Boundary Shear Stress Distribution in Smooth and Rough Open Channel Flow

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Boundary ShearStress Distribution in Smooth and Rough Open Channel Flow

Dissertation submitted in partial fulfilment

of the requirement for the degree of

Master of Technology

in

Water Resources Engineering

of

Civil Engineering Department

by

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Based on research carried out

Under the supervision of

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May, 2016

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May 28, 2016

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This is to certify that the work presented in the dissertation entitled *Boundary Shear Stress Distribution in Smooth and Rough Open Channel Flow*submitted by *R N Srusti Darshan Samal*, Roll Number 214CE4455, is a record of original research carried out by him under my supervision and guidance in partial fulfilment of the requirements of the degree of *Master in Technology* in *Civil Engineering Department*. Neither this dissertation nor any part of it has been submitted earlier for any degree or diploma to any institute or university in India or abroad.

Place: Prof. K. K. Khatua

Date: (Supervisor)

DEDICATED

TO

MY FAMILY

AND

FRIENDS

R N Srusti Darshan Samal

Declaration of Originality

I, R N Srusti Darshan Samal, Roll Number 214CE4455 hereby declare that this dissertation entitled Effect of Secondary Current on Flow Prediction in an Open Channel Flow presents my original work carried out as a Master student of NIT Rourkela and, to the best of my knowledge, contains no material previously published or written by another person, nor any material presented by me for the award of any degree or diploma of NIT Rourkela or any other institution. Any contribution made to this research by others, with whom I have worked at NIT Rourkela or elsewhere, is explicitly acknowledged in the dissertation. Works of other authors cited in this dissertation have been duly acknowledged under the section "Reference" or "Bibliography". I have also submitted my original research records to the External Examiner for evaluation of my dissertation.

I am fully aware that in the case of any non-compliance detected in future, the senate of NIT Rourkela may withdraw the degree awarded to me on the basis of the present dissertation.

May 28, 2016 *R N Srusti Darshan Samal*

NIT Rourkela

Acknowledgement

Firstly, I would like to thank my supervisor, **Prof. K.K. Khatua**, whose brief knowledge on hydraulic engineering helped me since the first day of my research till the completion of my project. His valuable guidance, encouragement and support made the research much easier. I know very well that without his supervision and hard work, it would have been difficult to complete this study on time.

I would like to extend my gratitude to all **Prof. K.C. Patra, Prof. A. Kumar** and **Dr. (Mrs.) S. N. Sahoo** for their kind co-operation and essential guidance that have been given to me when required. I am also thankful to Prof. S.K. Sahu (HOD, Civil Engineering) for providing all the administrative help whenever needed. I am thankful for well-disposed climate provided to me by the Department of Water Resources Engineering. I would like to thank the staff members and students associated with the Fluid Mechanics and Hydraulics Laboratory of Civil Engineering Department for their assistance and support during the experimental work.

I sincerely thank **Ms. Kamalini Devi,** Ph.D scholar for their guidance, support, I also thanks **Mr. Bhabani Shankar Das,** Ph.D scholar for their encouragement and my friends **Jnana Ranjan Khutia** and **Subhalaxmi Sial** for their help during my project work.

I wish to thank my all my friends, for their support and help during my course work.

I would like to thank my parents and family members, for their patience, love and support without them the journey so far couldn't have been so smooth.

Ultimately, Glory to Lord Shree Jagannath, whose blessings always protects and motivates me.

R. N SRUSTI DARSHAN SAMAL

Abstract

Boundary shear distribution in open channel flow is a crucial issue for river engineer and researchers working in this area. An experimental investigation has been carried out to measure the boundary shear stress distribution along the wetted perimeter of the smooth and rough channel using piston tube technique the accuracy of the method has been compared and checked with another convention method, NDM, VDM, MPM, Velocity Profile Method and energy gradient approach. The boundary shear along the bed and wall of the channel are different for different flow depth and for different roughness conditions. The percentage of boundary shear carried by the wall and bed has been analysed and found to depends on upon non-dimensional geometry and hydraulic parameters such as Aspect ratio, Reynolds number and Froude's number. A multi linear regression model has been applied to predict the boundary shear distribution for bed. The equation is useful to calculate the roughness coefficient (friction factor) of the wall and bed of the channel separately, which further determines the composite roughness of the open channel flow accuracy. The methodology has been applied successfully to calculate the stage discharge relationship of the open channel flow. The methodology has been validated against other experimental data, other researcher's models and Natural River.

Key words: Boundary shear stress distribution; Piston tube Technique; Aspect Ratio; Reynolds Number; Froude's number; Roughness Coefficient; Composite Roughness

Contents

Chapter-1

Chapter-2

Chapter-3

Chapter-4

Chapter-5

Chapter - 6

Chapter-7

List of Figures

List of tables

Notations

B	width of the channel;
d	outside diameter of the probe;
g	acceleration due to gravity;
H	in bank depth of flow;
h	main channel bank full depth;
k	turbulent kinetic energy;
P	wetted perimeter;
Q	discharge;
R	hydraulic radius;
S_o	bed slope of the channel;
N	manning’s roughness coefficient;
y	lateral distance along the channel bed;
z	vertical distance from the channel bed;
α	aspect ratio (b/h);
β	Relative flow Depth;
α	Width ratio
ρ	Fluid density
Θ	angle between channel bed and horizontal angle;
v	kinematic viscosity;
τ_0	overall boundary shear stress;
μ	coefficient of dynamic viscosity;
$x*$	logarithmic of the dimensionless pressure difference;
$y*$	logarithmic of the dimensionless shear stress;
ΔP	Preston tube differential pressure;

