FLOW ANALYSIS OF A COMPOUND CHANNEL WITH NON HOMOGENOUS ROUGHNESS

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

Master of Technology
In
Civil Engineering

SUBMITTED
BY

Rashmi Rekha Das

DEPARTMENT OF CIVIL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

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Rashmi Rekha Das

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In partial fulfillment of the requirements
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(Water Resources Engineering)

Under The Guidance of

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This is to certify that the thesis entitled, "**FLOW ANALYSIS OF A COMPOUND CHANNEL WITH NON HOMOGENOUS ROUGHNESS**" submitted by **Rashmi Rekha Das** in partial fulfillment of the requirement for the award of **Master of Technology** degree in **Civil Engineering** with specialization in **Water Resources Engineering** at the National Institute of Technology Rourkela is an authentic work carried out by her under our supervision and guidance. To the best of our knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any degree or diploma.

Research Guide

Place: Rourkela
Date:

Dr. K.K. Khatua
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ABSTRACT

Generally the natural channel consists of a wider and rougher floodplain than the main channel. Therefore the flow velocity in floodplain subsection is slower than the velocity at its main section. Due to this difference in velocities between faster moving main channel flow and slower moving floodplain flow, a relative drag and pull is created which gives rise to momentum transfer mechanism, which is called "kinematics effect". This effect is responsible for decreasing the overall rate of discharge for over bank flow in straight compound channel. Experiments are carried out to compute the velocity as well as boundary shear along the wetted perimeter of a straight compound channel to quantify the momentum transfer along the expected interfaces originating at the junction region between main channel and floodplain. The boundary shear stress distribution is not uniform over the wetted perimeter of uniformly or non-uniformly roughened channel section. Therefore, investigation which deals with the effect of differential roughness on the flow characteristics is essential. In the present work, experiments have been done in two differential roughness conditions of compound channel having width ratio of 2.923 to analyse the stream wise velocity at different points along the lateral direction, boundary shear stress on the wetted perimeter, prediction of flow parameters. The results have been found well validated with the results obtained from 3D numerical software ANSYS (Fluent).

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NOTATIONS

A	Cross Sectional Area
B	Top width of compound channel;
C_r	Courant number;
D	Hydraulic Depth;
Dr	Relative Depth;
H	Total depth of flow;
P	wetted perimeter;
Q	discharge;
R	hydraulic radius;
S	bed slope of the channel;
S	Slope of the energy gradient line;
S_m	Mass exchange between two phase (water and air);
$\overline{S_{ij}}$	Resolved strain rate tensor;
U_t	Velocity tangent to the wall;
U_b	Bulk Velocity along Stream-line of flow;
$\bar{U}$	Average velocity;
V	Flow Velocity;
b	Main channel width;
c	log-layer constant dependent on wall roughness;
g	acceleration due to gravity;
h	main channel bank full depth;

k	Von Karman constant;
n	Number of phase;
p	Reynolds averaged pressure;
t	Time;
u	Instantaneous Velocity;
$\bar{u}$	Mean velocity;
u'	Fluctuating Velocity;
u^+	Near wall velocity;
u_*	Friction velocity;
$\vec{v}_m$	Mass average velocity;
y	lateral distance along the channel bed;
y^+	Dimensionless distance from the wall;
z	vertical distance from the channel bed;
u, v, w	Velocity components in x, y, z direction;
α	Width Ratio;\
δ	Aspect Ratio;
θ	Angle between channel bed and horizontal;
μ_t	Turbulent viscosity;
μ	Dynamic Viscosity;
μ_m	Viscosity of the mixture;
ϑ	Kinematic viscosity;
v_R	Eddy viscosity of the residual motion;
ρ	Fluid Density;

ρ_m	Mixture density;
τ_w	Wall shear stress;
τ	Boundary shear stress;
γ	Unit weight of water;
Δt	Time Step size;
Δl	Grid cell size;

Chapter 1

INTRODUCTION

1. INTRODUTION

A river is more than amenity. It is so precious treasure that offers a necessity of life which should be distributed among those who have the power over it. It's a god's gift to living souls, to cleanse us, to purify us, to sustain us and to renew us. Greatest ancient civilizations grew beside the banks of the rivers. Even in this day and age, many a people all over the world live on the banks of the rivers and depend on them for their survival. However flooding in river is extremely dangerous and has the capability to strike away the whole city, coastline or area, and cause massive damage to life and property. It also has too much erosive power and can be exceptionally damaging. Floods differ in magnitude and happen at irregular interval. Therefore it is very important that risks of flooding should be taken into account in the course of any design process and should be managed so as to lessen its social and economic impacts.

The common shape of river is a main channel flanked by flood plains. This shape has great importance because during flood events in several cases the main channel of rivers is not sufficient to discharge the total flow. So the flood overwhelms the surrounding fields, called the floodplains. Compound channels comprising of generally a main river channel and its floodplain are very important for environmental, economical and design issues. Therefore it is required to study the mechanism of flow of rivers both in their inbank and overbank conditions.

A natural channel generally comprises of a compound section with a wider and rougher floodplain than that of main channel. Due to different hydraulic conditions prevailing in the main channel and adjoining floodplains the flow process becomes more complicated at over bank stages in open channel flow. Generally across the cross section the resulting velocity distribution is not uniform for over bank stage. As long as the flood plain contains small depth of flow and not comparable to main channel depth of flow, main channel holds higher velocity than that of the floodplain. As compared to deep main channel shallow floodplain offer more resistance to flow causing a variation of velocity in between these two sections. Due to these differences of flow velocities, lateral momentum transfer and mass exchange take place. Due to this lateral momentum transfer vertical vortices are created along the interface of the main channel and floodplain. This results in complicacy of the flow process, producing shear force and more resistance and thus consuming more energy. For this extra energy a little more effort is taken to predict the flow process.

To understand the distribution of flow and its variables it is necessary to investigate the flow structures that exist in compound channel. A non uniform distribution of flow variables takes place due to the flow interaction between primary longitudinal velocity and secondary flow velocity in compound open channel. There is a change in resistance to flow across the wetted perimeter is observed due to this non uniform distribution of flow variables. An individual different value is obtained in main channel and floodplain resistance and a composite change of resistance is marked. Many empirical models are developed to solve the problem in calculating discharge and composite friction factor in open channel. But there is a variation in inaccuracy of these models is seen because these models are developed based on a particular hydraulic condition and neglecting many factors.

There is a practical difficulty in obtaining sufficiently accurate and comprehensive field measurements of velocity and shear stress in compound channels under unsteady flood flow conditions (Bhowmik and Demissie, 1982), therefore laboratory investigations in a well-designed manner are still preferred as a trusted method to provide the information concerning the details of the flow structure. This information is also useful in the development of numerical models for solving certain practical hydraulics problems. Such practical problems are related to sediment transport, bank erosion, flood risk management, etc.

In the present work laboratory experiments have done in a symmetrical trapezoidal compound channel having width ratio 2.923 and roughened in a two different ways so that its floodplain offer more resistance than that of main channel. The effect of differential roughness on the flow characteristics is studied.

1.1 Differential roughness

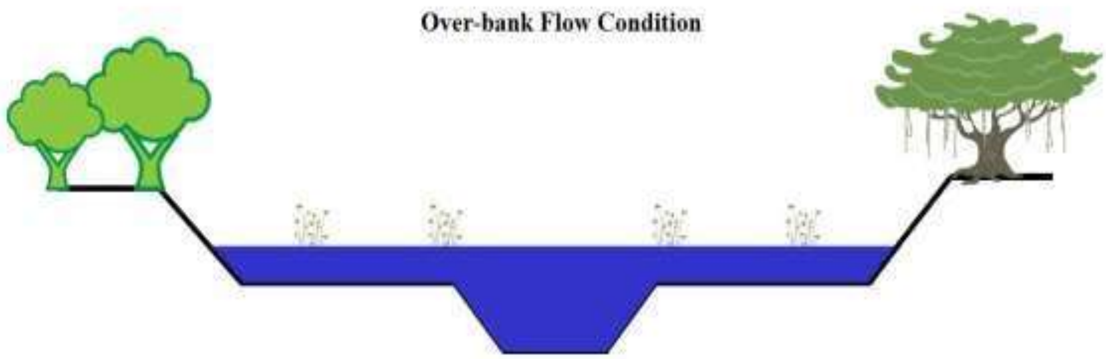
River engineers use the roughness value of bed material in case of compound channel flow to solve many practical problems. Generally it's found that the roughness of floodplain and main channel is not similar. Normally floodplains bear a greater value of resistance than main channel. Differential roughness is the ratio of roughness value of floodplain to the roughness value of main channel. The effect of roughness along with relative depth on flow characteristics is studied here.

1.2 Objectives of the present work

- To study the changing pattern of depth averaged velocity distribution by changing the relative depth and differential roughness.
- To study the velocity contour mapped from the experimental data taken at different points of channel cross section with the increase of differential roughness.
- To study the stage discharge relationship for increasing differential roughness condition.
- To study the boundary shear distribution across the wetted perimeter of channel cross section.
- To analyse the numerical model and validate the results with the data obtained from laboratory experiments.

Fig 1.1 Godavari , India

Fig 1.2 Indus river, Pakistan



1.3 Organisation of Thesis

The thesis comprises of six chapters

Chapter-1 presents a brief introduction of compound channel with non-uniform roughness with high relative depth and the objectives of the research are presented.

Chapter-2 presents literature review of the existing work. This chapter includes brief description of research carried out in a compound channel with smooth and rough surface.

Chapter-3 includes experimental investigation under which experimental channel design, water supply system, determination of bed slope, roughness , measurement of velocity, depth of flow, boundary shear, discharge are described.

Chapter-4 describes about the numerical model analysis.

Chapter-5 describes the analysis of results of depth averaged velocity distribution, boundary shear, stage discharge relationship and velocity contour validating with numerical model analysis.

Chapter-6 includes the conclusion part with scope of the future work.

Chapter 2

REVIEW OF LITERATURE

Flow characteristics, like prediction of stage discharge, depth averaged velocity, boundary shear distribution, velocity contour, flow resistance, etc., have been analysed by many researchers since last decades. In this chapter some of the compound channel flow studies are presented.

2.1 Studies in smooth compound channels

Sellin (1964) conducted a no of experiments in compound channel and came to a result of momentum transfer mechanism in a compound channel which is due to the relative velocity in between main channel and flood plain. He studied about the vortices which are formed at the interface of main channel and floodplain. He analysed discharge and velocities for compound and simple conditions. It was observed that the velocity found to be more in simple condition than that of compound condition.

Zheleznyakov (1971) studied the interaction junction between main channel and adjoining floodplain. He conducted a no of laboratory experiments and presented the momentum transfer effect. He expressed that because of momentum transfer the overall rate of discharge is decreased for lower floodplain depth and the impact of momentum transfer in decreased as the floodplain depth goes on increased. Due to faster moving main channel flow and slower moving floodplain flow a relative drag and pull is created which actually gave rise to the momentum transfer at junction which is called “kinematics effect”.

Ghosh and kar (1975) investigated the distribution of boundary shear in smooth compound channel. Depth of flow and roughness coefficient influence the proportion of distribution of drag force in different parts of the channel section.

Myers and Elsawy (1975) analysed the interaction phenomenon and estimated the variation of main channel flow velocity due to the effect of lateral momentum transfer, distribution of discharge and boundary shear stress for compound channel and simple channel condition in a straight asymmetric compound channel condition (floodplain on one side).They conducted experiments under combined and isolated condition for the measurements of distribution of boundary shear stress and found that for shallowest floodplain depth there is an increase of 260% in maximum shear stress of floodplain. Knowledge of lateral momentum transfer and correct distribution of it influences the understanding of local scour and calculation of maximum scour in flood plain zones.

Rajaratnam and Ahmadi (1979) reported the effect of flow interaction in a compound straight channel with smooth symmetrical floodplains. They stated during over bank flow the momentum transfer mechanism took place from main channel to floodplain. They also concluded that with the increment of depth of flow on floodplain the flow interaction effect is decreased. The main channel bed shear is decreased and floodplain-main channel interface bed shear increased due to this flow interaction.

Wormleaton et.al. (1982) Studied in straight compound channel and conducted a series of laboratory experiments in compound channel with symmetrical floodplains to measure discharge. He used divide channel method to calculate discharge. For choosing the method to be best method of dividing the channel for calculation of discharge an apparent shear stress ratio was suggested. Satisfactory results were obtained by the horizontal and diagonal interface divided channel method than the vertical interface divided channel method.

Knight and demetriou (1983) studied the discharge characteristics, boundary shear force distributions and boundary shear stress at a section of symmetrical compound channel. For estimating the percentage of shear force in floodplain equations were being proposed. They also studied various sub-areas of compound section and calculated the proportions of total flow. The apparent shear force for vertical interface between main channel and floodplain is found to be more for lower flow depth and higher floodplain width.

Wormleaton and Hadjipanos (1985) reported a study in compound channel for distribution of flow. They concluded that even though a discharge prediction method may give satisfactory results in overall discharge but the velocity flow distribution between the main channel and floodplain may be in sufficiently modelled.

Myers (1987) expressed the variation of discharge and velocities between main channel and floodplain. Between flow depth and ratios a relationship was established, and the result came out to a straight line relationship. Here the relation between flow depth and ratios was dependent on channel geometry but independent of bed slope. Mathematical equations are generated showing the relationship between flow depth and ratios. It was seen at both higher and lower depths the flow capacity of floodplain was always underestimated but in case of main channel at higher depth the full main channel flow carrying capacity was underestimated and at lower depth it was overestimated. He took the effort to pointed out the importance of accurate modelling of discharge capacity and distribution of flow in compound channel cross section as a whole.

Stephenson and Kolovopoulos (1990) analysed various methods to estimate the discharge prediction solution by taking shear stress variation between main channel and floodplain comparing to different flow conditions. They predicted discharge based on the previously published data and came to a conclusion that in predicting discharge the most reliable method is "area method".

Shiono and Knight (1988) studied about the straight compound channel with different cross section. He studied about trapezoidal model and developed an analytical model which predicts boundary shear stress and depth averaged velocity. For this, mathematical equations were proposed which influence the shear layer between main channel and floodplain.

Myers and Brennan (1990) analysed first series results of FCF (Flood channel Facility) data for simple and compound channel having smooth boundaries to estimate resistance characteristics of flow. They studied about momentum transfer from main channel to floodplain and the effect of it on discharge carrying capacity of compound channel. They presented flow resistance relationship for Manning's and Darcy-Weisbach roughness coefficients.

Ackers (1992, 1993) reported a design formula by taking into account the flow interaction effect between main channel and floodplain for straight compound channel. He proposed a parameter keeping the stability between main channel and floodplain interaction.

Lambert and Myers (1998) analysed straight compound channel and derived relation predicting the stage-discharge relationship in a straight compound channel. They investigated the variations in the mean velocities of the floodplains and main channel zones because of momentum transfer between the two zones and developed a model based on the proposed method. To develop a method which is capable of more accurate representation of mean velocities resulting in improved estimation of both zonal and overall estimation of discharge values FCF experimental results had been used.

