a cubic parabola is obtained. It can be seen from the Fig 4.2 and also by Eq 4.2 that there exists two positive roots which indicates that any particular discharge passing through a given channel can have same specific energy while flowing at two different depth. The two depths which are possible having the same specific energy are called alternate depths. Of the two alternate depths, the smaller one has a larger velocity head while the other has a larger depth and a smaller velocity head. For a particular discharge, any increase in the specific energy increases the difference between the two alternate depths. On the other hand, if the specific discharge decreases, the difference will decrease and at a certain value of specific energy, the two depths will merge with each other. In Fig 4.2. point ($E_c.y_c$) denotes such point. When $E < E_c$, no value of depth can be obtained. This implies that the flow, under the given conditions, is not possible in this region. The condition of minimum specific energy is known as the critical flow condition and the corresponding depth y_c is known as critical depth.

For unit discharge (q) similar graph will be obtained. If several different q values are taken and plotted them on the specific energy diagram, as shown in Fig 4.3., it can be seen that for increasing unit discharges i.e. $q_1 < q_2 < q_3$, the graph shifts toward the right. There is a clear asymptotic relationship as the top part of the curve approaches the $E = y$ line and the bottom part of the curve approaches the x-axis.

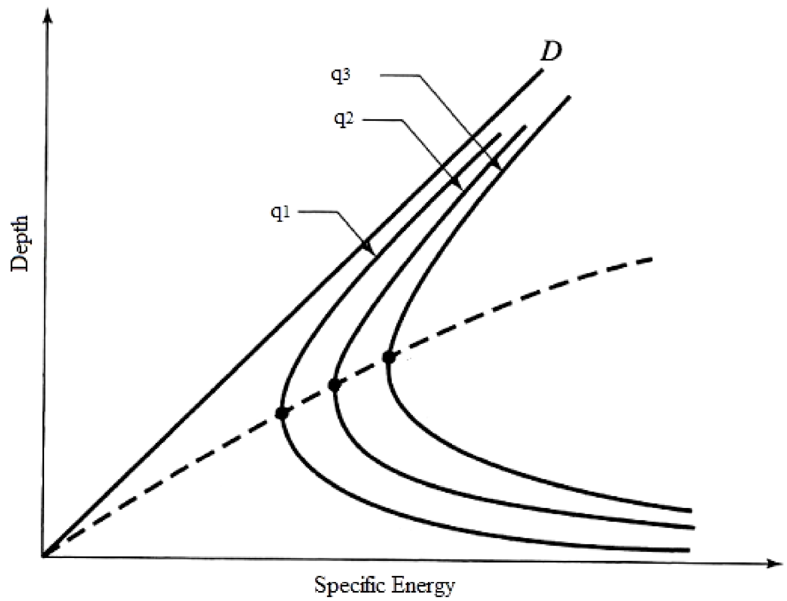

Fig 4.3. Specific energy curve for various unit discharges.

CHAPTER 5

CALCULATIONS AND RESULTS

The experiment is performed in the Fluid Mechanics Laboratory of the Civil Engineering Department in Delhi Technological University, Delhi, India. All the required readings are taken in order to plot the surface profile, velocity distribution along the length of the flume and to know how the specific energy varies along the length of the channel transition (contraction and expansion). The data from the experimental readings are arranged and grouped. All the data are grouped with respect to the channel contraction. All the calculations have been done in MS Excel 2007. The results have been determined and graphs have been plotted. The graphs plotted show the surface profile, velocity distribution along the length of the flume and how the specific energy varies along the length of the channel transition.

5.1. Data

In order to perform the experiment and to gather the relevant data, 3.5m of the 8m tilting flume is chosen as the test length. Water level point gauge has been used to measure the water levels at an interval of 10 cm starting 290 cm away from the end of the transition toward the upstream side. Some special points such as point where transition starts, point where the contraction is maximum and point from where expansion starts are also included apart from the interval readings.

A total of 4 data sets are created one data set for contraction width of 0.24m, 0.2m, 0.16m and 0.14m.

5.2 Calculations

All the calculations have been done in spreadsheet using MS Excel 2007. Few of the calculations and formula used are shown below in this sub heading.

5.2.1 Calculation Of Discharge

Discharge can be calculated using Eq 3.1

$$Q = C_d A_1 A_2 \sqrt{\frac{2gh}{A_1^2 - A_2^2}}$$

$h = \frac{P_1 - P_2}{\rho g}$

From the digital piezometers

P_1= 0.9320 Kg/cm^2

P_2= 0.8993 Kg/cm^2

ρ= 1000 Kg/m^3

g= 9.81 m/s^2

then

$h = \frac{0.9320 - 0.8993}{9810} x \frac{9.81}{10^{-4}}$

h = 0.32642 m

$Q = 0.67x0.00785x0.00196 \sqrt{\frac{2x9.81x0.32642}{0.00785^2 - 0.00196^2}}$

Q = 0.003432 m^3/s

5.2.2 Calculation Of Velocity

From continuity equation we know that,

$$Q = vA$$

For rectangular channel, area of cross section A= yB, as shown in Eq 3.2

$$\therefore v = \frac{Q}{yB}$$

$$v = \frac{0.003432}{0.012x0.3}$$

$$v = 0.95333\ m/s^2$$

5.2.3 Calculation Of Froude Number

The calculation of Froude's number is done with the help of the Eq3.3

$$F_r = \frac{v}{\sqrt{gy}}$$

$$F_r = \frac{0.95333}{\sqrt{9.81x0.012}}$$

$$F_r = 2.77856$$

5.2.4 Calculation Of Specific Energy

Formula used for the calculation of specific energy is Eq 4.2

$$E = y + \frac{Q^2}{2g(By)^2}$$

$$E = 0.012 + \frac{0.003432^2}{2x9.81(0.3x0.012)^2}$$

$$E = 0.05832\ m$$

5.2.5 Calculation Of Choking Width

Choking width can be calculated as

$$b_c = \sqrt{\frac{27Q^2}{8gE_c^3}} \qquad \text{... (5.1)}$$

$$b_c = \sqrt{\frac{27x0.003432^2}{8x9.81x0.05832^3}}$$

$$b_c = 0.1429\ m$$

5.3 Tabulation and Plotting of Data

All the collected data and calculated data are clubbed together into tabular form. Table No. 5.1 shows the collected data and calculated data for contraction width 0.16 m.