Δh	difference between dynamic and static head;
R_e	Reynolds number;
F_r	Froude number;
U	Mean velocity of flow;
D	Hydraulic depth;
D_m	qHydraulic mean depth;
τ_b	Boundary shear stress on bed;,
P_b	Wetted perimeter of bed;
τ_w	Boundary shear stress on wall;
P_w	Wetted perimeter of wall;
f_b	Friction factor of bed;
f_w	Friction factor of bed;
n_b	Manning’s roughness coefficient at bed;
n_w	Manning’s roughness coefficient at bed;
$\%S_W$	percentage of shear force at walls;
$\%Sb$	percentage of shear force on bed;
$\%Smc$	percentage of shear force on the main channel;
$\%Sfp$	percentage of shear force on main floodplain;

ABBREVIATION

FCF = Flood Channel Facility

Chapter-1

Introduction

1.1 Overview

Survive without water is not possible if there is not the availability of plentiful of fresh water. As the river is regarded as the main source of waterfor flourishing the life of each living being so itis considered as important for day to day functioning of every ecosystem.The river attracts the strong attention and interest of engineersandscientists.

The river is the basic source of providing a water supply for irrigation, industrial consumption, domestic and transportation etc.Rivers are great significancein geographically, biologically, historically and socially.Despite the fact that it contains around 0.0001% of total amount of water in the planet at any time, rivers areessential transporters of water and supplements to region all around the earth. It is the critical component of the hydrology cycle, acting as a drainage channel of surface water; the world's rivers drain almost 75% of earth's land surface. They also provide method of transportation to endless organisms; they leave important stores of sediments, for example, sand and rock; they shape boundless floodplains where a number of our urban communities are developed; and their energy gives a significant part of the electrical vitality we use in our regular lives. Rivers are fundamental to large numbers of the natural issues that worry society and they are concentrated on by an extensive variety of specialists including hydrologists, engineering and environmentalists.

1.2 Open Channel Flow

Open channel flow is the branch of hydraulic; it is a kind of fluid stream inside a course withhaving a free surface, commonly known as a channel.Open channel flow is driven by gravity force. The channels are made by man is known as artificial Channel. They comprise of irrigation canals, spillways, sewers, culverts, navigation canals, and drainage ditches. These are normallymade in a regular cross-section shape throughout and are thus prismatic channel. The channel which consists of both main channel and floodplains is generally called compound channel. They are of different cross-sectional geometry like rectangular, trapezoidal or nor uniform in configuration.

When there was a flow in the natural or main-made channel exceeds the depth of the main channel, the remainwater can be carry by floodplains of the river but the hydraulic conditions in the river and floodplains are different so that the mean velocity in the main channel and floodplains are different.

The importance of modelling the in bank flow (i.e. flow within the main channel) correctly, as the flow is always present in the main channel except in flood case when the flow goes to floodplains. Some of the flow mechanisms in the simple and compound channel are same, but in some cases flow characteristics can be avoided by strong mechanisms due to overtopping of flow from the main channel to floodplains. Flow in the simple rectangular channel is depended on the interface between wall and bed, secondary flow cells.

Examples of open channel flows are

- The common seepage of water through the waterway framework.
- The flow of water in the sewer of our home.
- The flow of water in the waterways, seepage and drains along the streets.
- The flow of water in the chutes of water rides..

An open channel flow may be classified as natural or artificial:

Natural: When open channels have an irregular shape, surface alignment and alignment is known as a natural open channel. e.g. - streams, rivers, waterways etc.

Artificial: When open channels are having in regular shape, uniform roughness and alignment. Which are built for the specific purposes, such as irrigation, water power development, water supply etc. are called artificial open channel.