Al-Khatib and Dmadi (1999) analysed rectangular compound channel with symmetrical rectangular floodplain. They analysed the distribution of boundary shear stress. The relation between relevant parameter of flow like depth of floodplain flow, relative depth, discharge was derived.

Bousmar and Zech (1999) proposed 1D model showing practiacal simulations of water surface profile and relation between stage-discharge .The exchanged mass discharge generated at the interface between main channel and floodplain from the turbulence effect is multiplied with the velocity gradient for the determination of momentum transfer. They concluded with the model predicting the stage discharge for both natural River and experimental data. Their model is working in a very good manner predicting the flow in a prototype river named as sambre in Belgium.

Atabay and Knight (2002) expressed equations related to stage discharge in compound channel using Flood Channel Facility (FCF) data. Here how the stage discharge relationship is influenced by aspect ratio and width of the floodplain is investigated. For varying floodplain width ratio and uniform roughness simple empirical analysis of stage discharge with total discharge as well as zonal discharge was proposed.

Abaza and Al-Khatib (2003) conducted experiment of five different types of boundary shear stress distribution, viz., shear stress at the bottom of main channel centreline, maximum shear stress at the bed of the floodplain, maximum shear stress at bottom of the main channel, average shear stress at the bed of the floodplain, average shear stress at the bottom of the main channel considering six different types of symmetrical rectangular compound channel. For the prediction of five shear stress which are measured experimentally as a function of three dimensional parameters a generalized regression model of multiple variables are derived. A regression model based on single multivariable was presented for the estimation of mean shear stress at the bottom of the rectangular compound channel average values of obtained regression coefficients of the multiple variable regression models.

Hosseini (2004) studied about straight compound channel which is having homogenous roughness taking large body of experimental data covering large scale and small scale laboratory compound channels. He studied about the discharge characteristics.by analysing some experimental results of FCF in these channels a method for discharge calculation had been proposed by him. In order to find more accurate values of mean velocities in the main channel and floodplains predicted by the traditional vertical division method using two correction coefficients which were applied to the component of the mean velocities. The coefficients had been expressed in terms of two dimensionless parameters of the channel, coherence and relative depth,viz.,ratio of floodplain to total depth.

Knight et al(2010) proposed a model which is useful for analysing a range of practical problems in river engineering based on lateral distribution of shiono & Knight method(SKM). The model is very useful in prediction of depth averaged velocity ,stage discharge relationship, lateral distribution of boundary shear stress, study of sedimentation and vegetation issues.

Rezaei and Knight (2011) studied about the compound channel with non-prismatic floodplain with different converging angles in overbank flow condition. They estimated boundary shear stress distributions, local velocity distributions, depth averaged velocity along the converging flume portion for different relative depth of flow. They analysed force acting on the flow in the main channel and for the whole cross section using momentum balance method. Apparent shear forces on the vertical interface between the main channel and floodplain for compound channel having non-prismatic floodplains had been estimated and then compared with the prismatic cases.

Khatua et al. (2012) presented a modified equation for the determination of boundary shear stress in compound channels. They studied about the stage discharge relationship and a method had been proposed by him using one dimensional approach. They considered momentum transfer concept while deriving the method. The proposed method found to give satisfactory results after tested for natural channels.

2.2 Studies in Rough Compound Channels

Ghosh and jena (1973) took series of experiments in straight compound channels for both smooth and rough boundaries and analysed boundary shear distribution. They focused in determination of total drag force exerted by different segments of the channel section to the flow depth of and roughness concentration.

Knight and hamed (1984) extended the work of Knight and Demetriou(1983), for the compound channels having rough floodplain. The floodplain were roughened in six different ways by adding strip roughness elements at specific longitudinal spacing. They studied about the momentum transfer mechanism and the effect of differential roughness between flood plain and main channel on the mechanism of momentum transfer. Equations for estimation of total shear force in compound channel flow and percentage of shear force in floodplain had been estimated by using dimensionless channel parameters (aspect ratio, width ratio, depth ratio, roughness ratio). They also estimated distribution of discharge in compound channel.

Myers and Lyness (1997) studied about compound channel of smooth and homogenously roughened channels of various scales finding discharge ratios, namely total to bank full discharge and main channel to floodplain discharge by the help of acquired data of small scale and large scale laboratory compound channel. The total to bank full discharge ratio was found to depend on channel cross section geometry but independent of bed slope. The other ratio main channel to floodplain discharge influenced by the lateral floodplain bed slope but independent of scale and bed slope. They also studied about flow ratios to flow depth and found some coefficients and exponents related to that.

Myers et al (2001) reported some experimental results by studying in compound channel having mobile bed and fixed bed along with two rough floodplains. They studied about the complex behaviour of compound channel river section. They established a relationship between velocity and discharge by river analysis. They calculated error in applying conventional methods in over bank flow condition for the calculation of discharge. A relationship between discharge and velocity has been presented to form the base of mathematical modelling of overbank flow estimation methods.

Seckin (2004) studied about the discharge capacity of compound channel by conducting a series of experiments with smooth main channel and smooth or rough floodplains. The floodplains were roughened in four different ways using metal meshes. In order to provide a particular roughness the metal meshes were placed on each floodplain at 4 different intervals spacing and the meshes are 35.5 cm in width, 15.5cm height placed at an angle of $30^{0.}$ Separate sets of experiments conducted for the determination of resistance properties of floodplain roughness.

Hin and bessaih (2004) analysed momentum transfer in a straight compound channel having rougher floodplain than the main channel. They also studied about the velocity distribution and stage discharge relationship in compound channel. The floodplain was artificially roughened by using wire mesh.

Yang et al. (2005) established relationship between local, zonal, overall resistance coefficients for a wide range of variations in geometry and differential roughness using FCF data. It had been concluded that the functional relationship of Darcy-Weisbach resistance coefficient with Reynolds number in compound channel is different from that of single channel. In smooth compound channel for a certain given relative depth the local resistance coefficients approximately remain constants but have individual different values for main channel and floodplain. As the relative depth increases these coefficients decreases in case of roughened compound channel and asymmetric channel.

Yang et al (2007) conducted series of experiments in large symmetric compound channel having rough main channel and rough floodplains finding resistance characteristics of inbank and overbank flow. They concluded that for the overbank flow in the large compound channels with a rough bed these flow resistance coefficients vary with the flow depth in a complicated way. Field data had been collected for compound channel and methods had been validated for the prediction of composite roughness. Errors had been analysed and proper reason also had been stated.

Joo and seng (2008) compared various methods for the prediction of discharge in a compound channel. Experimental investigations on a small scale asymmetrical compound channel with rough floodplain had been carried out. To check the validity of the horizontal division method and the vertical division method in predicting discharge weighted divided channel method was used. For wider floodplain in non-symmetrical compound channel horizontal division method provides more accurate results for the prediction of discharge and for narrower floodplain vertical division method is more accurate.

Kaen et al (2009) studied about straight compound channel whose floodplain was roughened by cobble for the determination of velocity and boundary shear stress distribution across the cross section. They analysed drag force and presented methods for estimation of velocity and boundary shear stress. They concluded that due to presence of secondary circulation there is a principal difference between measured and calculated field data. They studied the effect of width-to-depth ratio on the velocity and boundary shear stress across the channel by varying the width of the channel.

Chapter-3

Experimental Investigation

In order to ascertain the impact of differing qualities in floodplain roughness and main channel roughness on the flow characteristics (i.e. boundary shear distribution, flow distribution, depth-averaged velocity, variation in overall and zonal Manning's n and discharge) during over flow condition in a compound channel, tests were directed under controlled laboratory conditions in the Fluid Mechanics and Hydraulics Laboratory of the Civil Engineering Department at the National Institute of Technology, Rourkela, India. By changing the roughness of the floodplain as for the main channel experiments were conducted. This chapter explains the experimental channel design, roughness elements design and resoluteness of base n value for the roughness elements utilized.

3.1 EXPERIMENTAL CHANNEL DESIGN

3.1.1 Tilting flume

In this present study a straight compound channel was used. Experimental set up was built in Fluid mechanics and Hydraulics Laboratory of NIT, Rourkela. The compound channel with tilting flume having dimension 15m long, 1.9m wide, 0.275m.The channel is made up of cement concrete. Just after the inlet at the beginning of the flume and before head gate (called stilling chamber), a series of baffle walls were installed for energy dissipation purpose, i.e. to reduce turbulence and make water body uniform before passing over the channel. Head gate plays a vital role by reducing waves if formed in the water body before it passes over the channel. In this way we control the incoming flow for ensuring gravity flow or open channel condition. There was a facility of travelling or movable bridge for both span wise and stream wise movements so that each location on the plan of compound channel could be accessed for taking measurements. To make experimental work easier over 1.9m wide platform was there. Rectangular notch facility was there to find discharge foe each run. By the help of centrifugal pump (15Hp) the water is supplied to the flume from an underground sump via an overhead tank. This water is re circulated through the downstream volumetric tank fitted with closure valves for calibration purpose. Water entered the channel through bell mouth section via an upstream rectangular notch specifically built to measure discharge in such a wide laboratory channel. At the downstream end an adjustable tail gate was provided to control the flow depth and maintain a uniform flow in the channel.

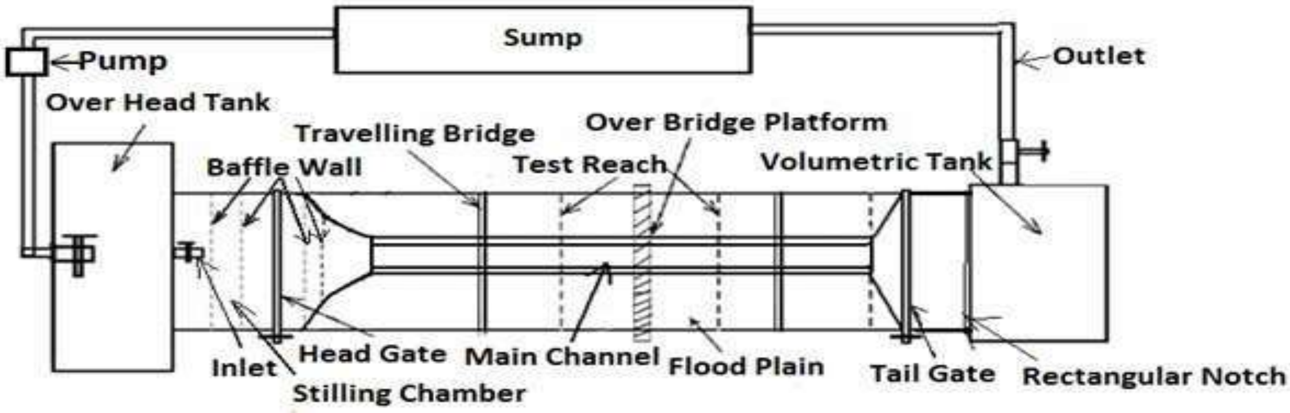


Fig. 3.1 Schematic drawing of whole experimental system with tilting flume

3.1.2 Experimental compound channel

In this present experiment, the compound channel which is used for investigation consist of a main channel of trapezoidal cross section 65cm wide at bottom, 90cm wide at top, having depth of 12.5cm and side slope of 1:1 along with symmetrical floodplain 50cm width and zero side slopes (Fig 3.2).

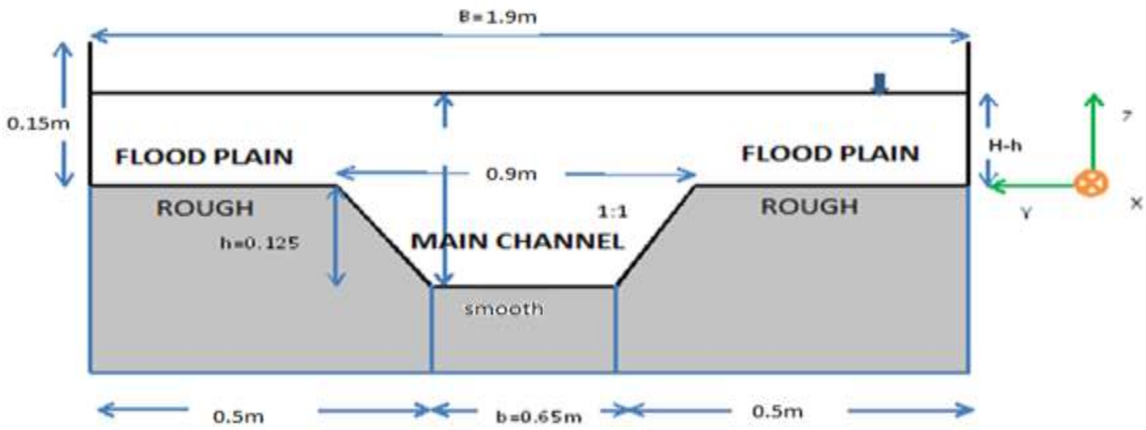


Fig-3.2 Cross sectional view of experimental channel

Table-3.1 Detailed geometrical features of the experimental channel

Sl no	Item Description	Present Experimental Channel
1	Channel type	Straight compound channel
2	Geometry of the main channel section	Trapezoidal(side slope 1:1)
3	Geometry of the floodplain section	Rectangular(side slope 0)
4	Floodplain type	Symmetric
5	Main channel width base width(b)	0.65m
6	Top width of compound channel(B)	1.9m
7	Depth of the main channel(h)	0.125m
8	Flood plain width	0.5m
9	Width ratio(α=B/b)	2.923
10	Aspect ratio(δ=b/h)	5.2
11	Bed slope of the channel	0.0022

3.1.3 Water Supply System

For the experiment water was supplied from an overhead tank and a water level indicator was attached for maintaining constant water level in the overhead tank. To pump water from an underground sump to the overhead tank two parallel pumps were installed .overhead tank delivered water to the stilling chamber allowing water to flow over trapezoidal channel ensuring flow under gravity ended with a volumetric tank situated at the end of the flume. From volumetric tank flow was allowed to get back to an underground sump. Recirculation of water supply system is maintained.

Fig 3.3 Overhead tank

Fig 3.4 Two parallel pumps

3.2 APPARATUS& EQUIPMENT USED

Measuring devices such as pointer gauge having least count of 0.1mm, one pitot tubes having 4.6 mm external diameter and one manometer, rectangular notch, ADV (acoustic Doppler velocity meter) were used in the experiments. For the measurement of longitudinal velocity in the direction of flow within the channel these measuring devices are used. Also structures like baffle walls, travelling bridge are used. To carry out the experiment proper arrangement of devices and measuring instruments were done.