Table No. 5.1 Data for contraction width = 0.16m

Q (m^3/s)	x (cm)	y (m)	v (m/s)	F_r	B (m)	E (m)
0.00343	0	0.012	0.95333	2.77856	0.3	0.05832
0.00343	10	0.012	0.95333	2.77856	0.3	0.05832
0.00343	20	0.012	0.95333	2.77856	0.3	0.05832
0.00343	30	0.012	0.95333	2.77856	0.3	0.05832
0.00343	40	0.012	0.95333	2.77856	0.3	0.05832
0.00343	50	0.012	0.95333	2.77856	0.3	0.05832
0.00343	60	0.012	0.95333	2.77856	0.3	0.05832
0.00343	70	0.012	0.95333	2.77856	0.3	0.05832
0.00343	80	0.012	0.95333	2.77856	0.3	0.05832
0.00343	90	0.012	0.95333	2.77856	0.3	0.05832
0.00343	100	0.012	0.95333	2.77856	0.3	0.05832
0.00343	110	0.012	0.95333	2.77856	0.3	0.05832
0.00343	120	0.012	0.95333	2.77856	0.3	0.05832
0.00343	130	0.012	0.95333	2.77856	0.3	0.05832
0.00343	140	0.012	0.95333	2.77856	0.3	0.05832
0.00343	150	0.012	0.95333	2.77856	0.3	0.05832
0.00343	160	0.012	0.95333	2.77856	0.3	0.05832
0.00343	168	0.012	0.95333	2.77856	0.3	0.05832
0.00343	170	0.012	0.98024	2.85699	0.29176	0.06097
0.00343	180	0.015	0.91305	2.38021	0.25059	0.05749
0.00343	190	0.019	0.86257	1.99793	0.20941	0.05692
0.00343	200	0.026	0.78462	1.55359	0.16824	0.05738
0.00343	202	0.027	0.79444	1.54364	0.16	0.05917
0.00343	210	0.027	0.79444	1.54364	0.16	0.05917
0.00343	220	0.027	0.79444	1.54364	0.16	0.05917
0.00343	230	0.027	0.79444	1.54364	0.16	0.05917
0.00343	240	0.027	0.79444	1.54364	0.16	0.05917
0.00343	250	0.027	0.79444	1.54364	0.16	0.05917
0.00343	256	0.026	0.825	1.63355	0.16	0.06069
0.00343	260	0.023	0.84557	1.78012	0.17647	0.05944
0.00343	270	0.017	0.92757	2.27136	0.21765	0.06085
0.00343	280	0.014	0.94714	2.55574	0.25882	0.05972
0.00343	290	0.013	0.88	2.4642	0.3	0.05247
0.00343	300	0.013	0.88	2.4642	0.3	0.05247
0.00343	310	0.013	0.88	2.4642	0.3	0.05247
0.00343	320	0.013	0.88	2.4642	0.3	0.05247
0.00343	330	0.013	0.88	2.4642	0.3	0.05247
0.00343	340	0.013	0.88	2.4642	0.3	0.05247
0.00343	350	0.013	0.88	2.4642	0.3	0.05247

In Table No. 5.1 it can be seen that as contraction width decreases height of water level/ flow depth increases. Since Froude number is always greater than one, the flow remains super critical throughout.

Similarly data for contraction width = 0.20m is shown in Table No. 5.2.

Table No 5.2 Data set for contraction width=0.2m

Q (m^3/s)	**x (cm)**	**y (m)**	**v (m/s)**	**F_r**	**B (m)**	**E (m)**
0.003432	0	0.012	0.953333	2.778559	0.3	0.058322
0.003432	10	0.012	0.953333	2.778559	0.3	0.058322
0.003432	20	0.012	0.953333	2.778559	0.3	0.058322
0.003432	30	0.012	0.953333	2.778559	0.3	0.058322
0.003432	40	0.012	0.953333	2.778559	0.3	0.058322
0.003432	50	0.012	0.953333	2.778559	0.3	0.058322
0.003432	60	0.012	0.953333	2.778559	0.3	0.058322
0.003432	70	0.012	0.953333	2.778559	0.3	0.058322
0.003432	80	0.012	0.953333	2.778559	0.3	0.058322
0.003432	90	0.012	0.953333	2.778559	0.3	0.058322
0.003432	100	0.012	0.953333	2.778559	0.3	0.058322
0.003432	110	0.012	0.953333	2.778559	0.3	0.058322
0.003432	120	0.012	0.953333	2.778559	0.3	0.058322
0.003432	130	0.012	0.953333	2.778559	0.3	0.058322
0.003432	140	0.012	0.953333	2.778559	0.3	0.058322
0.003432	150	0.012	0.953333	2.778559	0.3	0.058322
0.003432	160	0.012	0.953333	2.778559	0.3	0.058322
0.003432	168	0.012	0.953333	2.778559	0.3	0.058322
0.003432	170	0.012	0.9724	2.83413	0.294118	0.060194
0.003432	180	0.014	0.926095	2.498947	0.264706	0.057713
0.003432	190	0.017	0.858	2.101011	0.235294	0.054521
0.003432	200	0.019	0.877353	2.032185	0.205882	0.058233
0.003432	202	0.019	0.903158	2.091955	0.2	0.060575
0.003432	210	0.02	0.858	1.937036	0.2	0.057521
0.003432	220	0.02	0.858	1.937036	0.2	0.057521
0.003432	230	0.02	0.858	1.937036	0.2	0.057521
0.003432	240	0.02	0.858	1.937036	0.2	0.057521
0.003432	250	0.019	0.903158	2.091955	0.2	0.060575
0.003432	256	0.019	0.903158	2.091955	0.2	0.060575
0.003432	260	0.018	0.90037	2.142646	0.211765	0.059318
0.003432	270	0.015	0.948683	2.473096	0.241176	0.060872
0.003432	280	0.014	0.905963	2.444623	0.270588	0.055833
0.003432	290	0.013	0.88	2.464203	0.3	0.05247
0.003432	300	0.013	0.88	2.464203	0.3	0.05247
0.003432	310	0.013	0.88	2.464203	0.3	0.05247
0.003432	320	0.013	0.88	2.464203	0.3	0.05247
0.003432	330	0.013	0.88	2.464203	0.3	0.05247
0.003432	340	0.013	0.88	2.464203	0.3	0.05247
0.003432	350	0.013	0.88	2.464203	0.3	0.05247

In Table No. 5.2 it can be seen that as contraction width increases further height of water level/ flow depth decreases but the decrease in water level is lesser as compared to when the contraction width was 0.16m. Since Froude number is always greater than one, the flow remains super critical throughout here too.

Table No 5.3 Data set for contraction width=0.24m

Q (m^3/s)	x (cm)	y (m)	v (m/s)	F_r	B (m)	E (m)
0.003432	0	0.012	0.953333	2.778559	0.3	0.058322
0.003432	10	0.012	0.953333	2.778559	0.3	0.058322
0.003432	20	0.012	0.953333	2.778559	0.3	0.058322
0.003432	30	0.012	0.953333	2.778559	0.3	0.058322
0.003432	40	0.012	0.953333	2.778559	0.3	0.058322
0.003432	50	0.012	0.953333	2.778559	0.3	0.058322
0.003432	60	0.012	0.953333	2.778559	0.3	0.058322
0.003432	70	0.012	0.953333	2.778559	0.3	0.058322
0.003432	80	0.012	0.953333	2.778559	0.3	0.058322
0.003432	90	0.012	0.953333	2.778559	0.3	0.058322
0.003432	100	0.012	0.953333	2.778559	0.3	0.058322
0.003432	110	0.012	0.953333	2.778559	0.3	0.058322
0.003432	120	0.012	0.953333	2.778559	0.3	0.058322
0.003432	130	0.012	0.953333	2.778559	0.3	0.058322
0.003432	140	0.012	0.953333	2.778559	0.3	0.058322
0.003432	150	0.012	0.953333	2.778559	0.3	0.058322
0.003432	160	0.012	0.953333	2.778559	0.3	0.058322
0.003432	168	0.012	0.953333	2.778559	0.3	0.058322
0.003432	170	0.012	0.964683	2.811637	0.296471	0.059432
0.003432	180	0.013	0.946835	2.651358	0.278824	0.058693
0.003432	190	0.014	0.93861	2.532717	0.261176	0.058903
0.003432	200	0.015	0.939517	2.449201	0.243529	0.059989
0.003432	202	0.015	0.953333	2.485219	0.24	0.061322
0.003432	210	0.015	0.953333	2.485219	0.24	0.061322
0.003432	220	0.015	0.953333	2.485219	0.24	0.061322
0.003432	230	0.015	0.953333	2.485219	0.24	0.061322
0.003432	240	0.015	0.953333	2.485219	0.24	0.061322
0.003432	250	0.015	0.953333	2.485219	0.24	0.061322
0.003432	256	0.014	1.021429	2.756192	0.24	0.067176
0.003432	260	0.014	0.992245	2.677444	0.247059	0.064181
0.003432	270	0.013	0.997333	2.792763	0.264706	0.063697
0.003432	280	0.013	0.935	2.618216	0.282353	0.057558
0.003432	290	0.013	0.88	2.464203	0.3	0.05247
0.003432	300	0.013	0.88	2.464203	0.3	0.05247
0.003432	310	0.013	0.88	2.464203	0.3	0.05247
0.003432	320	0.013	0.88	2.464203	0.3	0.05247
0.003432	330	0.013	0.88	2.464203	0.3	0.05247
0.003432	340	0.013	0.88	2.464203	0.3	0.05247
0.003432	350	0.013	0.88	2.464203	0.3	0.05247