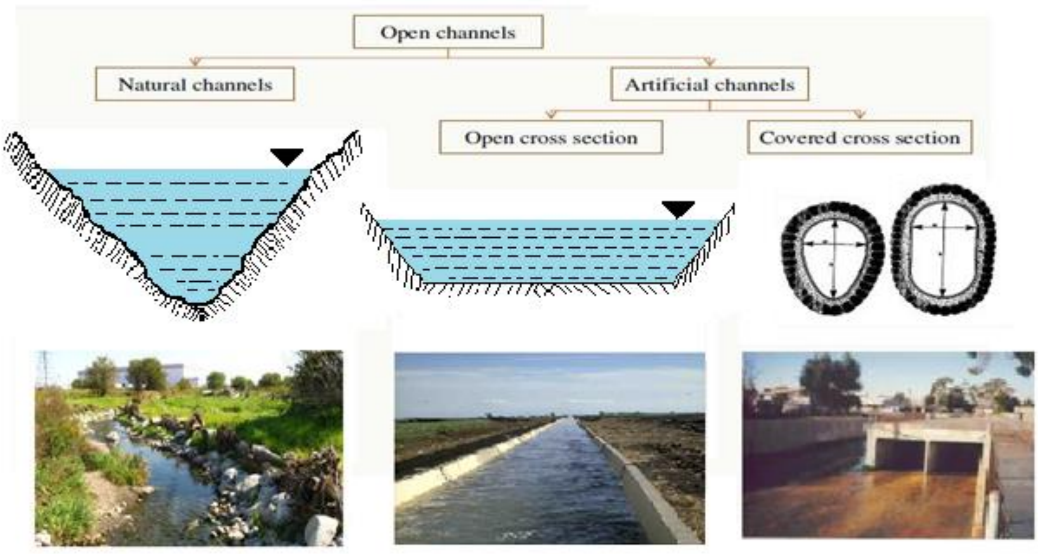


Figure1.1: Classification of open channel

1.3 Flow Mechanisms

Flow characters are classified by energy transfer mechanisms as they converted energy from one form to another through the development of vortex structures over various scales. vortices can be generated in open channel flow due to the effect of boundary shear ,vertical and horizontal shear interface, transverse currents and comprehensible structures, but it also depends on upon the cross-sectional geometry of the channel, flow depth and flow characteristics (i.e. laminar or turbulent)

1.4 Types of Flow

1.4.1Steady and Unsteady Flow

Flow in thechannel is said to be steady if the flow characteristics at any point do not change with time. However in thecase of prismatic channels the conditions of steady flow may be obtained if the only depth of flow does not change with time. On the other hand, if any flow characteristics change with time the flow is unsteady. Most of the openchannel problems involve the steady of flow under steady conditions. In our experimental investigation the flow is steady.

1.4.2Uniform andNon- uniform Flows

Flow in a channel is said to beuniform if the depth, slope, cross-section and velocity remain constant over a given length of the channel. Obviously a uniform flow can occur only in theprismatic channel in which the flow will be uniform if only the depth of flow is same at every section of the channel. Flow in channels is termed as non-uniform if the depth of flow changes from section to section. In our experimental investigation the flow is uniform.

1.5 Laminar Flow and Turbulent Flow

1.5.1Reynolds Number

The flow in channels is also characterised by as laminar, turbulent or in a transitional state, depending on the relative effect of viscous and inertia forces and Reynolds number (Re) is ameasure of this effect. However, the Reynolds no. flow in channels is commonly defined as

$$R_e = \frac{4UR}{\nu}$$

Where

U is the mean velocity of flow

R is the hydraulic radius of the channel crossection

ν is the dynamic viscosity of water.

On the basis of experimental data it has been found that up to Re equal to 500 to 600, the flow in channels may be considered to be laminar and for Re greater than 2000, the flow in the channel is turbulent.

1.5.2Froude Number:

Gravity is a predominant force in the case of channel flow. As such, depending on the relative effect of gravity and inertia forces the channel flow may be designated assubcritical, critical or super critical. The ratio of the inertia and the gravity forces is another dimensionless parameter called Froude number (F_r) which is defined as

$$F_r = \frac{U}{\sqrt{gD}}$$

Where:

U is the mean velocity of flow, g is the acceleration due to gravity, D is the hydraulic depth of channel section which is equal to(A/T),Ais the wetted area,Tis the top width of the channelsection at the free surface.

When:

F_r=1, critical flow

F_r>1, supercritical flow

F_r<1, subcritical flow

1.6 Geometric Properties Necessaryfor Analysis of Open Channel Flow

For analysis various geometric properties of channel cross-section are required. The commonly needed geometric properties are shown below:

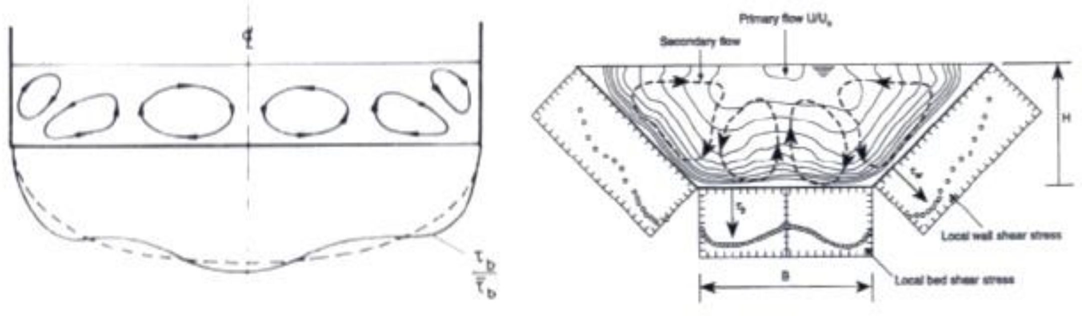
- Depth (Y), Area (A) ,Wetted perimeter (P)
- Hydraulic radius (R)- The ratio of area to wetted perimeter i.e.(A/P)
- Hydraulic mean depth (D_m) - Is the ratio of area to surface width of channel i.e.(A/B)
- Aspect Ratio – The ratio of bottom width to depth of channel i.e.(b/h)

1.7 Boundary Shear Stress Distribution

Boundary shear stress is a critical parameter in an open channel flow in order to model the evolution of the shape of the natural river channels; it is necessaryto find out the distributions of boundary shear stress in the vicinity of the river bank. Boundary shear distribution depends on upon the secondary flow cells, the shape of thecross-section and non-uniform roughness distribution around the wetted perimeter of the channel. The importance of boundary shear stress distribution was demonstrated by the use which is made of the local or mean boundary shear stress in may hydraulic equations concerning resistance,sediment,dispersion or cavitation problem.