3.2.1 ADV (Acoustic Doppler Velocity Meter)

Instantaneous velocities were measured with the use of a three component Acoustic Doppler velocity meter (ADV) manufactured by Sontek, Inc. The acoustic sensor was mounted on a rigid stem attached to a specially designed trolley allowing for its detailed positioning. The ADV works on pulse-to-pulse coherent Doppler techniques in relatively high temporal resolution. The ADV proved to yield a good description of the turbulence characteristics when certain conditions related to the flow itself and the configuration of the instrument were satisfied. The measurements were conducted with a maximum frequency of 50 Hz in the velocity range of 0–1.0 m/s with an accuracy of 0.25 cm/s. In cases of our experiments, longer time series were recorded to provide reliability of data and constancy of higher-order velocity moments.

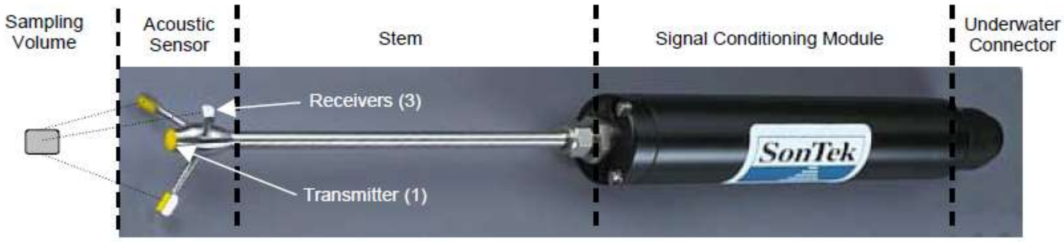


Fig 3.5 typical ADV probe

Figure – 3.6 Probes: (a) Down-looking 3D, (b) Side-looking 3D, (c) Up-looking 3D

Fig 3.7 observation taken by ADV and inclined manometer

3.3 EXPERIMENTAL PROCEDURES

All the observations are recorded in a section 7.5 m away from the inlet of the compound channel. Point velocities are taken across the main channel as well as floodplain along the vertical depth direction covering the entire width of the cross section. In each vertical, a horizontal layer of reading both in the main channel as well as floodplain was measured. Thus from left edge point to the right edge of the main channel as well as for the flood plain bed and side vertical walls measurements were taken. The grid points lateral spacing over which measurements taken was kept 5cm and also pitot tube is moved upward by 1cm up to the top. With the help of pitot static tube (outside diameter 4.77mm) , ADV (acoustic Doppler velocity meter) and two parameters fitted inside a transparent fibre block fixed to a wooden board and hung inclined by making an angle of 33^0 with vertical at the edge of flume velocity measurements were taken. One end of the static pitot tube was open to the atmosphere and other end was connected to total pressure hole and static hole of pitot tube using a long transparent PVC tube. Pitot tube along with the long tubes measuring about 5m were to be properly immersed in water and caution was exercised for complete expulsion of any air bubble present inside the Pitot tube or the PVC tube before taking readings. The discharge to be maintained in each run of the experiment was steady uniform and the pressure differences were measured. Here the readings were taken for two different conditions with different depth. First condition was by putting gravel in the flood plain and concrete in the main channel keeping the main channel comparatively smoother than that of main channel with a differential roughness value of 1.916 for a depth of 22.8 cm from main channel bed with relative depth of 0.824. Second condition was by putting gravel in the floodplain and sand in the main channel with a differential roughness value of 1.533 for a depth of 16cm from main channel bed.

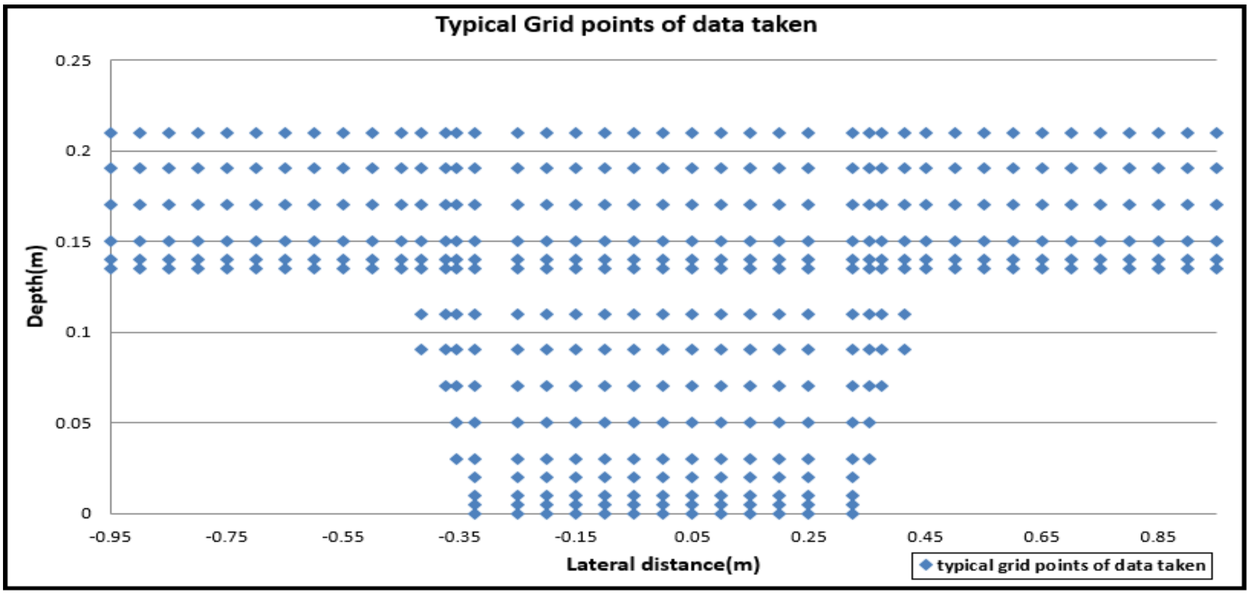


Fig 3.8 Typical grid showing the arrangement of velocity measurement points along horizontal and in the vertical direction of the test section in trapezoidal compound section with gravel as floodplain and concrete as the main channel with water depth of 22.

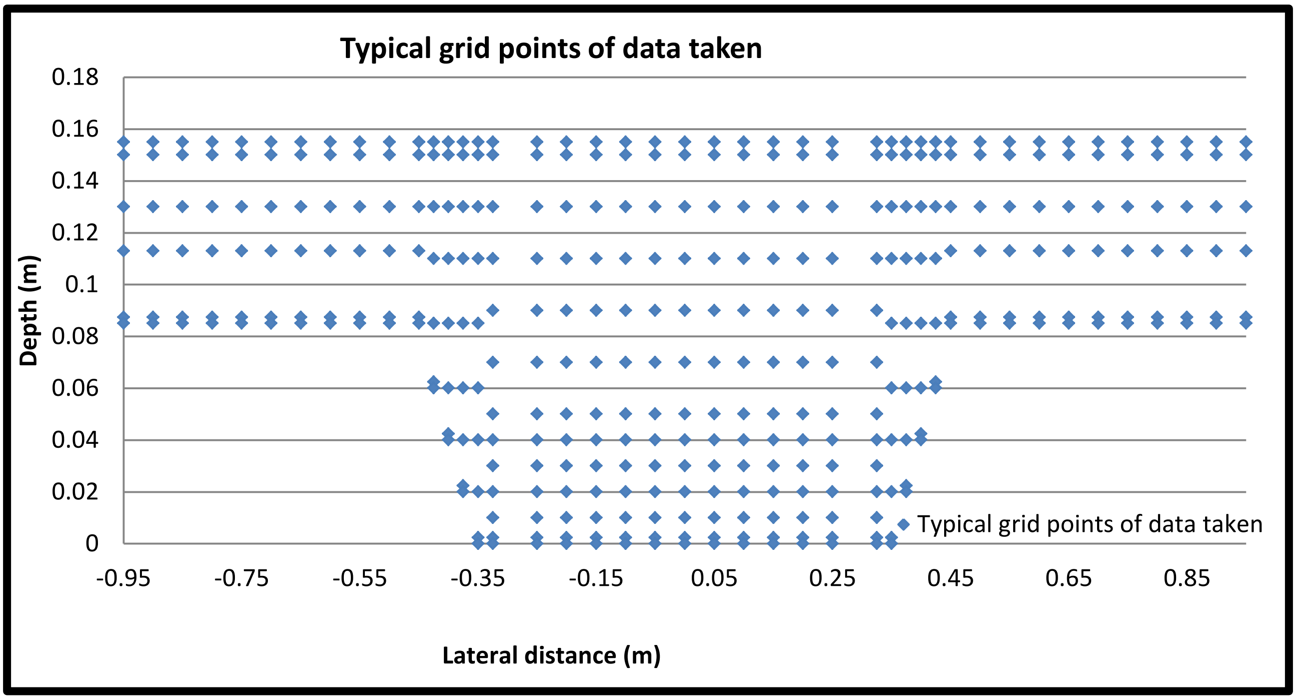


Fig 3.9 Typical grid showing the arrangement of velocity measurement points along horizontal and in vertical direction at the test section in trapezoidal compound section with gravel as floodplain and sand as main channel with water depth of 16cm.

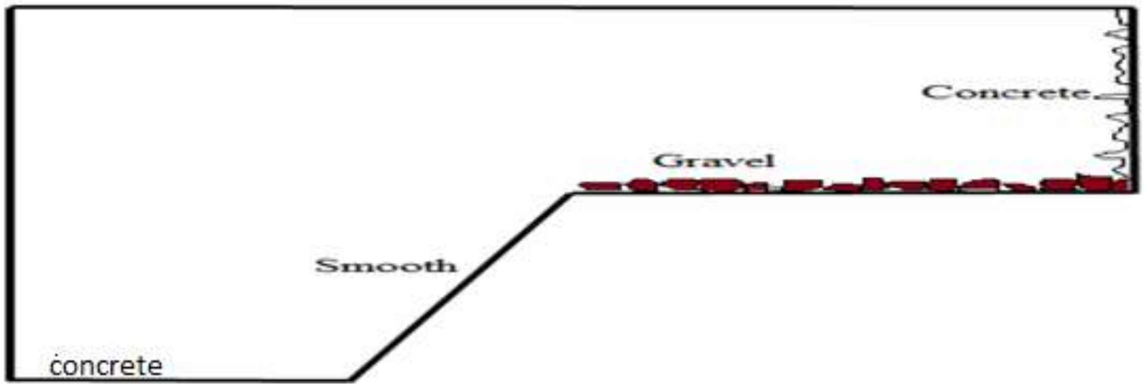


Fig 3.10 Half cross sectional view of the channel with gravel as floodplain and concrete as the main channel

Fig-3.11 Compound channel with gravel as floodplain

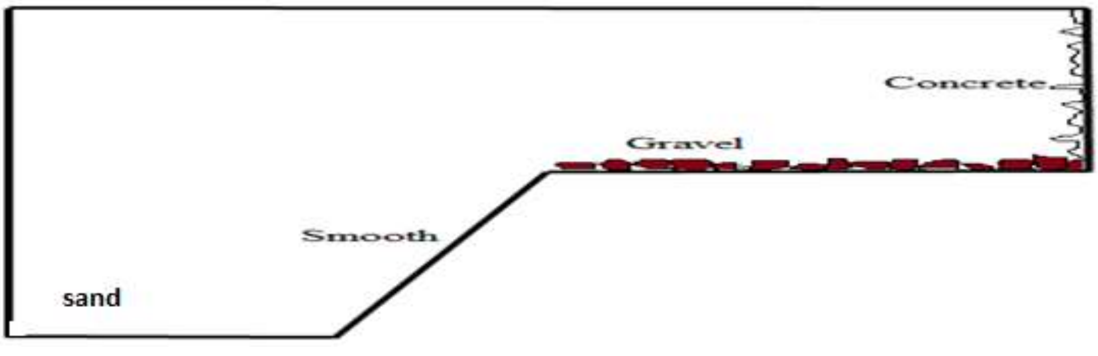


Fig 3.12 Half cross sectional view of channel with gravel as floodplain and sand in main channel

3.3.1 Construction of Rough Compound Channel

Experiments were performed in two different channel roughness conditions. In first condition experiments carried out in compound channel having its main surface as concrete and floodplain as gravel. In second condition main channel was roughened with sand and floodplains were roughened with gravel as roughening material.

Table-3.2 Channel boundary condition of over bank flow condition

Sl no	Main channel boundary	Floodplain bed	Floodplain wall	Named	No of runs
1	Concrete	Gravel	Concrete	Roughness-1	1
2	Sand	Gravel	Concrete	Roughness-2	2

3.3.2 Determination of differentia roughness (ϒ) value

In Natural River or practical condition the roughness of main channel and floodplain is generally different and that is called differential roughness. To calculate flow and other parameter river engineer river engineer deals with the roughness value of each subsection. For estimation of flow distribution and boundary shear distribution etc. differential roughness is an important non dimensional parameter and is obtained by dividing floodplain roughness to main channel roughness.

Table-3.3 Differential roughness (ϒ) value of all overbank flow

Sl no	Main channel (n) sec/(m^(1/3))	Floodplain(n) sec/(m^(1/3))	Differential roughness(ϒ)
1	Concrete (0.012)	Gravel(0.023)	1.916
2	Sand(0.015)	Gravel(0.023)	1.533

3.4 MEASUREMENT OF BED SLOPE

Several methods are there for measuring the bed slope of the flume. Based on the practical condition and interest of the researcher methods are selected. In this present work by the help of point gauge bed slope is measured. Using a pointer gauge having least count of 0.1mm from the standing water at a certain point the bed and water surface level are recorded. This procedure is repeated again and observations are recorded at a certain distance from the previous point. The mean slope of the channel is obtained by dividing the difference in level between channel bed and water surface between these two points by the length of the straight channel between these two points. For getting better and accurate result this procedure was repeated for three times and then by averaging slope of the channel was found to be 0.0022.

3.5 DETERMINATION OF THE BASE MANNING'S *N* VALUE OF CHANNEL SURFACE MATERIALS

Material roughness generally expressed in terms of roughness coefficient which creates resistance to flow. For estimating the flow carrying capacity of a channel the selection of an appropriate value of roughness coefficients is needed. The volumetric tank was constructed in the fluid mechanics laboratory and for discharge measurements the area of the volumetric tank was measured thrice properly and average result was found out to be 20.828784m^2. A glass tube water level indicator was attached to the volumetric tank and height of water in the volumetric tank was monitored. By time to rise method the discharge into the volumetric tank was measured. With the help of a stop watch having accuracy of 0.01 sec the change in the depth of the water in the volumetric tank with time was measured. The discharge was found out for 5-7 depths of flow, from which the velocity of the flow as estimated. Then by equating this velocity with the manning's equation of velocity, the n value was measured to be 0.023 s/ (m^ (1/3)) for gravel, 0.012 s/ (m^ (1/3)) for concrete, 0.016s/(m^(1/3)) for sand.

3.6 MEASUREMENT OF DEPTH OF FLOW

For the measurement of depth of flow pointer gauge is used for all the series of experiments. A vernier caliper is fitted with the point gauge with least count of 0.1 mm and movable bridge is having the facility to carry the total measuring devices to conduct the experiment manually.