Another set of reading is taken further increasing the contraction width to 0.24m. Experiment data for this part is shown in Table No. 5.3.

In Table No. 5.3 it can be seen that as contraction width further increases there is further decrease in height of water level/ flow depth but the decrease in water level is lesser as compared to when the contraction width was 0.16m and 0.2m. Since Froude number is always greater than one, the flow remains super critical throughout here too. So far it can be concluded that for super-critical flow as the contraction width increases the height of water level at the contracted part increases.

The next set of data consists of experimental data when the experiment is conducted by reducing the contraction width beyond the choking width. Table No. 5.4 shows the data collected and calculated data. The data collected are very different from the previous condition. Two type of flow is seen in the same stretch. Upstream is the subcritical flow and downstream it again becomes supercritical flow. Specific energy upstream of the contraction also increases. This was also predicted by the concept of specific energy.

Further, using these data, graphs were plotted to show the variation of velocity distribution, and how the specific energy is in the flow. Surface profile is also plotted on graph to show the difference between the 4 parts of the experiment.

Table No 5.4 Data set for contraction width=0.14m

Q (m^3/s)	x (cm)	y (m)	v (m/s)	F_r	B (m)	E (m)
0.003432	0	0.012	0.953333	2.778559	0.3	0.058322
0.003432	10	0.012	0.953333	2.778559	0.3	0.058322
0.003432	20	0.013	0.88	2.464203	0.3	0.05247
0.003432	30	0.028	0.408571	0.779569	0.3	0.036508
0.003432	40	0.036	0.317778	0.534734	0.3	0.041147
0.003432	50	0.041	0.279024	0.439963	0.3	0.044968
0.003432	60	0.045	0.254222	0.382624	0.3	0.048294
0.003432	70	0.047	0.243404	0.358463	0.3	0.05002
0.003432	80	0.049	0.233469	0.336742	0.3	0.051778
0.003432	90	0.049	0.233469	0.336742	0.3	0.051778
0.003432	100	0.05	0.2288	0.326691	0.3	0.052668
0.003432	110	0.051	0.224314	0.317129	0.3	0.053565
0.003432	120	0.051	0.224314	0.317129	0.3	0.053565
0.003432	130	0.052	0.22	0.308025	0.3	0.054467
0.003432	140	0.053	0.215849	0.299349	0.3	0.055375
0.003432	150	0.053	0.215849	0.299349	0.3	0.055375
0.003432	160	0.054	0.211852	0.291072	0.3	0.056288
0.003432	168	0.055	0.208	0.28317	0.3	0.057205
0.003432	170	0.055	0.214736	0.29234	0.29059	0.05735
0.003432	180	0.054	0.260976	0.358566	0.24353	0.057471
0.003432	190	0.052	0.335929	0.47034	0.19647	0.057752
0.003432	200	0.047	0.488731	0.719758	0.14941	0.059174
0.003432	202	0.047	0.521581	0.768136	0.14	0.060866
0.003432	210	0.045	0.544762	0.81991	0.14	0.060126
0.003432	220	0.045	0.544762	0.81991	0.14	0.060126
0.003432	230	0.044	0.557143	0.848019	0.14	0.059821
0.003432	240	0.042	0.583673	0.909308	0.14	0.059364
0.003432	250	0.041	0.597909	0.942777	0.14	0.059221
0.003432	256	0.038	0.645113	1.056597	0.14	0.059212
0.003432	260	0.027	0.800448	1.555309	0.1588	0.059656
0.003432	270	0.019	0.877363	2.032208	0.20588	0.058234
0.003432	280	0.016	0.848027	2.1405	0.25294	0.052654
0.003432	290	0.013	0.88	2.464203	0.3	0.05247
0.003432	300	0.013	0.88	2.464203	0.3	0.05247
0.003432	310	0.013	0.88	2.464203	0.3	0.05247
0.003432	320	0.013	0.88	2.464203	0.3	0.05247
0.003432	330	0.013	0.88	2.464203	0.3	0.05247
0.003432	340	0.013	0.88	2.464203	0.3	0.05247
0.003432	350	0.013	0.88	2.464203	0.3	0.05247

5.4 Water Level Profile

All the graphs shown below describe the water surface level profile. Fig 5.1, Fig 5.2 and Fig 5.3 is the graph showing the water level profile for the cases when the contraction widths are kept greater than choking width. If the profiles as shown in Fig 5.1, Fig 5.2 and Fig 5.3. are compared, it can be seen that the water level increases at the contraction. This increase in water level is most when the contraction width is 0.16m. The water rises up to a height of 0.026 m from 0.012m which is 0.014m above the upstream level. The rise in water level is least for when the contraction width is 0.24m. The water rises up to a height of 0.015m from 0.012m which is 0.003m above the upstream level. From this it can be said that as the contraction width decreases the rise in water level increases. This rise only occurs at the contraction.

Fig 5.4 has a very peculiar water surface profile. The water flow changes from super critical to sub critical at some distance from the contraction. Then the flow behaves like subcritical flow till the contraction.

Fig 5.1 Afflux formation.

Since the contraction width is less than choking width, the flow is not possible at the same specific energy. So the water keeps on rising till the specific energy becomes sufficient to cross the contraction. This causes the formation of the afflux on the upstream side. The afflux can be seen in Fig 5.5. The transition from super critical flow to sub critical flow took place by formation of a small hydraulic jump. The hydraulic jump can be seen in Fig 5.6.

Fig 5.2. Transition from super critical to sub critical flow.