Boundary shear is a fundamental problem in hydraulics that gives the attention of many researchers. Different researchers carried out the experimental work in different condition are straight square ducts (Gessner 1964); rectangular ducts (Knight & Patel 1985; Rhodes & Knight 1994); rectangular open channels (Rajaratnam; Tominagaetal.1989) and rectangular compound open channels (Rajaratnam&Ahmaid 1981; TominagaandNezu 1991). Researcher’s attempts (Almadi 1979; Knight 1981; Rhodes and Knight 1994) have been made to find out the mathematical expression for lateral boundary shear in rectangular channels.The mathematical expression gives the relation between average boundary shear stress on the wall and bed, not the local boundary shear stress.

Water flows in an open channel it is opposing by the resisting force from side slope and bed of the channel. This resisting force is known as the boundary shear stress. Boundary shear stress is the resultant component of the hydrodynamic forces that acting along the bed of the channel. Boundary shear force distribution along the wetted perimeter of the channel directly depends upon the flow criteria of the channel .Boundary shear stress can help to theanalysis of side wall correlation, sediment transport, dispersion, channel migration, computation of bed from resistance, cavitation and conveyance estimation etc. Shear force, fora uniform steady flow dependsuponthe hydraulic radius, bed slope, and unit weight of water. But the shear forces are not uniformly distributed also for the straight prismatic channel when we consider from a practical point of view, it depends on the geometry of channel, flow condition and roughness factors of the channel. Non-uniformity distribution of shear stress deepened mainly due to the secondary current formed by the anisotropy between vertical and transverse turbulent intensities, that given by Tominagaetal (1989); Knight and Demetriou (1983);andGessner(1973) determined that the when the secondary flow towards the wall boundary shear stress increases and when flows away from the wall shear stress decreases in the channel. The distribution of shear stress along the wetted perimeter of the channel can affect by the presence of secondary flow cell in themain channelwhich is given in Fig.1.2.Other parameters that affect the shear stress distribution are theshape of the channel, flow depth, velocity criteria roughness profile of the channel and sediment concentration.



(a)Rectangular Cross-section(Knight et al., 1983) (b) Trapezoidal Cross-section (Knight et al., 1994)

Figure 1.2: Schematic influence of secondary flow cell on boundary shear distribution

1.8 Objectives of Current Research:

The prime aim of this research is to understand the distributions of boundary shear stress in various types of bed i.e., smooth bed, rough small gravel bed in an open channel flow. The objectives of the present work are listed below:

- Experimental investigation on boundary shears distribution in an open channel flow.
- To investigate the boundary shear distribution between the bed and wall in smooth and rough open channel flow for different geometry and flow condition.

- To apply different techniques to measure the boundary shear stress in open channel flow and compare their results with energy gradient approach. Discussion of Merit and Demerit of these approaches under different flow condition
- To develop an improved mathematical model to predict the boundary shear distribution in bed and wall.
- Validation of purposed model with other data set and compression of the purposed model with the method of D.W. Knight (1984).
- To evaluate the composite roughness to find out the stage discharge of the channel flow by using the boundary shear distribution expression
- To compare the results of the present work with other researchers model and to validate with data sets of other researchers.

1.9 Organization of Thesis:

This project paper is the sequence of 6 main chapters. The general introduction is given in chapter-1, the literature review is conferred in the chapter-2, the experimental setup and procedure are depicted in chapter-3, experimental results and discussions are discussed in chapter-4, Model development are described in chapter-5, Application of model for discharge assessment are describe in chapter 6and at last the conclusions and scope for future work are presented in chapter-7

Chapter-1gives a concise introduction about open channel flow with different types of flows. It comprises of the definition of open channel flow, types of flow, the overall idea about boundary shear stress distribution, and the objective of the current research.

The detailed literature reviews of numerous famous researchers and scientists which are relating to the present project are presented in chapter-2. The chapter highlights the research which is executed the smooth and rough channels relating boundary shear and their distribution.

In chapter-3, the total experimental setup and procedure are explained. This section explains the arrangements of experimental setup and procedure to achieve the observations in experimental channel.

In chapter-4, the experimental results about the stage-discharge relationship, Boundary shear distribution by piston tube technique and another convention method, comparison of results with all the method are given in this chapter.

In chapter-5, the behaviour of percentage shear in wall and bed for simple and compound channels, effects of Reynolds number and Froude number for the smooth and rough channel, multi linear regression analysis, and a proposed model for smooth and rough channel given in this chapter.

In chapter-6, how to find out the discharge from purposed model by using the composite roughness models and comparison of purposed model with another model is also given in this chapter

At last in chapter-7, the conclusion reached by present work and scope of future work is listed out.

References that have been made in subsequent chapters provide at the end of the thesis

Chapter-2

Literature Review

2.1. Overview

Boundary shear stress distribution in an open channel flow along the wetted perimeter was affected by many factors mainly, the thecross-sectional shape of the channel, type of roughness, longitudinal variation in plan from geometry, secondary flow cell distribution and sediment concentration. To know the distribution of boundary shear stress in the lateral direction required to understand the three-dimensional flow structures that exist in an open channel. The non-uniform distribution of boundary shear in an open channel flow are observed due to the interaction between the primary longitudinal velocity *U*, and the secondary flow velocities *V* and *W* are responsible. In prior time as a result of one dimensional displaying of stream accentuation was given to nearby shear stresses and numerous experimental models are produced to register the dissemination of stream insightful segment of shear anxiety. However, with time distinctive scientists noticed that the nearness of auxiliary speed in the open channel stream because of complex blending happens to offer to ascend to a number of turbulent structure which influences the velocity, shear stress dissemination and at last the state of the channel. The impact of Reynolds and Froude number in the circulation of shear anxiety was additionally considered.