3.7 MEASUREMENT OF VELOCITY

When water flows from one point to another point energy loss occurs. The total energy includes potential energy, kinetic energy and pressure energy. The total energy is more influenced by the kinetic energy in open channel flow. Kinetic energy is the ratio of square of the velocity to twice of acceleration due to gravity. So the mean velocity is required to be found out of the fluid flowing in the channel. The total pressure head as well as static pressure head readings were taken with the help of pitot tube and their differences is estimated. Then the corresponding velocity at each point are calculated from the observed data. Pitot tube is placed in the direction of flow within the channel in horizontal direction as well as vertical direction. Until the head difference in manometer remains constant the pitot tube is kept at a place for an interval. A simple formula is used to measure the velocity i.e. $v=2gh$, for u tube manometer and $v=2ghsin\theta$ for inclined u-tube manometer, where g is the acceleration due to gravity. At the given grid points shown above (fig 3.9 & 3.10) velocities were calculated in the main channel as well as in floodplain in horizontal direction at an interval of 0.05m. Also in vertical direction velocities are measured depth wise at an interval of 0.01m from the bed up to the top using ADV (Acoustic Doppler velocity meter). Experiments are conducted in the channel for two different differential condition by maintaining the water surface slope parallel to the bed slope to ensure steady uniform condition in open channel flow.

3.8 MEASUREMENTS OF BOUNDARY SHEAR STRESS

The stress develops between the two layers of water at flowing condition is shear stress. Boundary shear stress is the main reason for erosion and sediment transport stress representing the local force by the fluid on a surface has a great importance in hydraulic research. The stress that is developed between the water flowing in the channel and its bed as well as wall of the channel is boundary shear stress. Boundary shear develops due to a relative velocity or velocity gradient occurs between the two layers of water flowing. A reduction of velocity occurs due to this shear stress. So it's important to calculate the boundary shear stress. The most common formula which is used to find out boundary shear stress is Patel's equation. Depending upon the range of Reynolds number three equations are proposed which are used while calculations of boundary shear stress.

3.8.1 Energy Gradient Method

In uniform flow condition for a prismatic channel the sum of retarding boundary shear forces acting on the wetted perimeter must be equal to the resolved weight force along the direction of flow. The mean boundary shear stress (τ) over the entire boundary of the channel can be expressed (τ) as:

$$\tau = \rho gRS \qquad (1)$$

Where ρ= density of flowing fluid, g = gravitational acceleration, R = hydraulic radius of the channel cross section *(A/P)*, S = slope of the energy line, A = area of channel cross section, and P = wetted perimeter of the channel section. This is known as energy gradient method. For local, small-scale estimates of the variations in shear stress due to the larger length this method might not be suitable. Moreover, precise energy slope measurement is not always possible which eventually affects the accuracy of the method.

3.8.2 Preston Tube Technique

Preston (1954), developed a simple technique for measuring local shear ($\tau 0$) in a turbulent boundary layer using a pitot (preston) tube. The tube is taken in contact with the surface. From the differential pressure (Δp) between total and static pressure at the wall the velocity distribution at the wall is calculated. Preston suggested a non- dimensional relationship between differential pressure (Δp) and local shear ($\tau 0$) as:

$(\Delta p * d^2) / \rho \upsilon^2 = F (d^2 \tau_0 / \rho \upsilon^2)$ (2)

Where υ is kinematic viscosity of fluid, ρ is density of fluid and d is diameter of priston tube and functional relationship F needs to be determined. Preston proposed the following calibration equation

$y' = 0.875x' - 1.396$ for $4.1 \leq x' \leq 6.5$ (3)

$where\ x' = log10(\frac{\Delta p d2}{4\rho \upsilon 2})$ and $y' = log10\ ((\tau_0 d^2)/(4\rho \upsilon^2))$

Patel (1965), proposed a relationship for F in Eq (2) valid in three ranges (y' between 1 . 5 - 5 . 5) Where ρ, υ, d denote the same as previous.

$y' = 0.5x' + 0.037$ For $y' \leq 1.5$ (4.a)

$y' = 0.8272 - 0.1381x' + 0.1437x'^2 - 0.006x'^3$ For $1.5 < y' \leq 3.5$ (4.b)

$x' = y' + 2log10\ (1.95y' + 4.10)$ For $3.5 < y' \leq 5.5$ (4.c)

CHAPTER-4

NUMERICAL

MODELLING

4.1 DESCRIPTION OF NUMERICAL MODEL PARAMETERS

In the present work,Computational Fluid Dynamics tool is used for model verification which is based on the three dimensional form of Navier-Stokes equations. Computational Fluid Dynamics uses numerical methods and algorithms to solve and analyse problems that involve fluid flows. Computers have been used to execute the calculations necessary to simulate the contact of liquids and gases with surfaces defined by boundary conditions. The CFD based simulation relies on numerical accuracy, modelling precision and computational cost.

Generally (FVM) is used in CFD. Both structured and unstructured grids are used in fluent. In free surface modelling the governing equations are discretized in both space and time e.g VOF and height of liquid. Here the k € model is used for turbulence modelling and equations are discretized in both space and time. Here the PISO algorithms is used to solve the link between pressure and velocity field. To calculate the transient problem and to converge the problems faster this noniterative solution method PISO is used. The mathematical result is said to be converged when the solution bears a constant value with further iterations or the residuals reach a value of 0.001.

4.2 TURBULENCE MODELLING

“Turbulence is an irregular motion which in general makes it appear as fluid, gas or liquid, Even if they flow past or solid surface of even when neighbouring streams of the same fluid past or over one another.” ***GI Taylor and von Karman, 1937.***

The flow in a compound channel is turbulent in nature. Channel geometry or shape in accordance with gravitational force is mainly responsible for the turbulent flow. Turbulent flow is a flow regime characterized by stochastic and chaotic property changes. This includes rapid variation of pressure and velocity in space and time with low momentum diffusion and high momentum convection. When the inertia forces in the fluid become significant and is characterized by a high Reynolds number then, turbulence occurs. Generally turbulence is a three dimensional time dependent motion with many large scales eddies. The three dimensional nature of turbulent flows are decomposed in two different parts i.e. mean part and fluctuation part which is also known as Reynolds decomposition. In turbulence, separated fluid particles are brought close together by eddying motion which causes the effective exchange of mass, momentum and heat. The turbulence in compound channel is quite complex and the flow structure involved in it creates uncertainty in prediction of flow variables. Particularly in compound channel due to the difference in velocity between main channel and floodplain, turbulent structures are generated creating large shear layer at the interface. Due to this large shear layer vortices both in longitudinal as well as in vertical direction is created. Secondary currents are created due to anisotropy and inhomogeneity of turbulent structure. CFD considers the instantaneous velocity and a fluctuating velocity component in case of turbulence.

Instantaneous velocity = mean velocity + fluctuating velocity given as

$$u = \bar{u} + u' \tag{4.1}$$

The Navier-Stokes momentum equation is taken as:

$$\frac{\partial \rho u_i u_j}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\mu \frac{\partial u_i}{\partial x_j}\right) \tag{4.2}$$

By substituting $\bar{u} + u'$ for u in equation (4.2) and averaging the term we get

$$\overline{\frac{\partial u}{\partial x}} = \frac{\overline{\partial(\bar{u}+u')}}{\partial x} = \frac{\partial \bar{u}}{\partial x} \tag{4.3}$$

For non-linear function the equation (1) becomes

$$\frac{\partial(uu)}{\partial x} = \frac{\partial(\overline{u}\overline{u})}{\partial x} + \frac{\partial \overline{u'u'}}{\partial x} \qquad (4.4)$$

Now the Navier-Stokes equation becomes:

$$\frac{\partial \overline{u_j}}{\partial x_j} = 0 \qquad (4.5)$$

$$\frac{\partial \rho \overline{u_i}\,\overline{u_j}}{\partial x_j} = -\frac{\partial \overline{p}}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\mu \frac{\partial \overline{u_i}}{\partial x_j}\right) - \frac{\partial \rho(u_i' u_j')}{\partial x_j} \qquad (4.6)$$

$\frac{\partial \rho\left(u_i' u_j'\right)}{\partial x_j}$ is known as the "Reynolds stress". Due to the closer problem of both the equation (4.5) and (4.6) we have to come up with ways of replacing the extra terms with other terms that were known or devising ways of calculating these terms.

A first attempt at closing the equations is

$$\frac{\partial}{\partial x_j}\left(\mu \frac{\partial \overline{u_i}}{\partial x_j}\right) = \frac{\partial \rho\left(u_i' u_j'\right)}{\partial x_j} \qquad (4.7)$$

In above equation (4.7) both terms represent a diffusion of energy. The term $\frac{\partial}{\partial x_j}\left(\mu \frac{\partial \overline{u_i}}{\partial x_j}\right)$ Represents diffusion of energy through viscosity and the other term $\frac{\partial \rho\left(u_i' u_j'\right)}{\partial x_j}$ represents the diffusion through turbulence. By defining μ_t as turbulent viscosity, equation (4.6) becomes

$$\frac{\partial \rho \overline{u_i}\,\overline{u_j}}{\partial x_j} = -\frac{\partial \overline{p}}{\partial x_i} + \frac{\partial}{\partial x_j}\left((\mu + \mu_t) \frac{\partial \overline{u_i}}{\partial x_j}\right) \qquad (4.8)$$

Most turbulence models are statistical turbulence model ,as mentioned below,

Turbulence models

- Algebraic (zero-equation) model.
- k-ε, RNG k-ε model.

- Shear stress transport model.
- K-ω model.
- Reynolds stress transport model (second moment closure).
- K-ω Reynolds stress.
- Detached eddy simulation (DES) turbulence model.
- SST scale adaptive simulation (SAS) turbulence model.
- Smagorinsky large eddy simulation model (LES).
- Scalable wall functions.
- Automatic near-wall treatment including integration to the wall.
- User-defined turbulent wall functions and heat transfer.

4.3 GOVERNING EQUATION

The governing equation used here is based on conservation of mass, momentum and energy. The C.F.D package, namely Fluent was employed to solve the governing equations, which uses Finite Volume Method (FVM) to solve the equations. FVM involves discretization and integration of the governing equations over the control volume. The numerical method FVM was based on the integral conservation, which is applied for solving the partial difference, i.e. Navier-Stokes equation then calculates the values of the variables, averaged across the volume. The integration of the equations over each control volume results in a balance equation. The conservation law is enforced on small control a volume which is defined by computational mesh. The set of balance equations then discretized with respect to a set of discretization schemes and is solved by using the initial and boundary conditions.

The governing Reynolds Averaged Navier-Stokes and continuity equations are related as

$$\frac{\partial(\rho)}{\partial t} + \frac{\partial(\rho u_i)}{\partial x_i} = S_m \tag{4.9}$$

$$\frac{\partial(\rho u_i)}{\partial t}+\frac{\partial(\rho u_i u_j)}{\partial x_j} u_i = -\frac{\partial p}{\partial x_i}+\frac{\partial}{\partial x_j}\mu\left[\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right]+\frac{\partial(-\rho\overline{u_i' u_j'})}{\partial x_j} \quad (4.10)$$

Where t=time, u_i=i-th component of the Reynolds-averaged velocity, x_i=i-th axis, ρ=water density, p= Reynolds averaged pressure, g=acceleration due to gravity, μ=viscosity (here it is equal to zero),

S_mA =mass exchange between two phases (water and air). Here for unsteady solves the time-averaged values of velocities and other solution variables are taken instead of instantaneous values. The term $\left(-\rho\overline{u_i' u_j'}\right)$ is called as Reynolds Stress. To link the mean rate of deformation with Reynolds stresses, Boussinesq hypothesis is used:

$$-\rho u_i' u_j' = \mu_t\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right) \quad (4.11)$$

Where μ_t=the turbulent viscosity.

4.4 NUMERICAL SIMULATION

4.4.1 Methodology:

The process of the numerical simulation of fluid flow using the above equation generally involves four different steps and the details are given below.

a) *Problem identification*

1. Defining the modelling goals

2. Identifying the domain to model

(b) *Pre-Processing*

1. Creating a solid model to represent the domain (Geometry Setup)

2. Design and create the mesh (grid)

(c) *Solver*

1. Set up the physics

- ☐ Defining the condition of flow (e.g. turbulent, laminar etc.)
- ☐ Specification of appropriate boundary condition and temporal condition.

2. Using different numerical schemes to discretize the governing equations.

3. Controlling the convergence by iterating the equation till accuracy is achieved

4. Compute Solution by Solver Setting.

- Initialization
- Solution Control
- Monitoring Solution

(d) *Post processing*

1. Visualizing and examining the results

2. X-Y Plots

3. Contour Draw

4.4.2 Preprocessing

In this initial step all the necessary information which defines the problem is assigned by the user. This consists of geometry, the properties of the computational grid, various models to be used, and the number of Eulerian phases, the time step and the numerical schemes.

4.4.2.1 Creation Geometry

The first step in CFD analysis is the explanation and creation of computational geometry of the fluid flow region. A consistent frame of reference for coordinate axis was adopted for creation of geometry. Here in coordinating system, Z axis corresponded the stream wise direction of fluid flow. X axis aligned with the lateral direction which indicates the width of channel bed and Y axis represented the vertical component or aligned with depth of water in the channel. The origin was placed at the upstream boundary and coincided with the base of the centre line of the channel. The water flowed along the positive direction of the Z-axis.