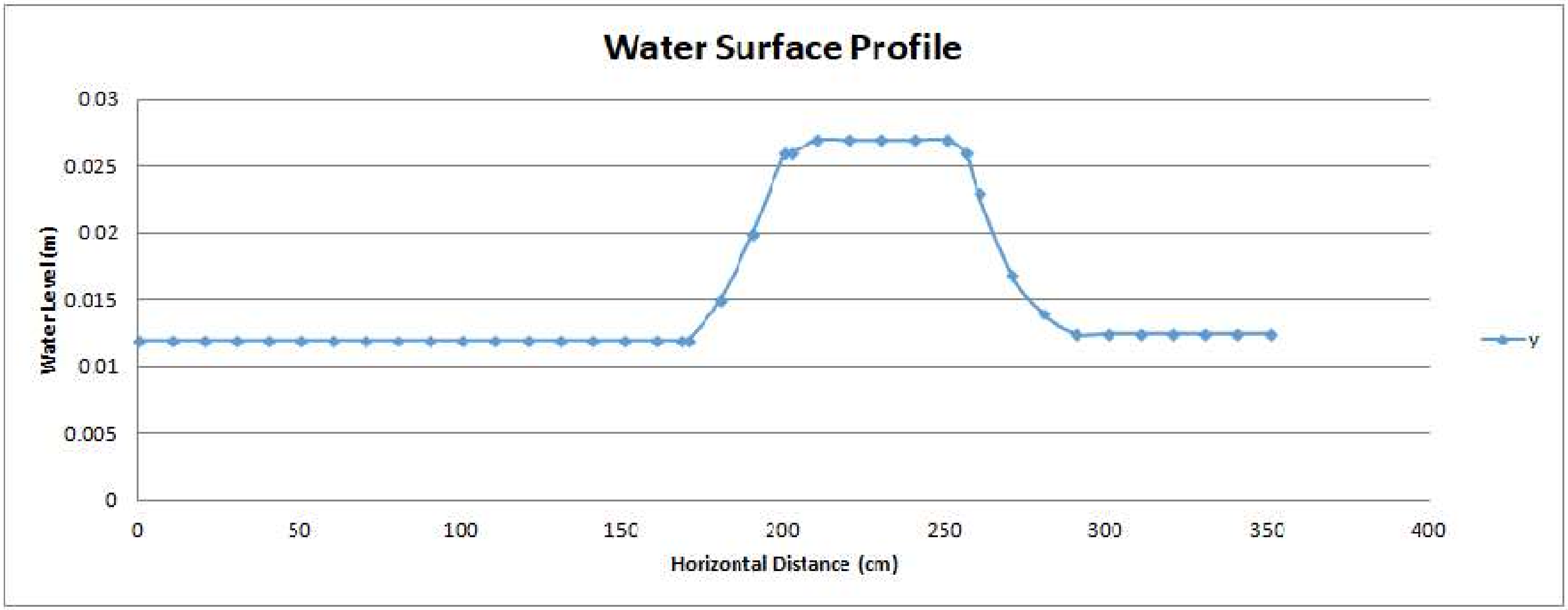

Fig 5.1. Water level profile for contraction width 0.16m

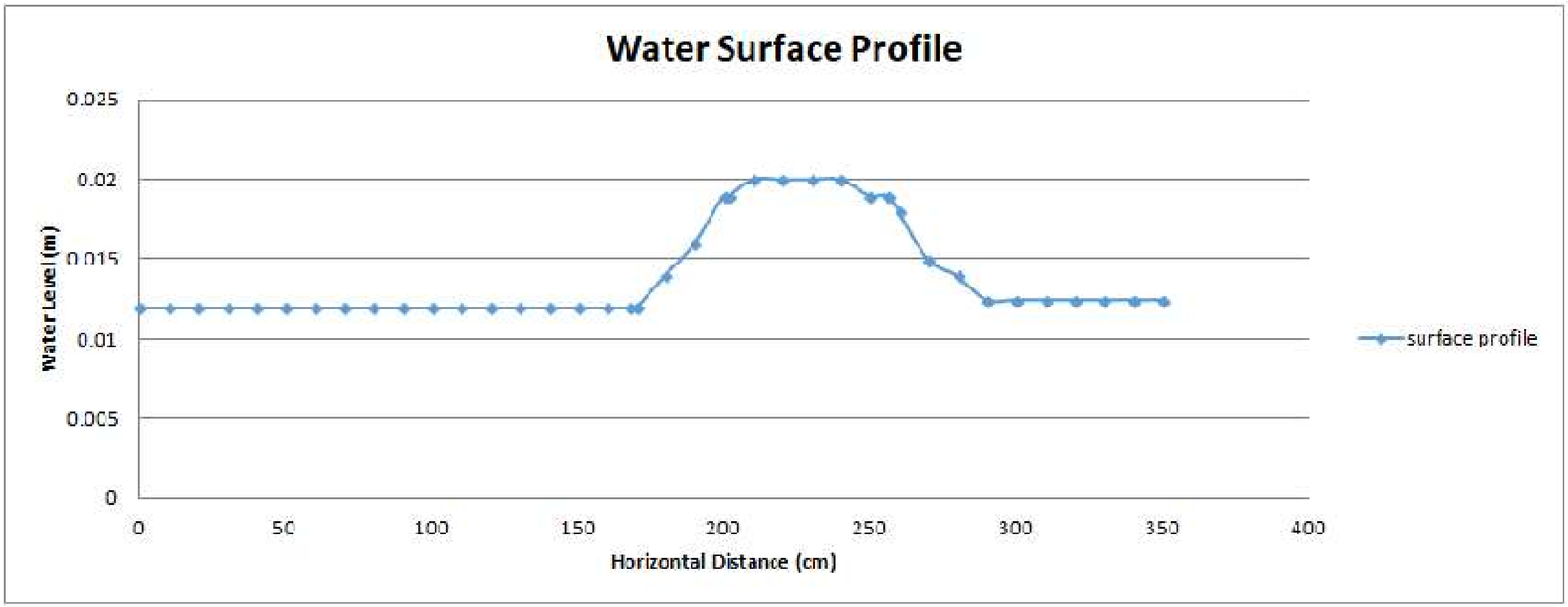

Fig 5.2. Water level profile for contraction width 0.2m

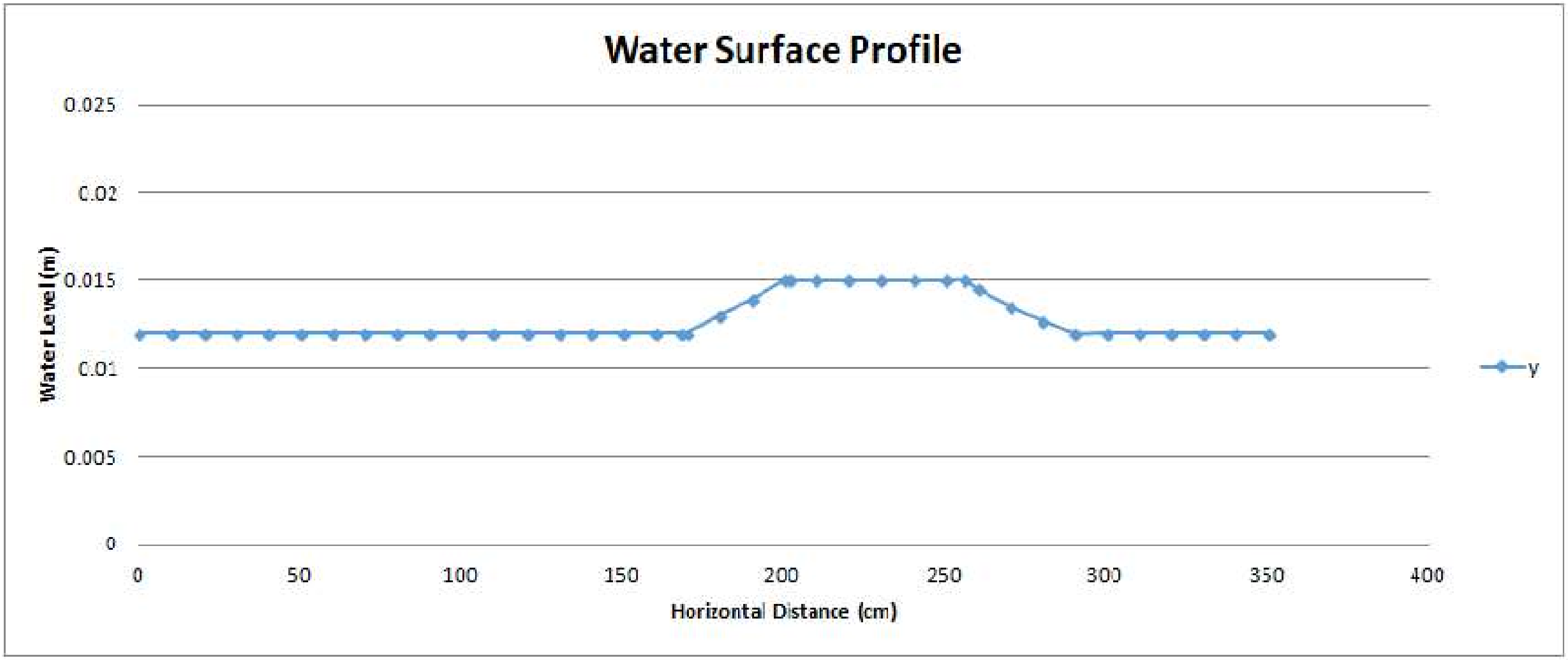

Fig 5.3. Water level profile for contraction width 0.24m

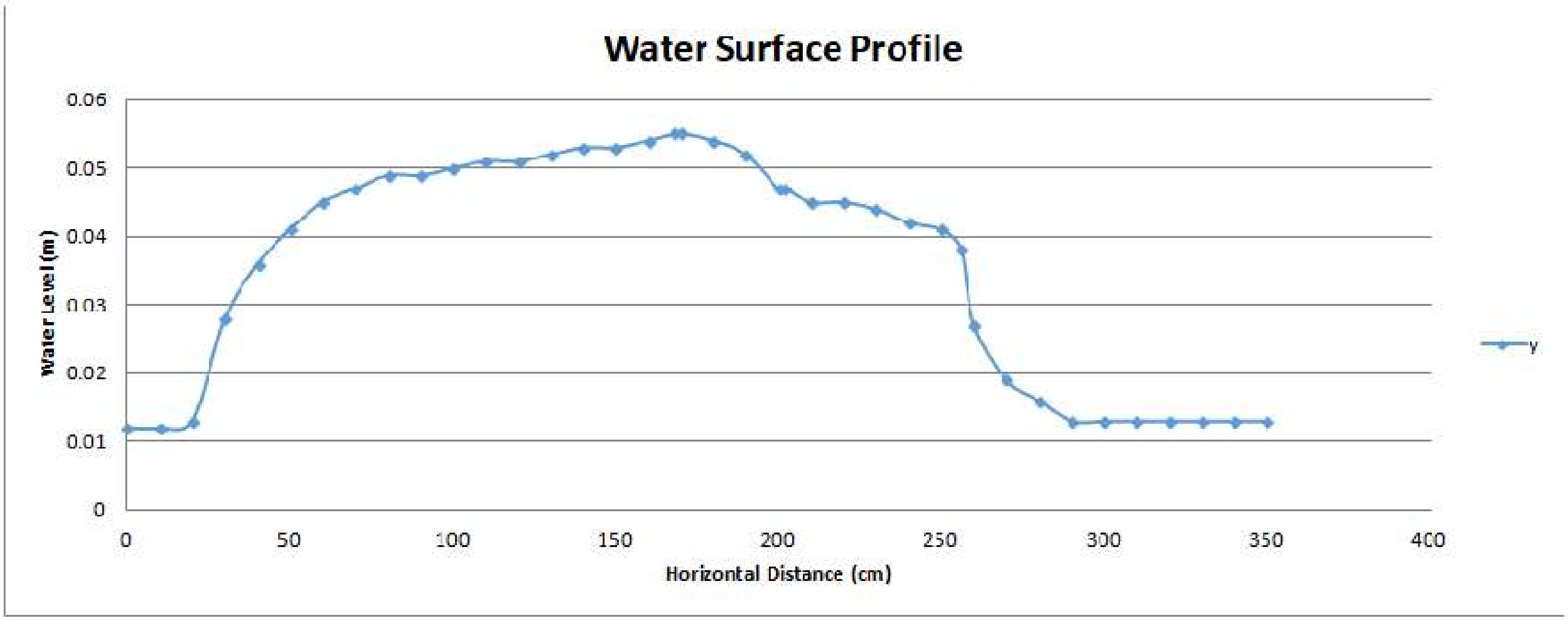

Fig 5.4. Water level profile for contraction width 0.14m

5.5 Velocity Profile

All the above graphs describe the velocity profile along the rectangular channel. Fig 5.7, Fig 5.8 and Fig 5.9 are the graphs