Previous Research on Boundary Shear Stress

Literature review contains a large number of research on the subject of boundary shear stress distribution in an open channel flow. This review expects to present a portion of the chose critical commitment to the investigationof boundary shear stress in open channel flow. Researchers are covering a few perspectives, for example, distinctive channel cross-sections like rectangular, trapezoidal; different channel geometry, for example, a straight, basic and compound channel with various surface conditions like smooth and rough channels to study the effects of boundary shear stress.

2.1.1. Straight Simple Channel

Seven decades prior, **Leighly (1932)** proposed utilizing conformal mapping to consider the course boundary shear stress in open-channel flow. He offered astuteness in regards to that, without closeness of discretionary rhythmic movements, the boundary shear stress catching up on the bed must be adjusted by the downstream parcel of the heaviness of water contained inside the ricocheting orthogonal.

The einstein's (1942) water driven extent parcel procedure is still extensively used as a piece of lab studies and building hone. Einstein apportioned a cross-sectional reach into two zones A_b and A_w and expected that the down-stream portion of the fluid weight in district A_b is balanced by the resistance of the bed. In like way, the downstream part of the fluid weight in zone A_w was balanced by the resistance of the two side-dividers. There was no contact at the interface between the two zones A_b and A_w. To the extent vitality, the potential vitality gave by zone A_b was scattered by the channels bed, and the potential vitality gave by reach A_w was spread by the two side-dividers. Regardless he didn't propose any method for choosing the unequivocal territory of division line.

Ghosh and Roy (1970) shown the limit shear conveyance in both rough and smooth open channels of rectangular and trapezoidal territories acquired by direct estimation of shear delay a segregated length of the test channel utilizing the technique for three point suspension framework proposed by Bagnold. Existing shear estimation strategies were inspected on a very basic level. Relationships were made of the deliberate conveyance with other backhanded estimations, from isovels, and Preston-tube estimations. The inconsistencies between the indirect and direct assessments were clarified and out of the two circuitous evaluations the surface Pitot tube strategy was seen to be more dependable. The effect of secondary flow on the boundary shear appropriation was not precisely characterized without dependable theory on secondary flow.

Kartha and Leutheusser (1970) proposed that the outlines of alluvial channels by the tractive power strategy require data on the dispersion of divider shear stress over the wetted border of the cross-segment. The trials were completed in a smooth-walled research facility flume at different profundities to width proportion of the rectangular cross-area. Divider shear stress measured with Preston tubes were balanced by a strategy abusing the logarithmic type of the inward law of speed circulation. Results were introduced which plainly suggested that none of the present explanatory procedure couldn't give any subtle elements on tractive power dissemination in turbulent channel stream.

Myers (1978) Preston tube technique was used for measurement of shear stress distributions around thewetted perimeter of the channel. Perusing has brought with full cross area flow and flow kept to the profound, or channel segment. The determined results were utilized to know the energy exchange because of the collaboration between the channel flow and that over its flood plain.

Knight (1981)determined a tentatively inferred condition that communicated the rate of shear force conveyed by the divider as an element of the aspect ratio of the rate of and the proportion between the Nikuradse identical roughness sizes for bed and wall of the channel. The outcome was contrasted and different analyst's information set for a smooth channel and a couple of contrasts noted. The precise diminishment in the shear power conveyed by the dividers with expanding the aspect proportion and bed harshness was outlined. Further conditions were shown giving the mean divider and bed shear stress variety with aspect proportion and unpleasantness parameters. This thought was further consided by Noutsopoulos and Hadjipanos (1982).

Knight and Hamed(1983) presented the experimental results are relating to boundary shear stress and boundary shear force distributions in arectangular compound channel. They also studied the impact of differential roughness between the flood plains and the main channel on the lateral momentum transfer process progressively in six steps. They demonstrated the equations for shear force on the flood plains expressed as the percentage of total shear force in the terms of four dimensionless parameters. Supplementary equations are also presented giving the apparent shear force on vertical, slanted and even interfaces inside the cross area of channel.

Knight etal. (1984) studied the boundary shear stress and its distribution in a smooth rectangular channel and reported some experimental data regarding these parameters. They also derived an empirical equation from providing the percentage shear force carried by the walls which are a function of the aspect ratio. Traditional equations are used for estimating the shear stress on the mean wall, bed and bed centre as a function of aspect ratio. They showed a comparison between the distribution of boundary shear stress in the open channel and closed conduit. The results from the proposed empirical model are found suitable for researchers engaged in resistance, sediment, or dispersion studies.

Zheng and Vee-Chung Jin (1998)built up the condition for the horizontal dissemination of boundary shear begins from a translated stream shrewd vorticity condition which incorporates just the optional Reynolds stress. Force exchange model was influenced by an auxiliary stream on the limit shear. On the premise of these investigations, an experimental condition is connected to depict the parallel limit shear conveyances. The deliberate information of the limit shear in square courses are utilized to figure some observational coefficients..

Khodashenas and Paquier (1999)inferred a strategy called Merged Perpendicular Method (M.P.M) have been produced to register the appropriation of boundary shear stress crosswise over irregular straight channels. In a curved point of the cross-segment, figured shear anxiety is lower than in an arched edge.