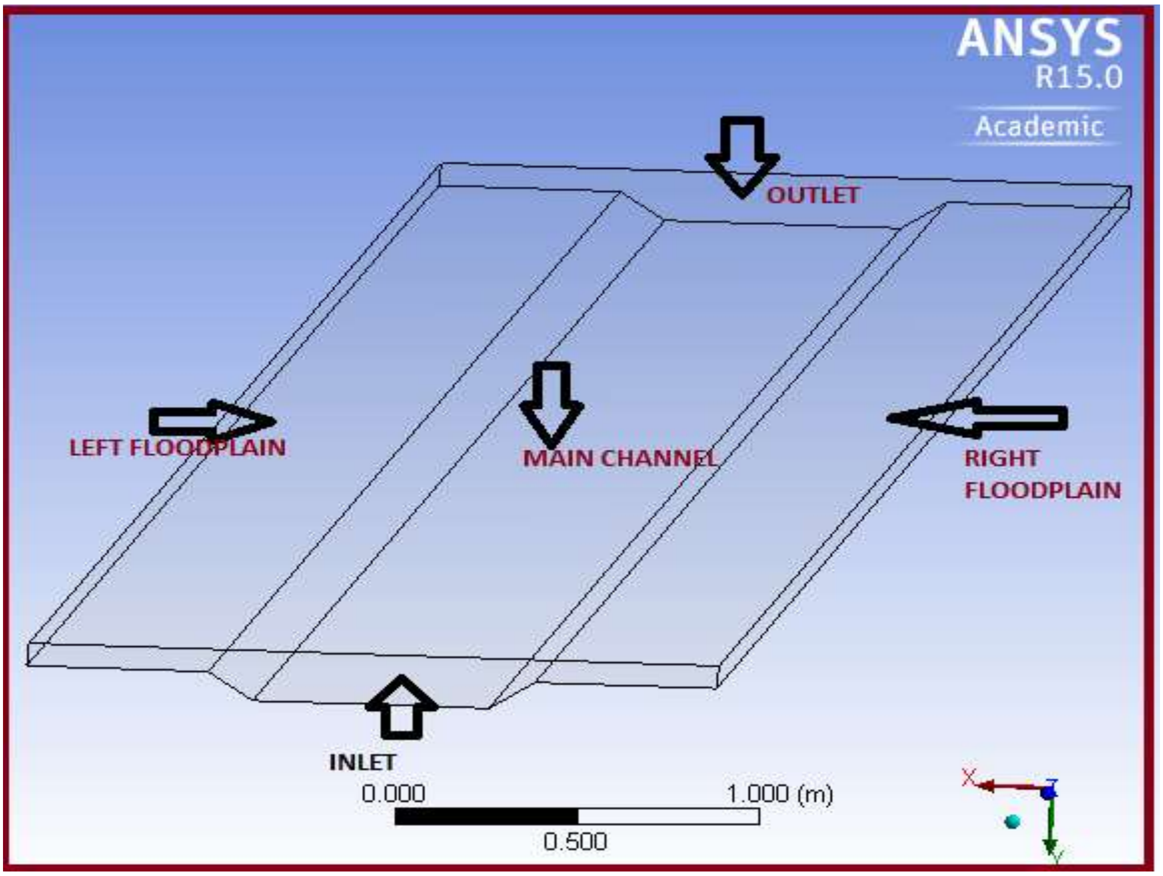


Fig 4.1 Geometry set up of a compound channel

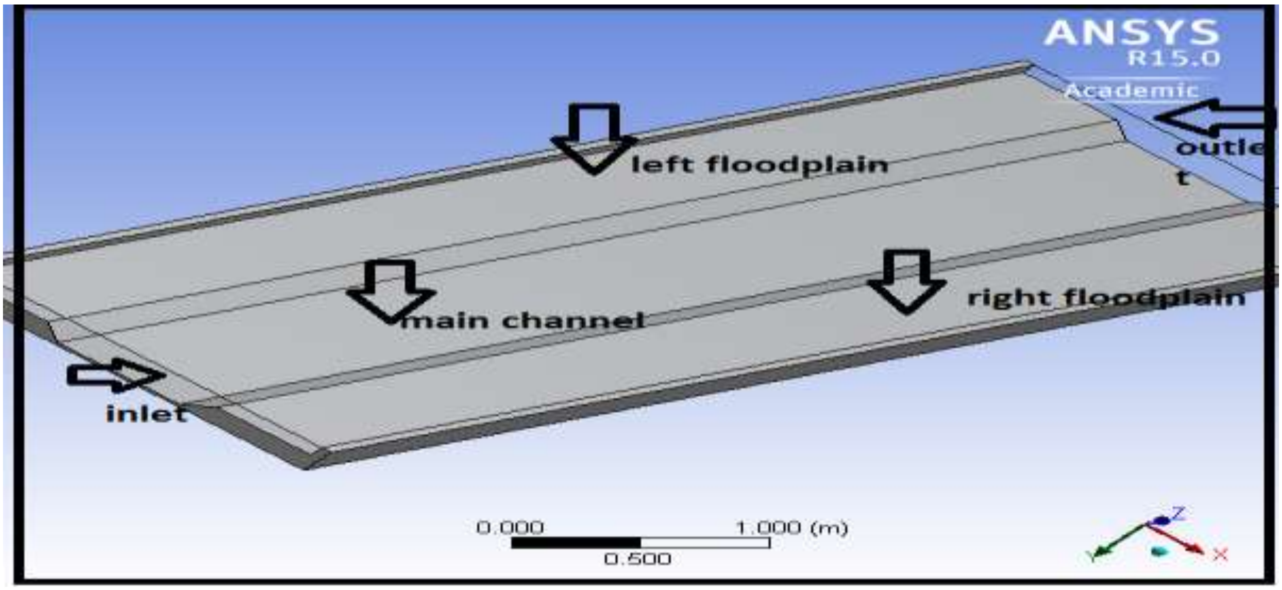


Fig 4.2 Geometry of a compound channel

It can be seen from the above figure that the channel geometries were 15 m lengh ,1.9 m width and 0.275m height. In a straight trapezoidal compound channel the width of the main channel is 0.65 at bottom and 0.9 at top and main channel height is 0.125m. the width of the both left and right floodplain symmetric channel is 0.5m.

4.4.2.2 Mesh Generation

Second and very most important step in numerical analysis is setting up the grid associated with the construction of geometry. The Navier-Stokes Equations are non-linear partial differential equations, which consider the whole fluid domain as a continuum. In order to simplify the problem the equations are simplified as simple flows have been directly solved at very low Reynolds numbers. The simplification can be made using what is called discretization. Construction of mesh involves discretizing or subdividing the geometry into the cells or elements at which the variables will be computed numerically. By using the Cartesian co-ordinate system, the fluid flow governing equations i.e. momentum equation, continuity equation are solved based on the discretization of domain. The CFD analysis needs a spatial discretization scheme and time marching scheme. Meshing divides the continuum into finite number of nodes. Generally the domains are discretized by three different ways i.e. Finite element, Finite Volume and Finite Difference Method. Finite element method is based on dividing the domain into elements. In finite element method the numerical solutions are obtained by integrating the shape function and weighted factor in an appropriate domain. This method is suitable for both structured and unstructured mesh. But the Finite Volume method divides the domain into finite number of volumes. Finite volume method solves the discretization equation in the center of the cell and calculates some specified variables. The values of quantities, such as pressure, density and velocity that are present in the equations to be solved are stored at the center of each volume. The flux into a region is calculated as the sum of the fluxes at the boundaries of that region. As the values of quantities are stored at nodes but not at boundaries this method requires some interpolation at nodes. Generally finite Volume method is suitable for unstructured domain. Whereas finite Difference method is based on approximation of Taylor's series. This method is more suitable for regular domain. For transient problems an appropriate time step needs to be specified. To capture the required features of fluid flow with in a domain, the time step should be sufficiently small but not too much small which may cause waste of computational power and time. Spatial and time discretization are linked, as evident in the Courant number.

4.4.2.2.1 Courant Number

A criterion often used to determine time step size is known as Courant number. The Courant number stops the time step from being large enough for information to travel entirely through one cell during one iteration. For explicit time stepping schemes Courant number should not be greater than 1. For implicit time stepping schemes this number may be higher than 1.

The Courant number is defined a

$$C_r = \frac{\bar{U}\Delta t}{\Delta l} \qquad (4.12)$$

Where C_r is the Courant number, $\bar{U}$ is the average velocity, Δt is the maximum time step size and Δl is the largest grid cell size along the direction of flow.

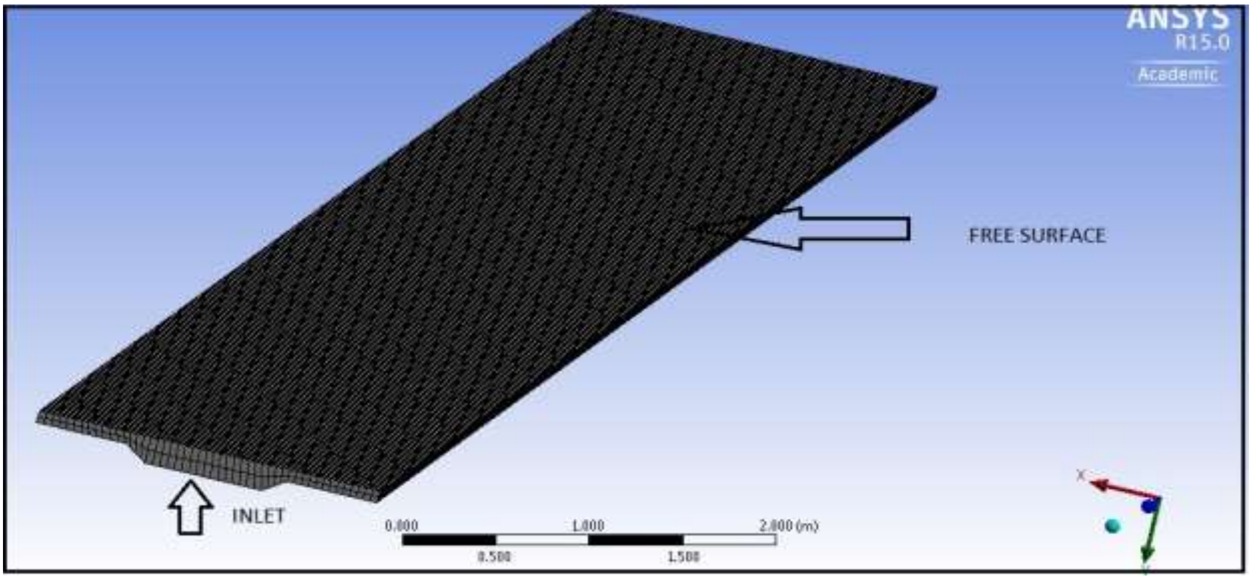


Fig- 4.3 schematic view of grid used in numerical model

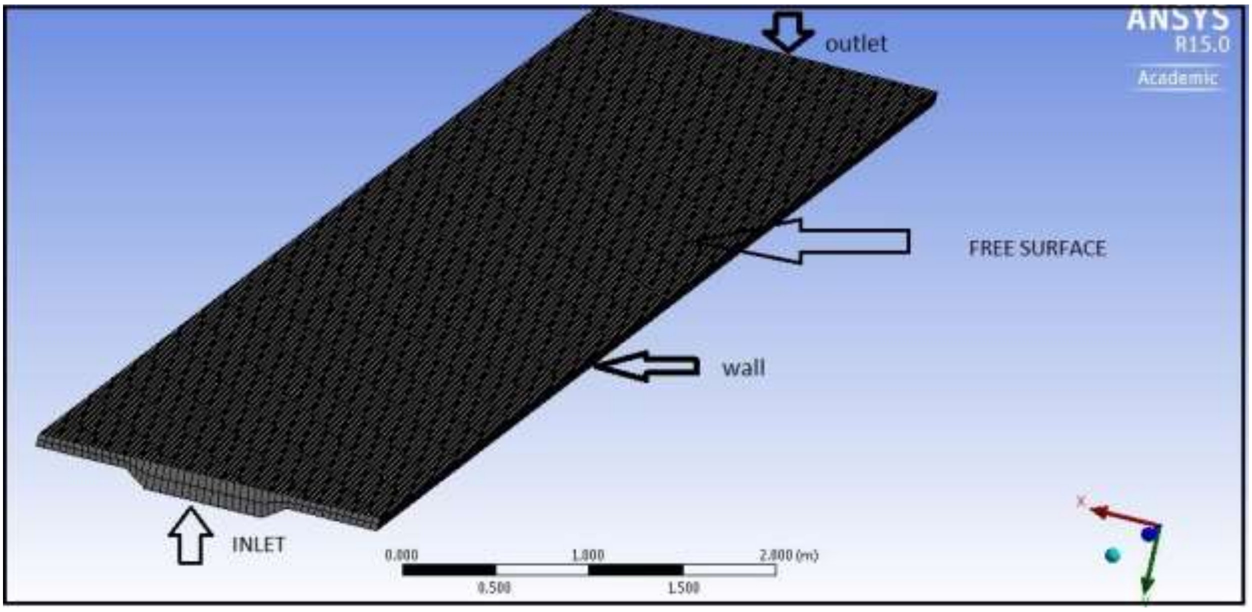


Fig 4.4 schematic view of grid showing inlet, outlet, free surface, wall

4.4.3 Setup Physics

For a given computational domain, boundary conditions are imposed which can sometimes over specify or under-specify the problem. Usually, after imposing boundary conditions in non-physical domain may lead to failure of the solution to converge. It is therefore important, to understand the meaning of well-posed boundary conditions.

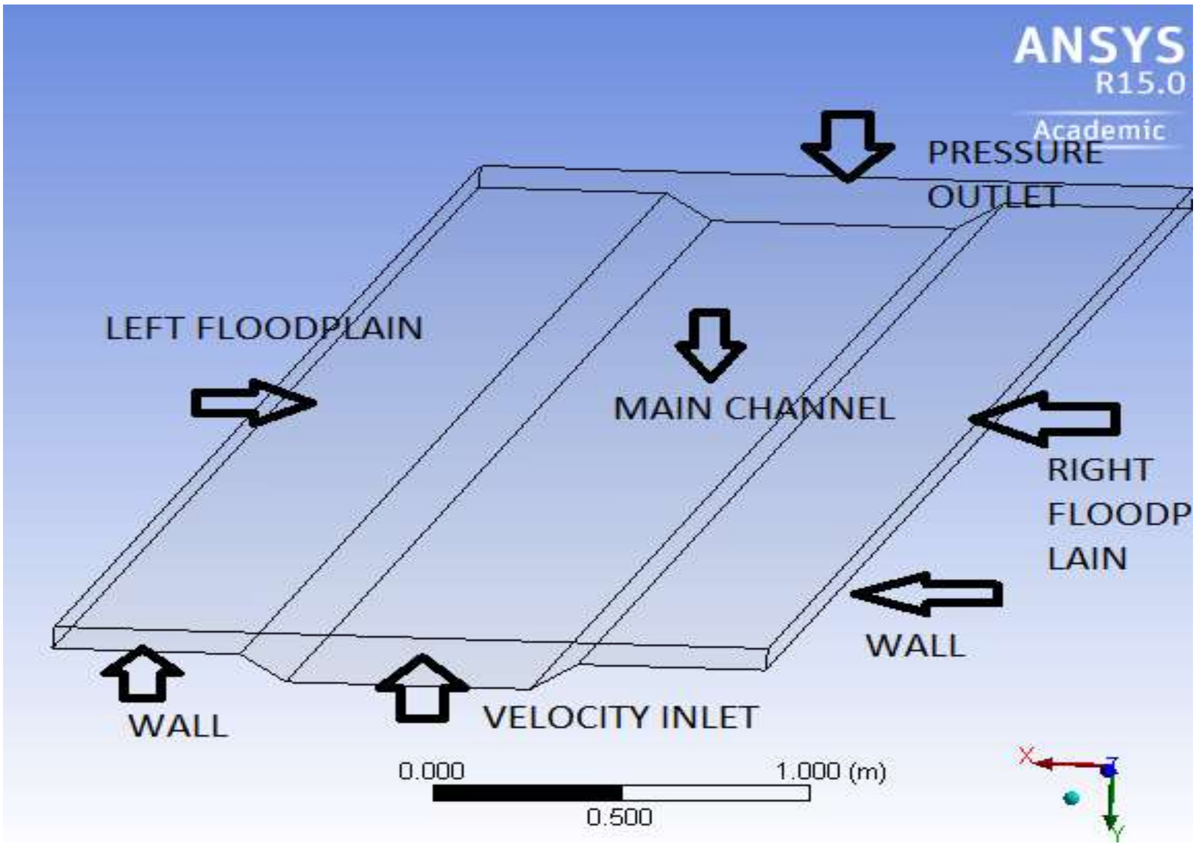


Fig 4.5 Schematic diagram of compound channel with boundary condition

4.4.3.1 Inlet and Outlet Boundary Condition

All of the channels reported were performed with translational periodic boundaries in the stream wise direction of the flow which allow the values on the inlet and outlet boundaries to coincide. Further the pressure gradient was specified across the domain to drive the flow. To initialize the flow, a mean velocity is specified over the whole inlet plane upon which velocity fluctuations are imposed. The inlet mean velocities are derived from the experimental average values. The mean velocities are specified over the whole inlet plane and is computed by $U_{in} = Q/A$, where Q is the flow discharge of the channel and A is the cross sectional area of the inlet. In order to simplify slope changes and specify pressure gradient the channel geometries were all created flat. The effects of gravity and channel slope implemented via a resolved gravity vector. Here the angle θ represents the angle between the bed of the channel and the horizontal, the gravity vector is resolved in x, y and z components as

($\rho g \sin\theta, 0 - \rho g \cos\theta$) (4.13)

Where θ = angle between bed surface to horizontal axis and tan θ= slope of the channel.