showing the velocity profile for the cases when the contraction widths are kept greater than choking width.

In the Fig 5.7., longitudinal velocity distribution for contraction width 0.16m has been shown. It can be seen that there is a dip in velocity at the contraction. The small rise at the starting of the contraction is due to the approximation of depth value. In actual the velocity starts to decrease from the starting of the contraction.

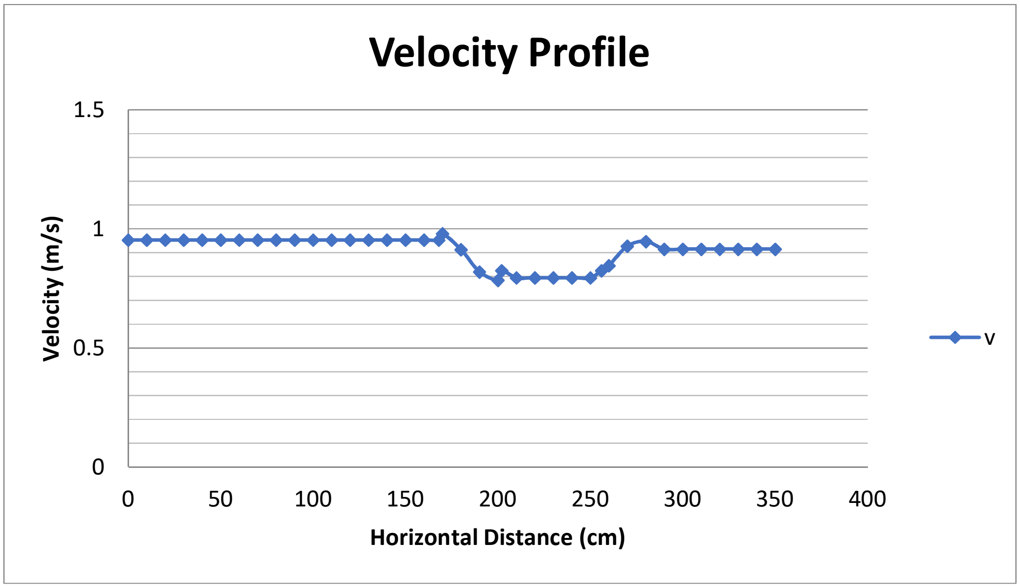

Fig 5.7. Velocity profile for contraction width 0.16m.