Al-khatib and Dmadi (1999) presented the experimental results regarding the boundary shear stress distribution in a rectangular compound channel. This rectangular compound channel consists of one main channel and two symmetrically floodplains. Shear stress distributions had different dimensionless ratios and related to the important parameter. The floodplains are due to the momentum transfer between the deep section and flood plains have been measured. They derive some important results concerning the uniformity of shear stress distribution in the channel. This is useful in alluvial channels to state the possible locations of erosion and deposition are presented.

Shu-Qing Yang and J.A. McCorquodale (2004) derived a method for computing Reynolds shear stress and distribution of boundary shear stress in smooth rectangular channels. They also developed the magnitude analysis by which the integrate of the Reynolds equations can be done. And they also give a relationship between the lateral and vertical terms are considered for which the Reynolds equation can be solvable.

Guo and Julien (2005) decided the progression and force condition for processing normal quaint little in shear stresses in the smooth rectangular open channel. They investigated shear stress is relied on the capacity of three parts: i.e. (1) gravitational (2) secondary flows and (3) interfacial shear stress. The systematic arrangement of this arrangement extension is gotten for consistent whirlpool thickness without auxiliary streams. The proposed condition for progression and force condition are contrasted and approved and another arrangement of information.

Shu-Qing yang and Siow-Yong Lim (2005) studied the distribution of boundary shear stress in the trapezoidal open channel. They observed the direction of transport of the surplus energy in the trapezoidal channel and found that surplus energy within any unit volume of fluid will be transferred to dissipate towards the nearest boundary. They divided the cross-sectional area of the trapezoidal open channel on this concept of energy transport according to the shape of geometry, aspect ratio and roughness distribution. Then they derived analytical equations for computing the local and mean boundary shear stress along the wetted perimeter of the channel.

GalipSeckin et al.(2006)conducted experiments on a smooth rectangular channel for finding out the boundary shear stress and force. They also derived a nonlinear regression equation based on percentage shear force carried by wall and bed of the channel as a function of aspect ratio. Proposed education compared and well correlated with other studies.

Khodashenas et al.(2008)discussed six different methods for evaluating of the boundary shear stress distribution, mean bed and wall shear stresses in prismatic open channel flows and also compared the results against experimental data. From the comparisons, they studied that the results from Vertical Depth Method (VDM) did not match the experimental data. They observed that the Merged Perpendicular Method (MPM) and Yang and Lim Method (YLM), when applied to trapezoidal and circular channels provide the best predictions of the local shear stress.

Lashkar-Ara and Fathi-Moghadam(2010) conducted experiments on the rectangular channel to know the effects of wall and bed shear force in the channel by varying different aspect ratio. The main objective of this research is to find out the contribution of wall shear on the total shear force. A nonlinear regression analysis is used to analysis the results and to developed an education to find out the percentage of shear force on wall and bed at the wetted perimeter of the rectangular channel. Suggested equation was compared and well correlated with another dataset

Patra et al. (2012) for uniform flow conditions, the water powered resistance might be lead to nature of roughness and flow qualities of the channel. In this present examination, they accepted the proposed conditions of shear anxiety dispersions over the fringe of the exploratory channel and roughened surge plain are broke down and tried for a compound channel having high width ratio of 15.75. They thought about the flow conditions utilizing new lab information recorded for this reason and additionally for FCF information for better examination.

Samani et al. (2012) derived semi-analytical equations for computing of the mean boundary shear stress in smooth trapezoidal open channels by using different conformal mapping techniques. This process which is computed based on a numerical integration and a mathematical analysis. This approach dividing the flow area of the channel into bed and sidewalls to different segments.The boundary shear stress distribution which estimates based on the between adjacent subsections of the flow area of a channel. This model has been validated the analytical results which compared with the other experimental results.

Al-khatib (2015) conducted nine experiments in a physical model of the asymmetric compound channel to compute the boundary shear stress distribution at the interface of the main channel and floodplain. Shear stress distributions across the bottom of the main channel and floodplain interfaces were calculated and tested for different types of asymmetric compound channel and their flow conditions. The lateral momentum transfer has been also calculated between the main channel and adjacent shallow floodplain was found to affect extremely the shear stress distributions at the bottom of the main channel and the floodplain.

2.1.2. Straight Rough Channel

Ghosh and Jena (1973)find out that the limit shear stress conveyance in straight compound channels for having both smooth and rough conditions. They relate the commitment of aggregate drag power applied to different portions of the channel segment to the stream profundity of roughness focus.

Myers (1987) showed that the ratios of main channel velocity and floodplain discharge values are independent in bed slope which is influenced by different geometry. The theoretical prediction is using the data from different symmetrical compound channel shapes. He compared the measured discharge data with conventional methods to validate between the main channel and floodplain.

Yang et al. (2004) analysed that in certain calculable reasoning for sediment transport and environmental studies which include lateral distributions of depth-averaged apparent shear stress, depth mean velocity and diffusion coefficients. The relation between the flows parameters is based on the surplus energy transport concept. They also found that the depth-averaged apparent shear stress which is determined by boundary shear stress, depth mean velocity

Wilkerson et al. (2005) created two methods to predict the depth-averaged velocity in trapezoidal channels which are not wide, at the banks exert form drag on the fluid and control the depth-averaged velocity distribution. In any case, these techniques are not reasonable for wide trapezoidal channels. For the improvement of models, they utilized different ranges of flow parameters. The principal model required for measured velocity information to adjusting the model coefficients when the second data utilized for recommended coefficients. The principal model is recommended for depth-averaged velocity data. The second model is utilized for predicted velocities which give better results.