Here, x component causes the direction responsible for flow of water along the channel and the z the component is responsible for creating the hydrostatic pressure upon the channel bed. From the simulation, ”z” component of the gravity vector ($-\rho g \cos\theta$) is found to be responsible for the convergence problem of the solver.

4.4.3.2 Wall

No slip wall condition is used for channel walls, bottom and side walls. A no-slip boundary condition is the most common boundary condition implemented at the wall and prescribes that the fluid next to the wall assumes the velocity at the wall,which is zero i.e

$U= V = W = 0$ (4.14)

4.4.3.3 Free surface

Here the boundary condition which is used for free surface is symmetry condition. This signifies at the wall the shear stress is zero . The stream wise and lateral velocities of the fluid near the wall are not retarded by wall friction effects as with a no-slip boundary condition. This shows that across the boundary no flow of scalar flux occurs.

CHAPTER-5

RESULTS

&

DISCUSSION

In chapter 3 the experimental procedures have been described. In this chapter the results of experiments conducted in NIT Rourkela will be presented. The primary aim of this research is to investigate the effect of the differential roughness on flow characteristics in compound channel. Based on the analysis of the test results from two different differential conditions, a cumulative summary discussing the results and common findings of all the experiments are described.

5.1 STAGE DISCHARGE RESULTS

Stage discharge relationship is one of the most important relationships for a River Engineer which is required for design and flood management purposes. It is possible to predict the discharge and channel capacity from the stage discharge data.

In the present investigation an overall steady and uniform flow during experimentation was maintained. The bed slope of the compound channel was measured (section 3.4). The slope was kept constant in the present study. For discharge measurements the volumetric tank was constructed in the Fluid Mechanics Laboratory which is of area 20.928784m$^{2.}$ Height of water in volumetric tank was monitored in a glass tube water level indicator attached to it. The change in the depth of water in the volumetric tank with time was measured with the help of a stopwatch having accuracy of 0.01 sec. The discharge into the volumetric tank was measured by the time to rise method. The depth of flow on main channel (H) was taken as the stage, which gave particular discharge under steady and uniform condition.

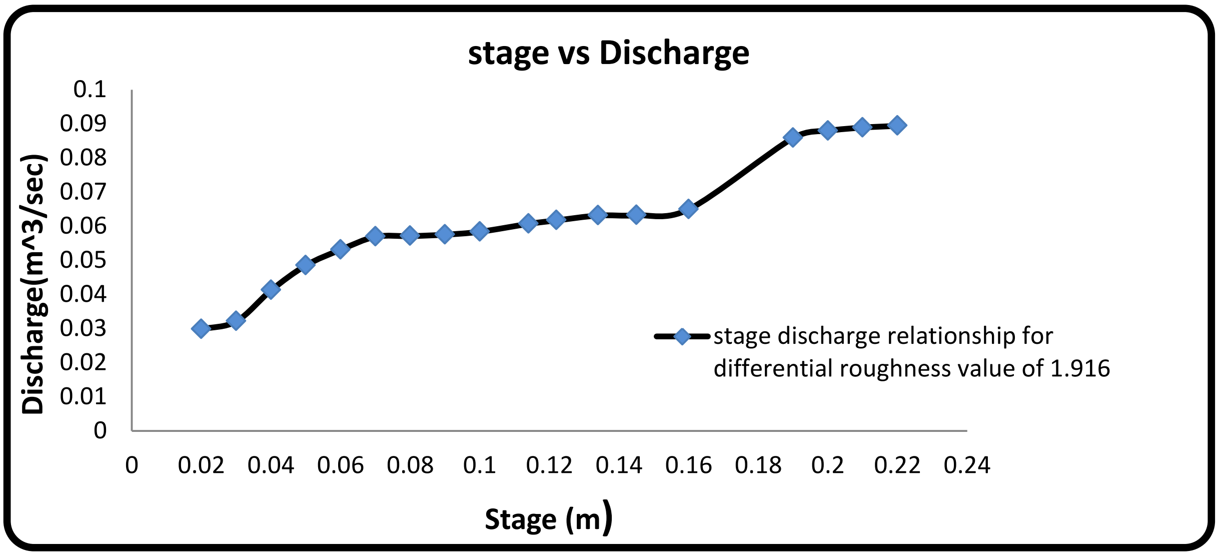


Fig-5.1 Stage discharge relationship for differential roughness(ϒ) value of 1.916

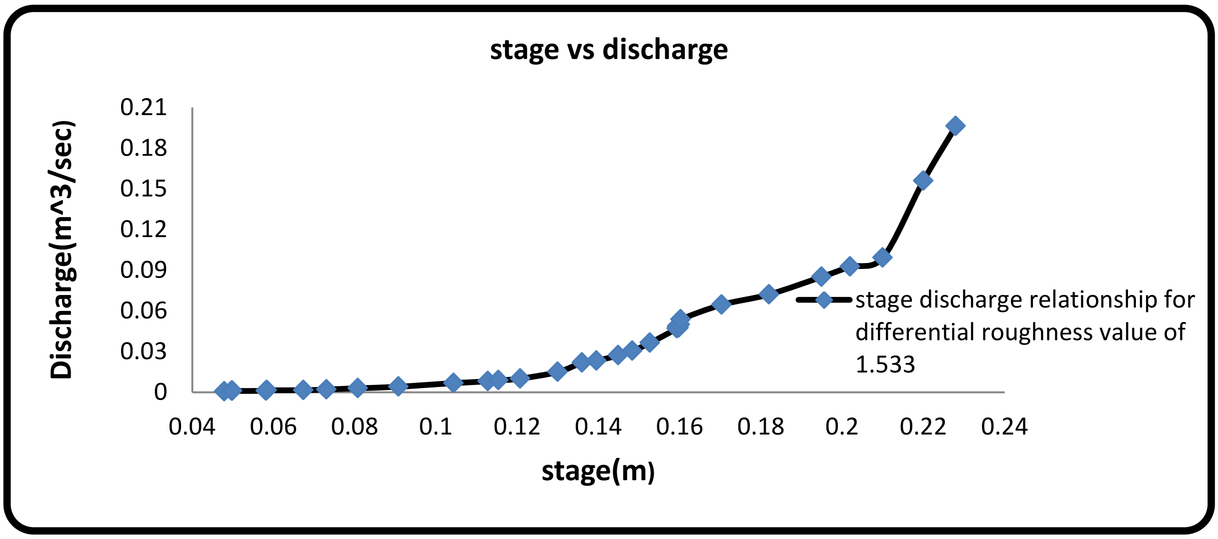


Fig -5.2 Stage discharge relationship for differential roughness (ϒ) value of 1.533

The overall discharge increases for increasing depth of flow and decreases with the increase in differential roughness. For a constant depth of flow, discharge decreases with the increase in differential roughness.

5.2 DISTRIBUTION OF LONGITUDINAL DEPTH AVERAGED VELOCITY RESULTS IN LATERAL DIRECTION.

The distribution of depth averaged velocity at a section 7.5m away from the inlet along lateral direction is measured under two differential conditions of flow with different depth of flow also. It is required to know the average velocity of flow at each specified section of the channel which is helpful in calculating the discharge.

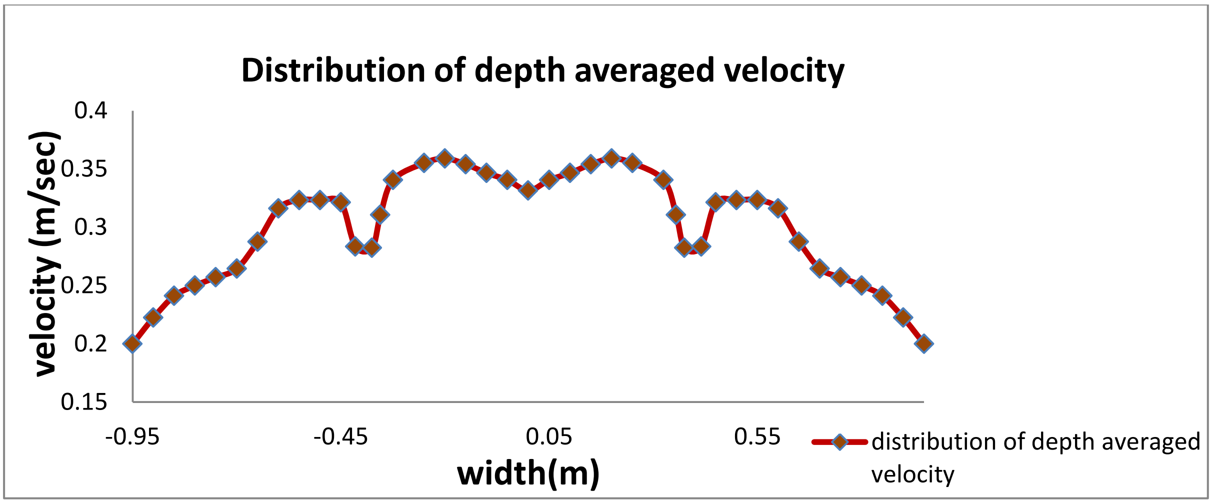


Fig-5.3 Distribution of depth averaged velocity with relative depth 0.451 with differential roughness 1.916

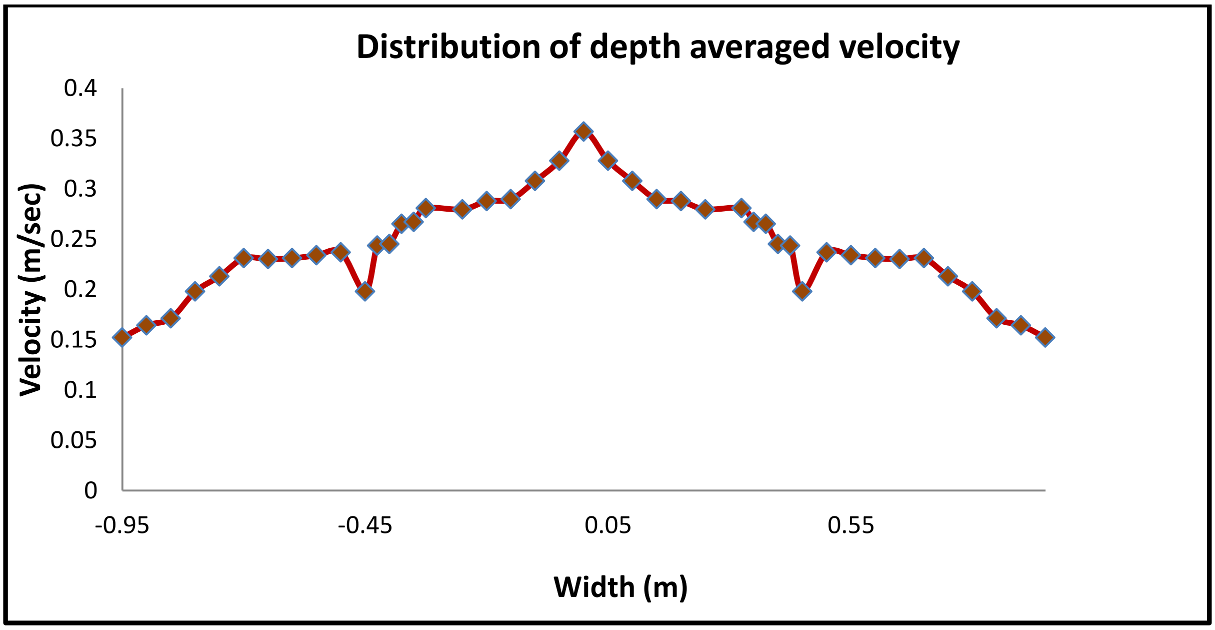


Fig 5.4 Distribution of depth averaged velocity with relative depth 0.218 with differential roughness 1.533

A general procedure for determining the depth- averaged velocity is to average the velocity measured at 0.2d and 0.8d from the water surface, or the velocity measured at 0.6d from the water surface.(where d= depth of flow on a surface) .Here the depth averaged velocity was measured at 0.6d from the water surface.

- The variation of depth averaged velocity, in main channel and floodplain region is minimum for uniform roughness. The variation increases with increase in differential roughness.
- The depth-averaged velocity in main channel decreases with the increase in relative depth.
- The resistance to flow on floodplain by floodplain surface decreases with increase in differential roughness.

5.3 VELOCITY CONTOUR

In this present work , the velocity contour across the cross section were found out by using ADV for overbank flow condition. For mapping of contour the middle of the contour is taken as origin and base as datum.