The graph shown in the next page represents the longitudinal average velocity distribution when the contraction width is reduced to 0.2m. The graph in Fig 5.8. is very similar to previous graph. Only the decrease in velocity is lesser as compared to previous case.

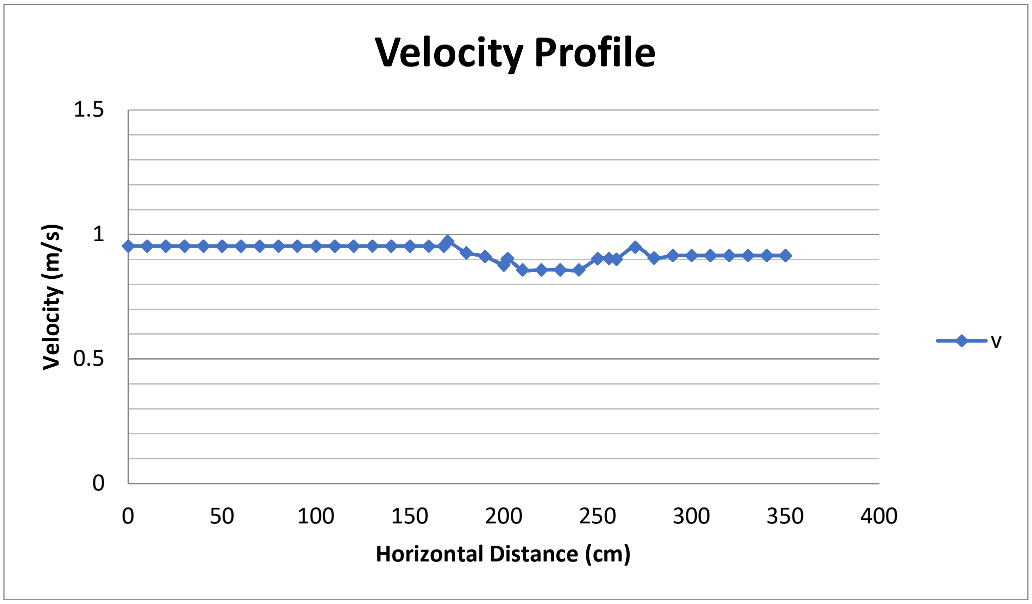

Fig 5.8. Velocity profile for contraction width 0.2m.

The figure shown below (Fig 5.9.) is the average velocity distribution graph when the width of contraction is 0.24m. The graph is almost a straight line. There is very less change in the velocity because the contraction is very small. The change in width is only 6mm.

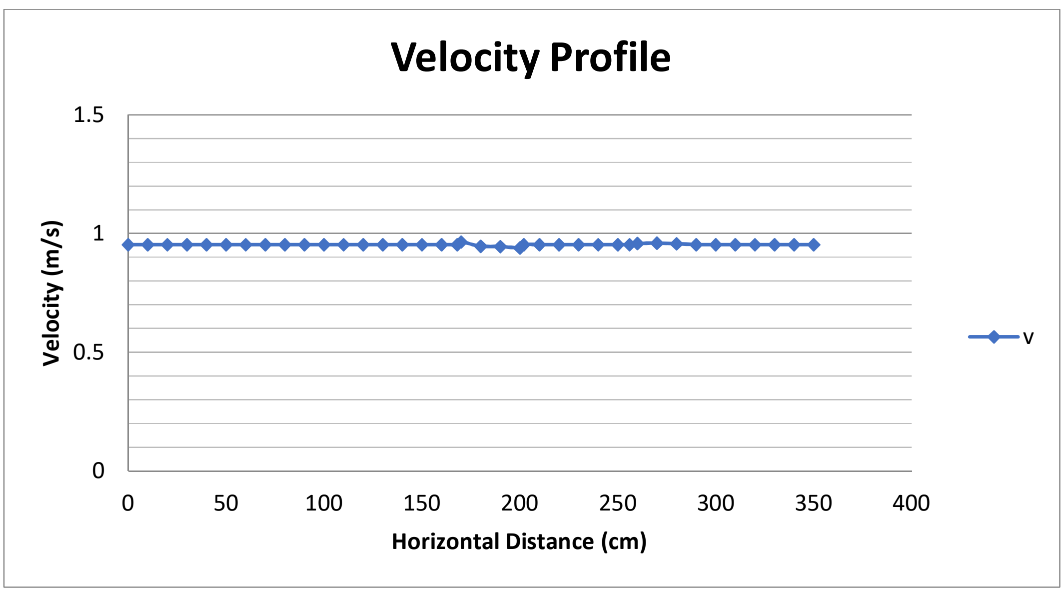

Fig 5.9. Velocity profile for contraction width 0.24m.

The velocity profile shown in Fig 5.10. is for the case when contraction width is reduced to 0.14m. It can be seen that the velocity decreases sharply. It is because of the fact that through the formation of hydraulic jump the flow changes from super critical to sub critical. This change occurs because the flow cannot be maintained with the current specific energy so the specific energy has to be increased. This can be better understood with help of the Fig 4.3. in the previous chapter. For a given value of specific energy, the unit discharge can only be increased to a certain value, till the specific energy becomes minimum for that flow. If the unit discharge is further increased the flow is not possible by keeping the specific energy constant, it has to be increased. Same case is happening here.

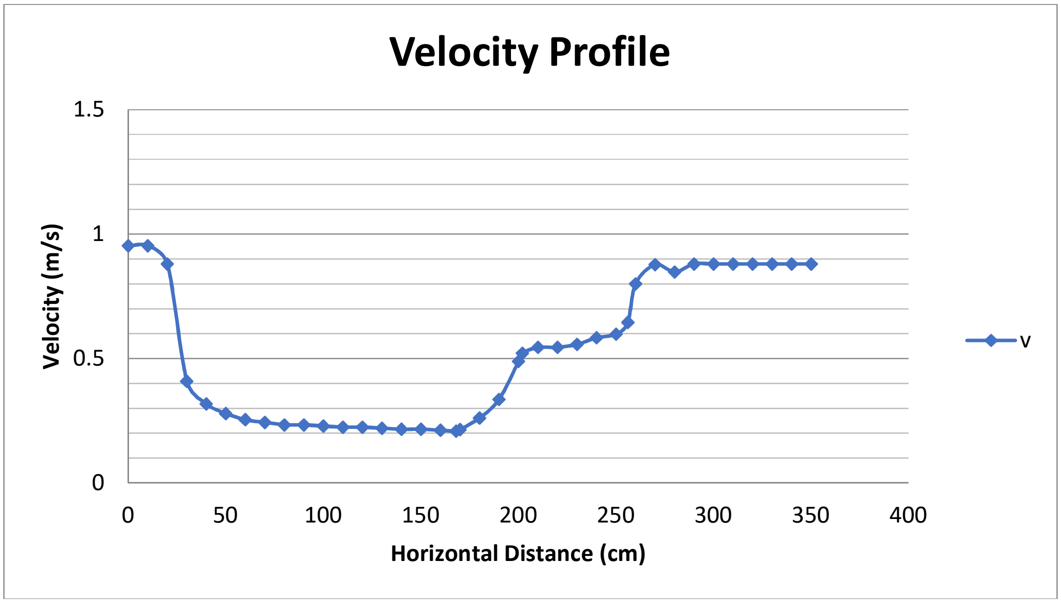

Fig 5.10. Velocity profile for contraction width 0.14m.