Shu-Qing Yang (2010) investigated the depth-averaged shear and velocity in rough channels and derived a model based on the theoretical relation between depth averaged shear stress and boundary shear stress. Then he also developed an equation to find out depth mean velocity in rough channels by including the effects of roughness and water surface. For validation of his model he also used the experimental data of other researchers and found that his model is reliable with experiment data.

Kundu and Ghosal (2012) reinvestigated the velocity circulation in open channel flows which rely on upon the flume exploratory data. They proposed the wake layer in the outer area into two layers i.e. generally feeble external locale and moderately solid external area. In like manner, they joined the log law and allegorical law for the external district and proposed an unequivocal condition for mean speed conveyance of relentless and uniform turbulent move through the straight open channel. It is found that the silt fixation has a critical consequences for speed circulation in the generally feeble external locale.

2.2. Critical Review of Literature

There are a lot of work have been done for predicting boundary shear stress distribution in an open channel flow. Some of them are based on analytical model depending upon the hydraulic and geometric parameters. Also there are some theoretical models have been developed by investigators for prediction of bed shear stress distribution along the lateral direction. Many researchers worked on the distribution of boundary shear stress and boundary shear force on the different components of the channel like walls and beds. They provide mathematical models for the distribution of the shear stress depending on the aspect ratio. But there is less work has been made for this distribution of bed shear which is depending upon geometric and hydraulic parameters.

Chapter-3

Experimental Setup and Procedure

3.1 Overview

Experimental work on natural rivers was very difficult; so the flow characteristics of a river can be analysed by studying them on a model designed close to natural rivers. In present study boundary shear distribution, velocity of flow, variation of Manning's n in different boundary conditions and discharge over different flow conditions in a simple channel are found out, the experiments was carried out in Fluid Mechanics and Hydraulics Laboratory of the Civil Engineering Department at the National Institute of Technology, Rourkela, Odisha, India by changing the roughness of the channel. For the better understand the flow condition in simple channels the experiments was conducted in the laboratory flume.

3.2 Design and Construction of the Channel

The large experimental flume was made up of MS bars, plates and angles with a gear arrangement over an inclined metallic ramp for providing an alongitudinal slope. To keep the flow in subcritical condition, the gear arrangement moves up and down.A large overhead tank made up RCC was constructed on the upstream side of the flume for feeding water into the channels. At the downstream end, a masonry volumetric tank was constructed for measurement of discharge. For providing a continuous water supply an underground sump was present outside of the laboratory and the water from volumetric tank comes to this large sump then feeds totheoverhead tank using centrifugal pumps of capacity 15HP and 10HP. For regulating the flow to be uniform and reduce the turbulence at the entrance region of the flow coming from theoverhead tank, a stilling chamber is provided with a regulating head gate. On the downstream side of the flume, atail gate was fitted to control the depth of flow to be uniform throughout the channel.

3.3 Construction of Rough Channel

To create small gravel roughened on the main channel the flowing procedure was adopted. Gravels was glued to the main channel by using adhesive and left for 24hrs to dry. After

24hrs, the excess material was swept out to get uniform roughness in the channel. By this process, the surface area of the main channel of the test reach was roughened.

Figure 3.1:schematic diagram of rough channel

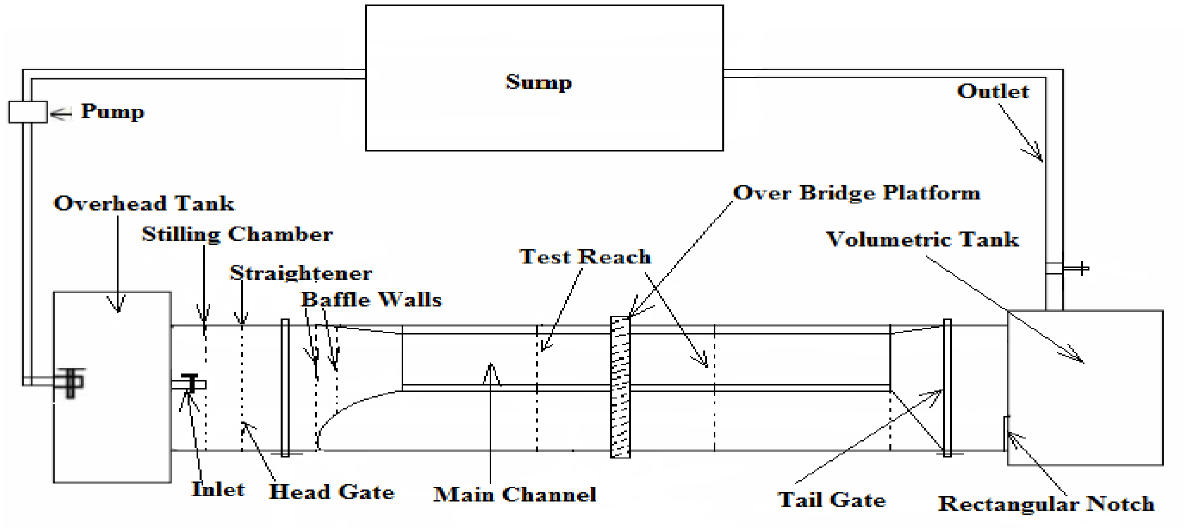


Figure3.2: Schematic drawing of whole experimental setup

3.4 Apparatus and Equipment Used

In this research work, point gauge is a measuring device that has least count 0.1 mm , the micro-pitot tube having external diameter 4.7 mm and an inclined manometer was used in the experiments. Velocity and depth of flow in the channel are measured by these devices. In the experiments structure like the stilling chamber, baffle wall, head gate, travelling bridge, tail gate, volumetric tank, sump, overhead tank arrangement, two parallel pumps, water supply device etc. are used. The measuring device and equipments were arranged properly to carry out the experiments in the channel.