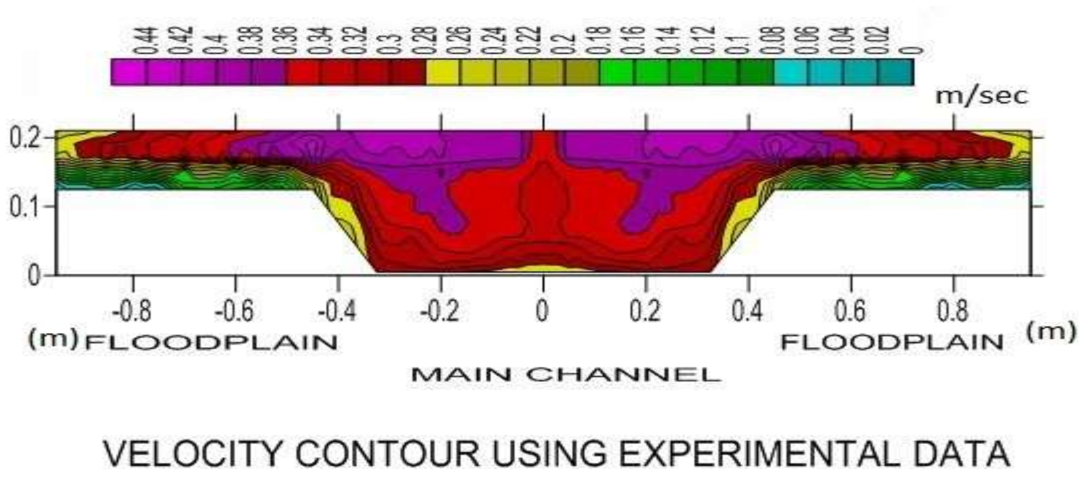


Fig -5.5 Velocity contour for relative depth 0.451 with differential roughness of 1.916

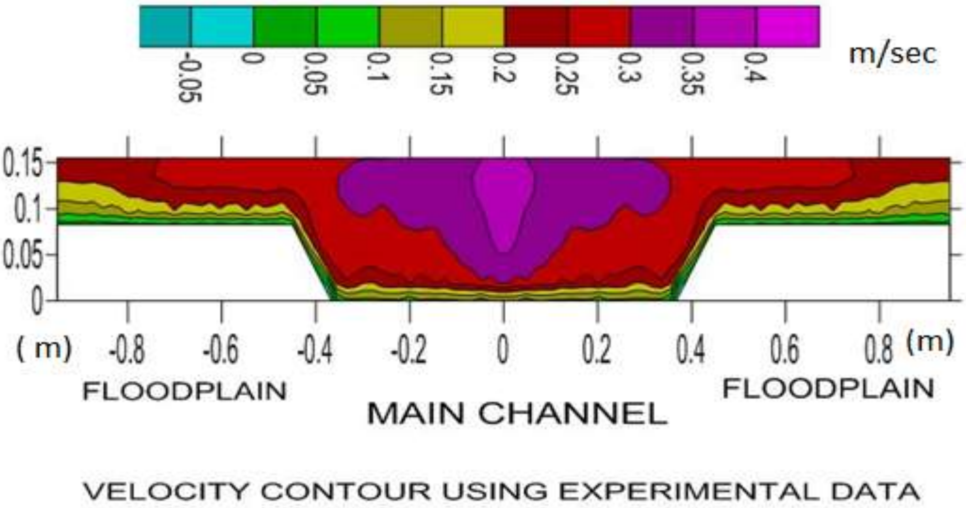


Fig- 5.6 Velocity contour for relative depth 0.218 with differential roughness of 1.533

- The velocity variation on floodplain gradually becomes stabilised with the increase in depth of flow.
- The maximum concentration of lower velocity contour is found in floodplain.
- For ϒ= 1.916, the value of maximum velocity contours is found more than that of ϒ=1.533.
- For ϒ=1.916 , the overall concentration of higher velocity contours in main channel is found more than that of ϒ=1.533.
- The overall variation in velocity increases with the increase in depth of flow.
- The variation of velocity in main channel increases for growing depth of flow.
- Concentration of higher velocity contours on floodplain gradually increases with the increase in depth of flow.

5.5 COMPARISON OF VELOCITY CONTOUR WITH ANSYS RESULTS

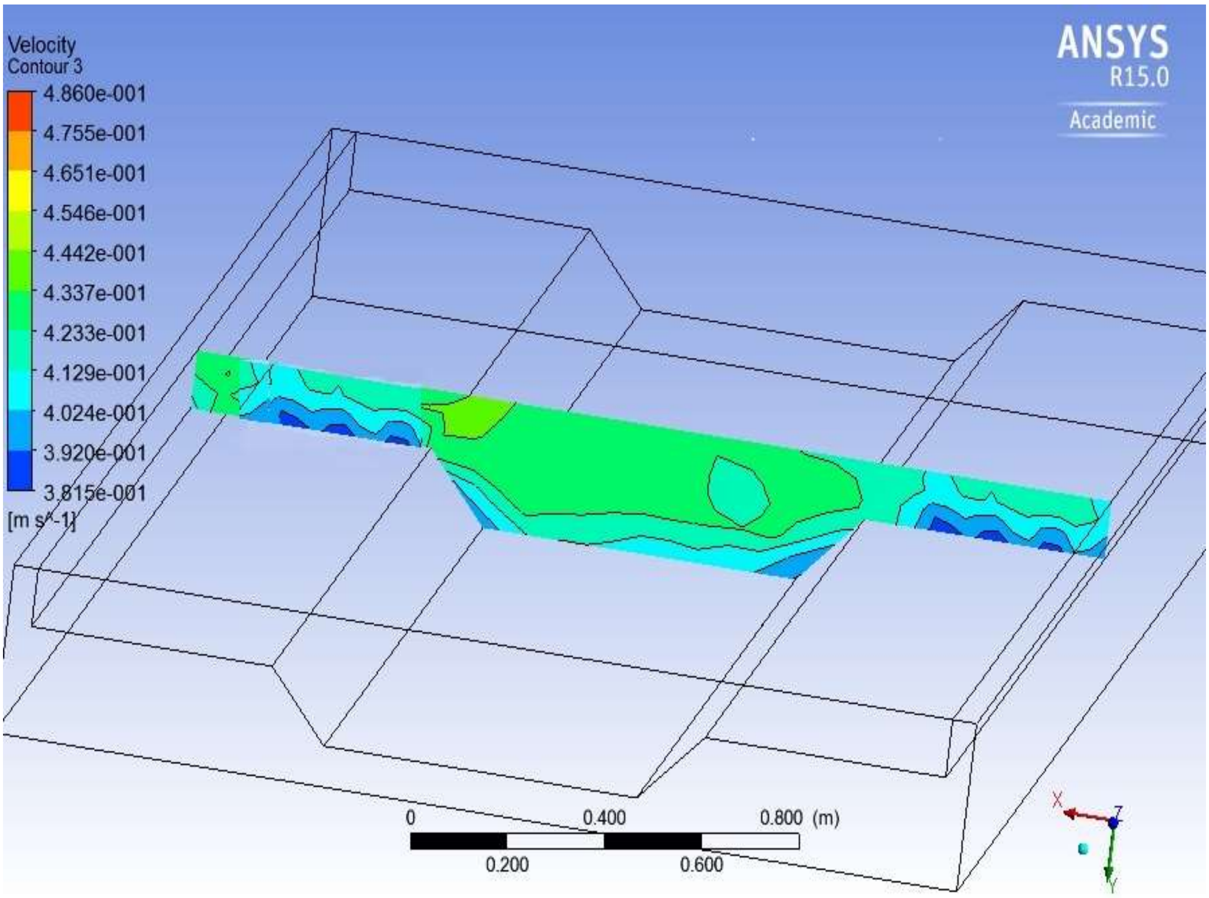


Fig 5.7 Velocity contour in ANSYS for relative depth 0.451 and differential roughness 1.916

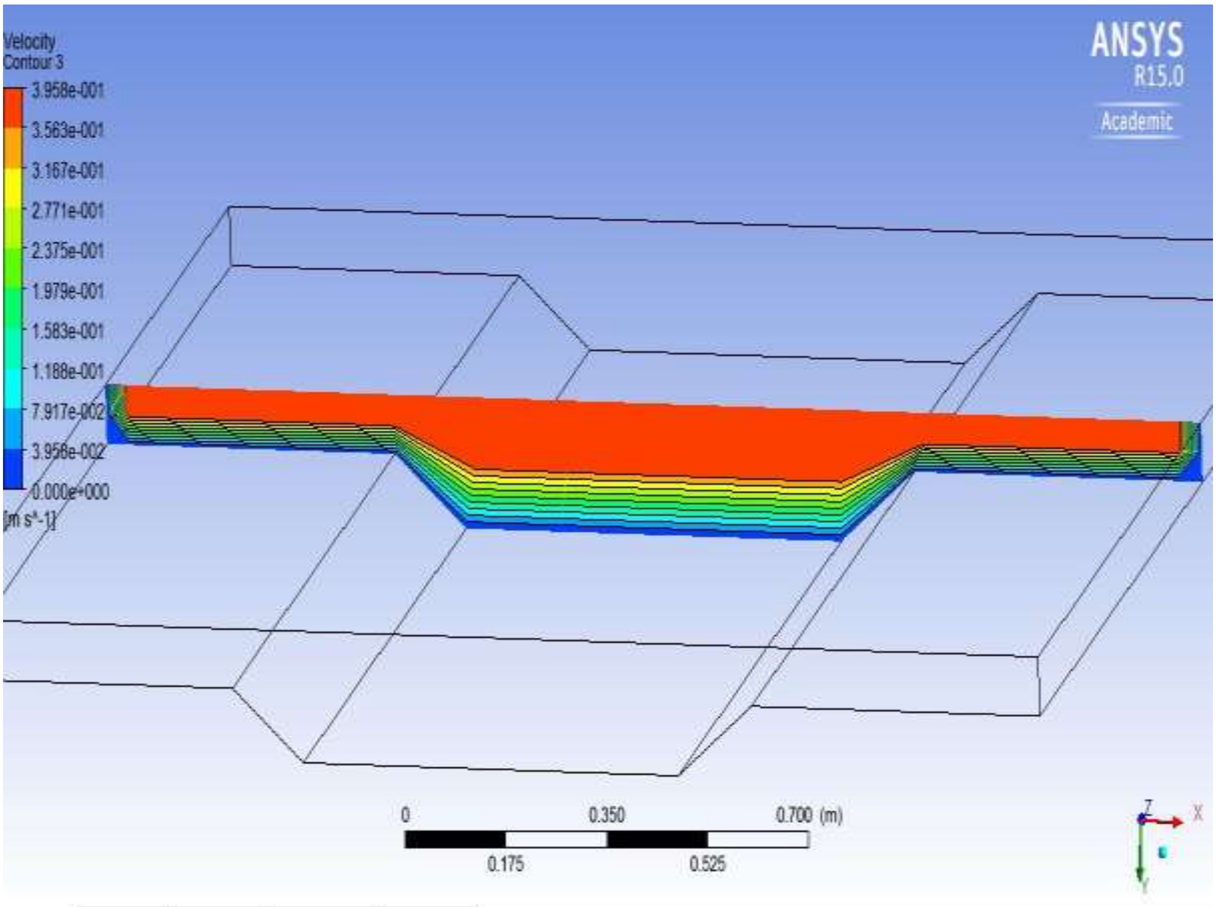


Fig 5.8 Velocity contour in ANSYS for relative depth 0.218 and differential roughness 1.533

5.4 COMPARISON OF DEPTH AVERAGED VELOCITY DISTRIBUTION WITH ANSYS RESULTS

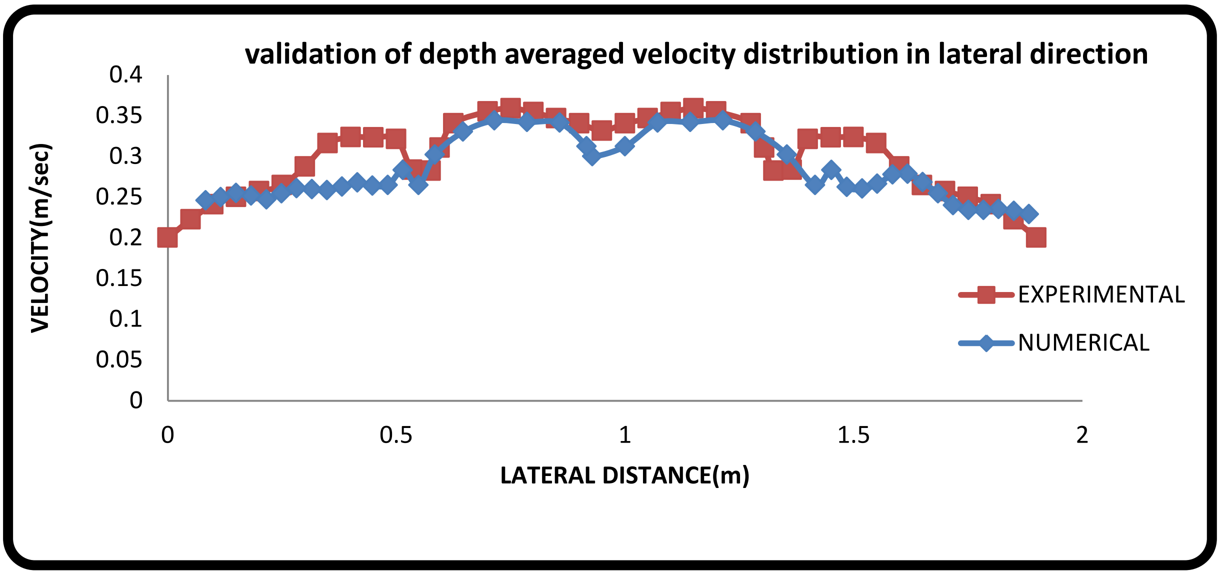


Fig 5.9 Distribution of depth averaged velocity distribution with relative depth 0.451 and differential roughness of 1.916

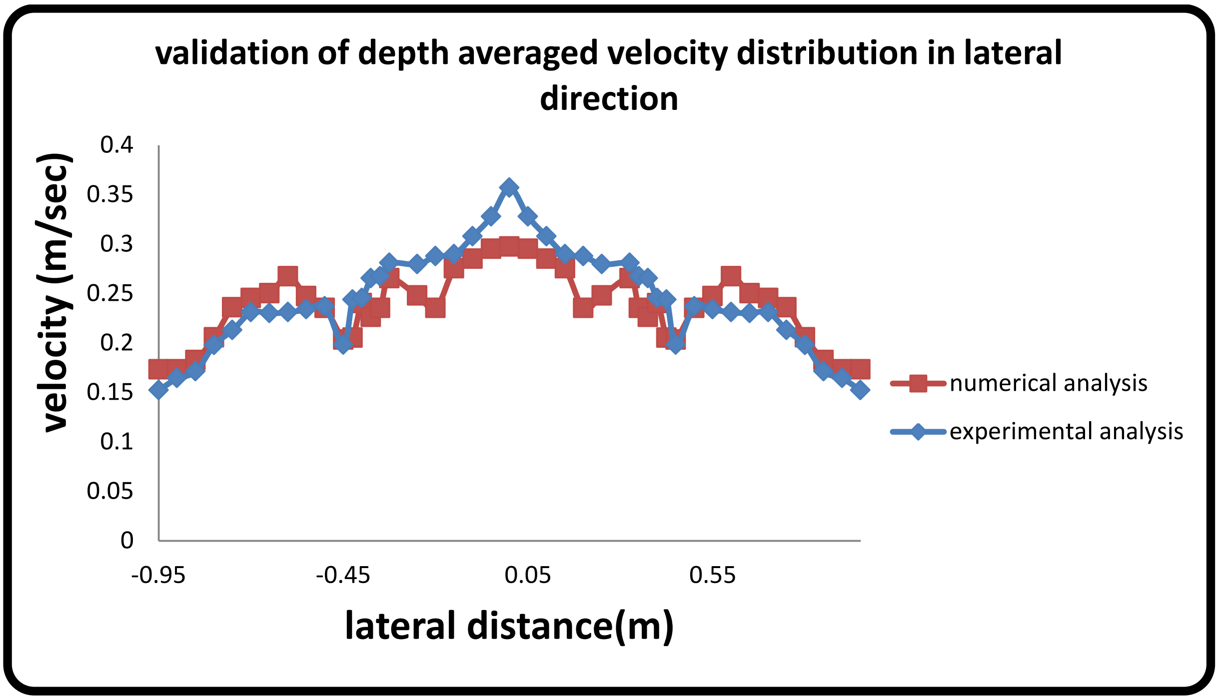


Fig 5.10 Distribution of depth averaged velocity distribution in lateral direction with relative depth 0.218 and differential roughness 1.533

5.5 BOUNDARY SHEAR

Due to no slip condition or law of wall velocity of fluid adjacent to wall is zero but at a distance farther away from the boundary a velocity exist for the flowing fluid. So due to this variation of velocity between the layers of fluid a velocity gradient exist. Because of this velocity gradient a shear stress is seen.