Fig 5.11 shows the comparison of velocity distribution for different contraction width. It can be seen that there is a small decrease in velocity downstream of the structure compared to upstream of the structure. This is because of the fact that some energy is being lost in between.

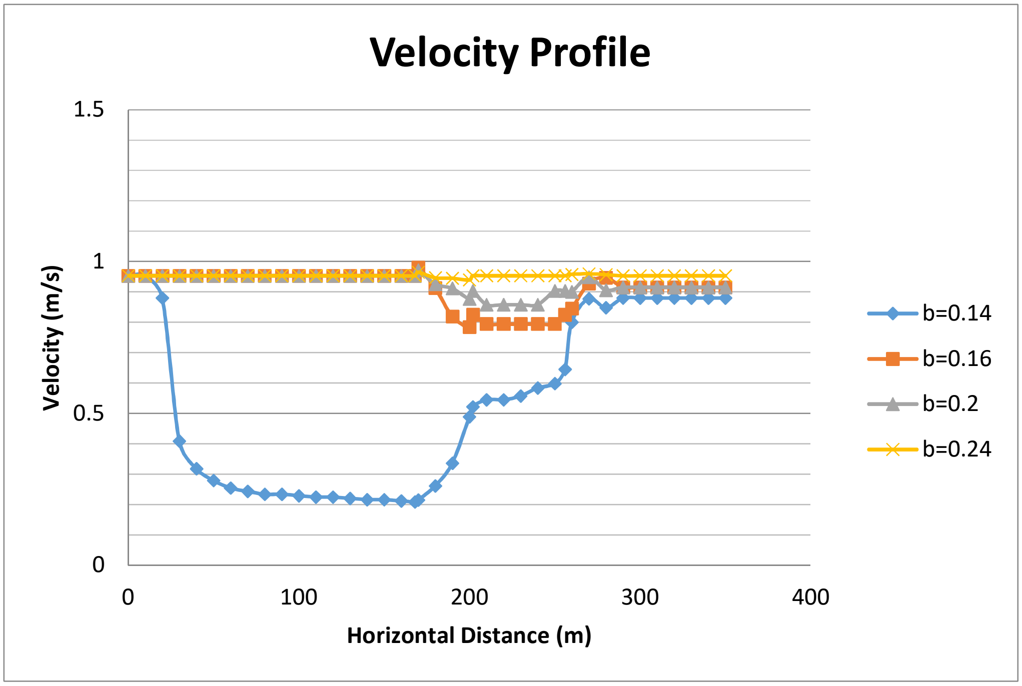

Fig 5.11.Comparision of velocity profile for all the contraction width

If the profiles as shown in Fig 5.7 and Fig 5.8 are compared, it can be seen that the velocity decreases at the contraction. This decrease in velocity is most when the contraction width is 0.16m. The velocity decreases to 0.7944 m/s from 0.9533 which is 0.1589 m/s. For the case when contraction width is 0.2m, the velocity decreases to 0.8580 m/s from 0.9533 which is 0.0953 m/s. For contraction width, from Fig 5.9, it can be seen that there is not much change in the velocity. This is owing to the fact that the contraction is very small. From this it can be said that as the contraction width decreases the velocity also decreases. In all the above cases, till the contraction is reduced beyond choking length,

In Fig 5.10 it can be seen that the velocity distribution for contraction width 0.14m which is lesser than the choking width. The velocity abruptly decreases some distance before the contraction. It continues to decrease till it reaches contraction. As the contraction starts the velocity again start to increase. The rate of increase is small. After contraction width reaches 0.14 m, the rate of increase of velocity increases. At the start of expansion again the velocity increases at fast rate till it matches the previous velocity.

5.6 Specific Energy Variation

Fig 5.12, Fig 5.13 and Fig 5.14 shows the state of specific energy during the flow. It can be seen very clearly that there is almost no change in specific energy. There is some undulation but that is due to rounding off error.

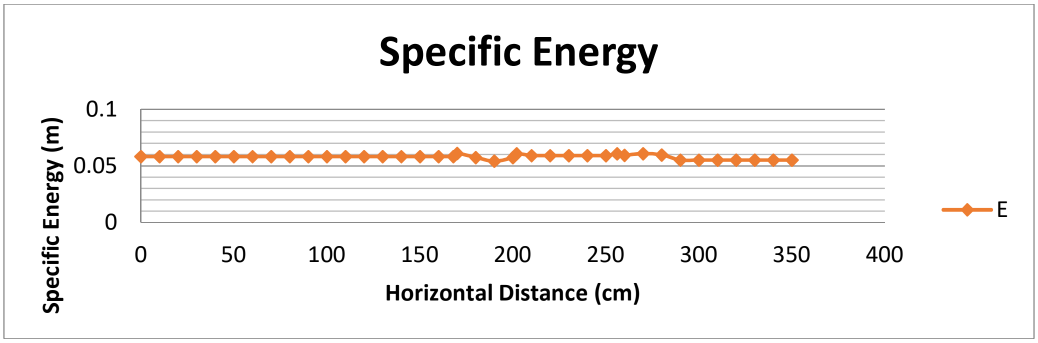

Fig 5.12 Specific Energy for contraction width 0.16m

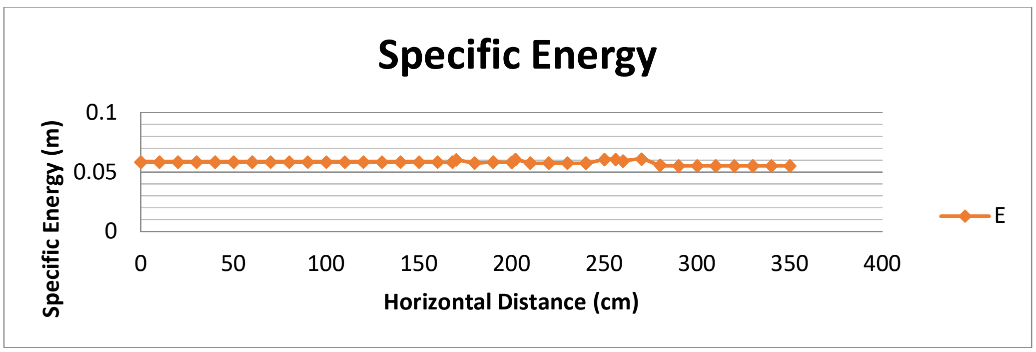

Fig 5.13 Specific Energy for contraction width 0.2m

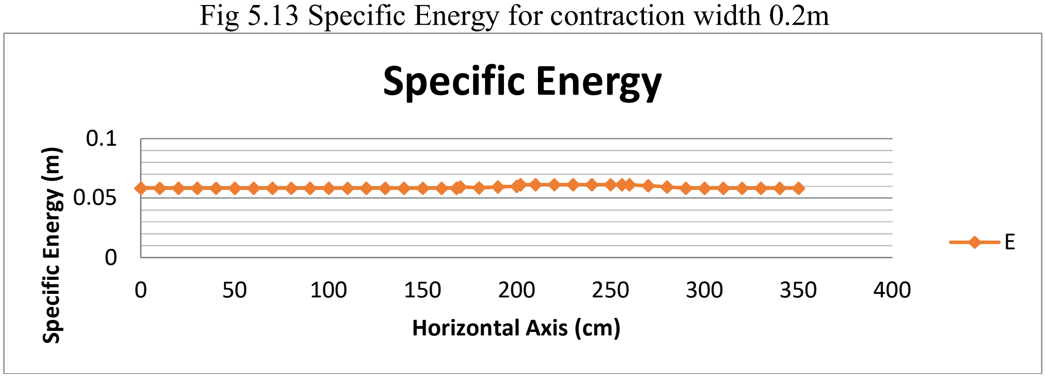

Fig 5.14 Specific Energy for contraction width 0.24m

Fig 5.15 shows the specific energy for contraction width 0.14m. the specific energy first decreases sharply at the location of the hydraulic jump and the increases slowly till it becomes sufficient to maintain the flow. This leads to the formation of afflux or backwater in the channel. It is very important to know the height of the back water curve to prevent overflowing of the channel.