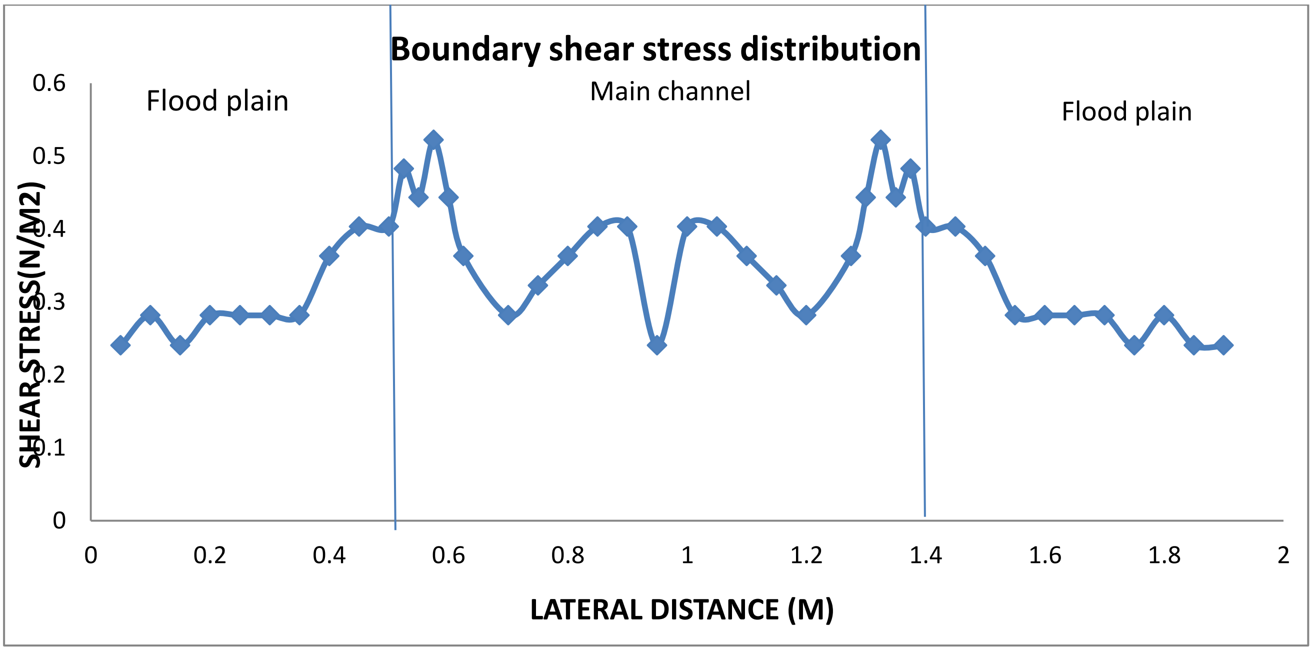


Fig 5.11 Boundary shear stress distribution for relative depth 0.218 with ϒ=1.533

Here boundary shear at the interface region is found higher than the other region because of high relative velocity at junction and higher momentum transfer. As it is a symmetric channel the distribution is uniform from main channel mid-section. At main channel mid-section the velocity is higher but the relative velocity is not found higher so the bed shear value is less.

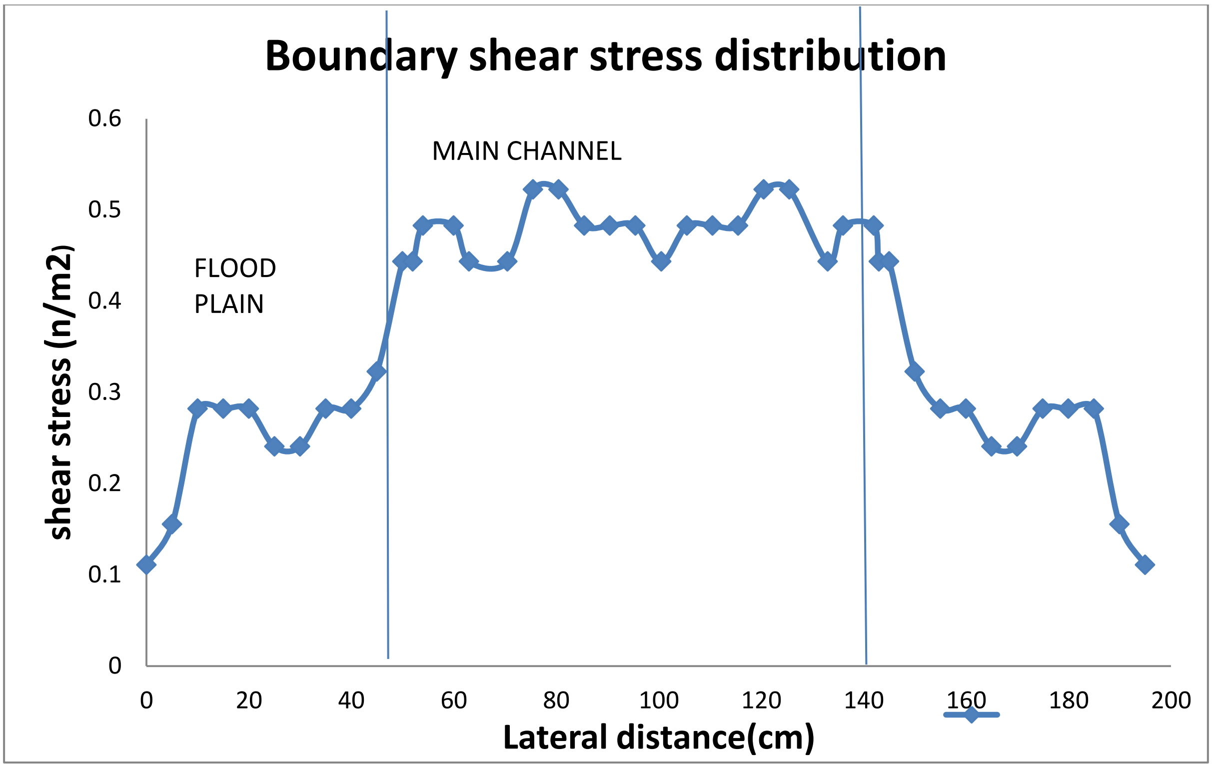


Fig 5.12 Boundary shear stress distribution for relative depth 0.451 with ϒ=1.916

5.6 LONGITUDINAL VELOCITY PROFILES

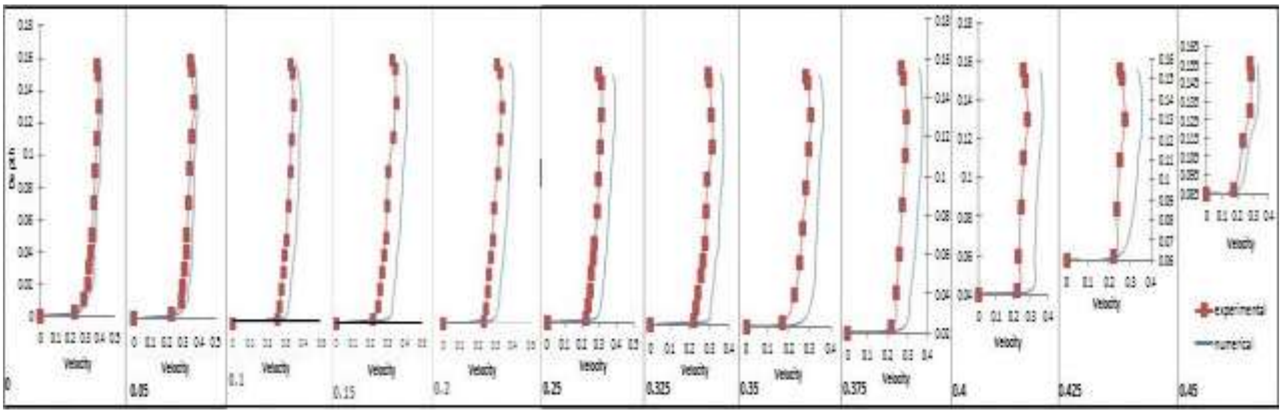


Fig- 5.13 longitudinal velocity profiles along lateral direction in main channel for relative depth of 0.218 with ϒ=1.533

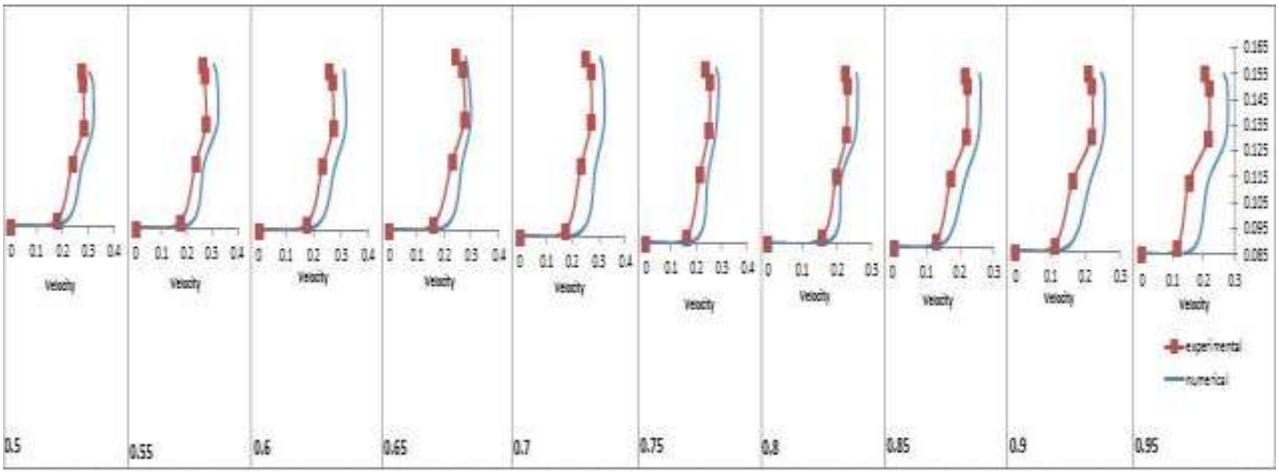


Fig-5.14 Longitudinal velocity profiles along lateral direction in floodplain for relative depth of 0.218 with ϒ=1.533

Here it is seen from the velocity profile as the depth increases the velocity increases. The highest value of velocity occurs at a height of 0.8H from the bottom of the bed of the main channel. Similarly the heighest value of velocity occurs at the top point for the floodplain height. However for the floodplain height heighest value of velocity occurs at 0.6(H-h) from the bottom of the floodplain depending upon the flow depth over floodplain.

CHAPTER 6

CONCLUSIONS

To observe the result of differential roughness on flow characteristics during overbank flow in a compound channel laboratory experiments has been carried out and the following conclusions can be drawn.

From the results of stage-discharge relationship, it can be concluded that

- With the increase in depth of flow, discharge increases.
- For a constant depth of flow, discharge decreases with the increase in differential roughness.
- The roughness effect on flow decreases slowly with the increase in depth of flow.
- The overall discharge are found to increase with the increase in depth of flow and decrease with the increase in differential roughness; this is due to the reason that the effect of differential roughness as well as that of the momentum transfer between main channel and floodplain decreases as depth of flow increases.

From the results of depth averaged velocity ,it can be concluded that:

- Depth averaged velocity in main channel region found to decrease with the increase in relative depth of flow.
- With a very high relative depth i.e ($\beta > 0.3$) the higher value of depth averaged velocity is found towards the floodplain region not at the mid of main channel region.
- The depth-averaged velocity in main channel region decreases with the increase in relative depth (β). i.e the resistance to the flow on floodplain by floodplain surface decreases with the increase in relative depth of flow.
- With the increase in relative depth, the depth averaged velocity near the wall increases i.e the resistance to flow offered by the wall decreases with the increase in depth of flow as well as increase in differential roughness.

From stream-wise velocity isovels of contour, it can be concluded that :

- For the highest depth of flow, minimum velocity variation both in the main channel and floodplain regions are seen.
- The maximum velocity contour is always found in main channel of the experimental compound channel
- With the increase in differential roughness value, the overall variation in velocity contour also increases.
- With the increase in depth of flow, the concentration of higher velocity contours on the floodplain increases due to the reason that the velocity on the floodplain increases with the increase in depth of flow.

From the results of boundary shear distribution ,it can be concluded that

Due to no slip condition or law of wall velocity of fluid adjacent to wall is zero but at a distance farther away from the boundary a velocity exist for the flowing fluid. So due to this variation of velocity between the layers of fluid a velocity gradient exist. Because of this velocity gradient a shear stress is seen.

- With the increase in differential roughness, boundary shear decreases in main channel as compared to the floodplain.
- With the increase in relative velocity, the boundary shear increases. At the interface region due to momentum transfer high range of velocity variation takes place resulting high bed shear.

From the result of longitudinal velocity profiles it is observed that

- Velocity is increasing as the depth of flow goes on increasing.
- Highest value of longitudinal velocity occurs at 0.8H depth from the bottom for the main channel. Where *H* = full depth of flow over the main channel, *h* = bankfull depth. For the flood plain height value of the velocity occurs at the top point where the velocity measurements are taken. Most of the cases the highest value of velocities occurs at 0.6(H-h) from the bottom of the flood plain depending upon the depth of water flowing over the flood plain.

The present work leaves a wide scope for future research to find many aspects of differential roughness analysis.

- In the present work sand and concrete are used as roughening material for main channel. Which can be further replaced by other roughening materials such as : mesh and door mat etc.
- The flow characteristics can be studied for different bed slopes and different width ratios.
- The flow characteristics like boundary shear stress distribution, depth averaged velocity , etc can be studied for other differential roughness condition ,width ratios and relative depth of flow.

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