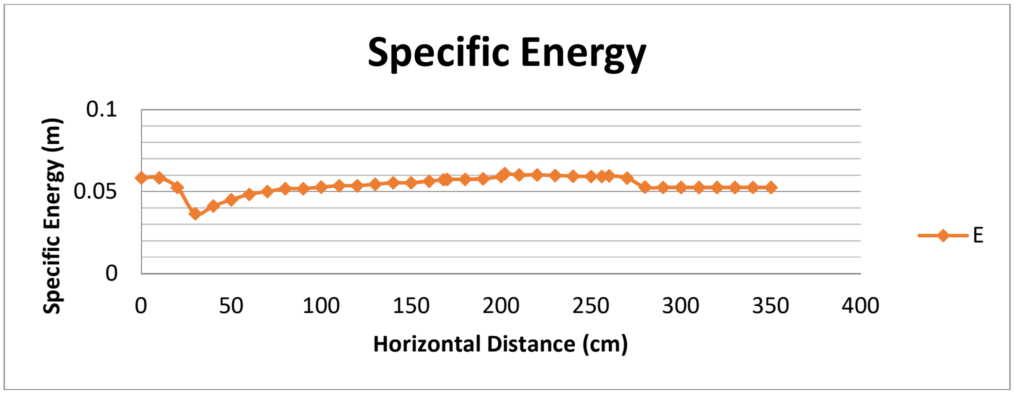

Fig 5.15 Specific Energy for contraction width 0.14m

According to the theory the specific energy has to be constant throughout but it can be seen from the data that there is a small decrease in specific energy. This is due to the fact that some energy is being lost at the transition. The formation of waves and small turbulation created in the fast flowing water causes the energy loss.

CHAPTER 6

CONCLUSION

This chapter consists of the summary of this project work and conclusion drawn from the experiments and results.

6.1 Conclusion

Using all the tables and graphs conclusions were drawn. The conclusion drawn is as the theories predicted it would be. The conclusion drawn are-

- For super-critical flow, till the contraction width is greater than the choking width, as the contraction width decreases the rise in water level increases.
- When the contraction width is reduced beyond the choking width, the water flow changes from super critical to sub critical at some distance upstream from the contraction through a small hydraulic jump.
- The water keeps on rising till the specific energy becomes sufficient to cross the contraction. This causes the formation of the afflux on the upstream side.
- As the contraction starts the flow behaves as sub critical and the water level starts to decrease. The decrease is much less. At expansion and beyond that the water level dips sharply to become equal to the flow depth before afflux was formed.
- The length of the afflux can be calculated by using the Froude Number variation graph. (jump occurs were $F_r>1$ changes to $F_r<1$)
- For super-critical flow, till the contraction width is greater than the choking width, as the contraction width decreases the velocity also decreases.
- When the contraction width is reduced beyond the choking width, the velocity abruptly decreases some distance before the contraction. It continues to decrease till it reaches contraction.

- As the contraction starts the velocity again start to increase, at expansion the velocity again increases sharply.
- Till the contraction width is greater than the choking width, the specific energy remains almost constant.
- When the contraction width becomes smaller than the choking width, the specific energy first decreases sharply at the hydraulic jump and then starts to increase and at the start of the contraction it becomes greater than the previous value which helps to maintain the flow.

6.2 Future Scope

Few suggestions for increasing the scope of the project are-

- Replace the contraction with a constriction, which is again a very common structure in a channel
- Instead of contraction a hump or depression can be used.
- The transition can also be in the form of gradual change of cross section of the channel, e.g. from rectangular channel to trapezoidal channel, circular to rectangular etc.
- By using local velocities, momentum correction factor (β) and energy correction factor (α) can also be determined for the transitions.
- In this experiment, only super-critical flow has been used. Sub critical flow can also be studied. For studying subcritical flow a longer upstream side will be needed.

Reference

[1] Abdul Rahman (2008) "Direct Solution to Problems of Open Channel Transitions: Rectangular Channels", *J. Irrig. Drain Eng*, 134, 533-537.

[2] Lopes, Vincent L. and Shirley, Edward D. (1993) " Computation Of Flow Transitions In Open Channels With Steady Uniform Lateral Inflow", *J. Irrig. Drain Eng*, 119(1), 187-200.

[3] Wilkerson, Gregory V. and McGahan Jessica L. (2005) "Depth-Averaged Velocity Distribution In Straight Trapezoidal Channels", *J. Hydraul. Eng*, 131, 509-512.

[4] Rashwan, Ibrahim (2013) "Open Chanel Flow", *J. Hydraul. Eng*, 149, 313-374.

[5] Han, L.S. (1960), available online at http://appliedmechanics.asmedigitalcollection.asme.org/

[6] Vreman, A.W., Al-Tarazi, Kuipers, J. A. M. M. van Sint Annaland, and Bokhove,O. (2007) "Supercritical shallow granular flow through a contraction: Experiment, theory and simulation*," J. Fluid Mech*. 578, 233

[7] Benjamin Akers and Onno Bokhove (2008). ―Hydraulic flow through a channel contraction: Multiple steady state. *Physics Of Fluids*, 20, 1-18.

[8] Afzal, N., Seena, A., and Bushra, A. (2007). ―Power law velocity profile in fully developed turbulent pipe and channel flows. *J. Hydr. Eng*, 133 (9), 1080-1086.

[9] Kundu, S., and Ghoshal, K. (2010). ―Velocity Distribution in Open Channels:

[10] Open Channel Flow, Advanced Hydraulics, NPTEL. Available: http://nptel.ac.in/courses/105107059/4

[11] P.Baines (2003). ―Multiple states in single layer flow. *Physics of Fluids*, 15,

1-13.

[12] B. Akers (2005). ―Shallow water flow through a contraction. Geophysical Fluid

[13] Dynamics Fellowship Program, pp. 97–117, available online at http://www.whoi.edu/page.do?pid_12955.

[14] Vittal Nandana (2008). ―Direct Solution to Problems of Open Channel Transition. *Journal of Hydraulics Division*, 1, 23-56.

[15] Garg, S.K. (2009). "Irrigation Engineering and Hydraulic Structures" . New Delhi, India. Khanna publications.

[16] Ippen A.T. and Dawson, J.H. (1951) Design of channel contractions," Trans. *ASCE* 116, 268.