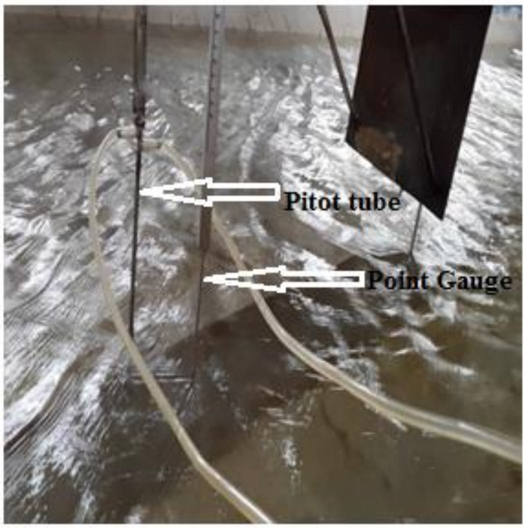


Figure 3.3:(a) Arrangement of Pitot tube and point gaugeFigure 3.3:(b) inclined manometer

3.5 Experimental Procedure

Main parameters to measure during the experiment are discharge, bed slope and the velocity. Those are measured in following procedure.

3.5.1 Experimental Channel

The experiment was conducted in a straightsimple channel; having the configuration of the channel is trapezoidal in shape with bottom width 33cm, theheight of 11 cm and side slope of 1V:1H. The longitudinal slope was given 0.001325 for smooth and 0.001 for the rough channel, so that water could flow under gravity. Experiments were carried out inside the channel keeping the geometrical and roughness parameter same for analysis of boundary shear stressdistribution. A typical cross section of the simple channel is shown in Fig 3.4. Detailed geometrical features of experimental channel are given in table 1

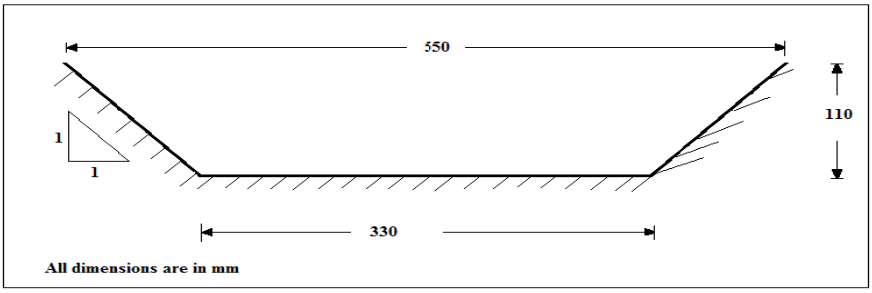


Figure 3.4:Cross sectional view of the simple channel

Figure:3.5(a)Photos of Pumps

Figure:3.5(b) Overhead tank

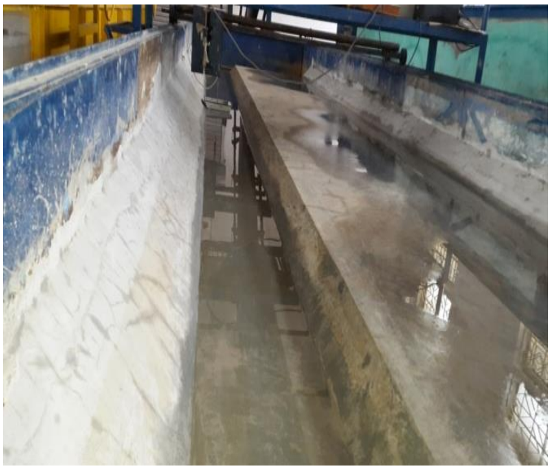


Figure:3.5 (c) Testing Channel (Smooth)

Figure:3.5 (d) Testing Channel (Rough)

Figure :3.5 (e) Stilling Chamber

Figure:3.5 (f) Volumetric tank

Table1:shows the details geometric feature of the experimental channel with their shape, size and bed slope of the channel.

Table:1 Detailed Geometrical Features of the Experimental Channel

Sl no.	**Item Description**	**Present Experimental Channel**
1	Type of Channel	Straight
2	Geometry of Channel	Trapezoidal with side slope 1:1
3	Base width of Channel (b)	0.33 m
4	Depth of Channel (H)	0.11 m
5	Bed slope of Channel	0.001325 for Smooth channel and 0.001 for Rough channel

3.6 Calculation of Bed Slope

By maintaining subcritical flow condition all smooth and rough cannel experiments are done. To find out the bed slope of the channel, the tailgate of the flume was closed so that water tight chamber could be created in the main channel. The traverse bridge with the point gauge having least count of 0.1 mm was able to move in transverse as well as in the longitudinal direction of the channel to measure depth at the predetermined point. The slope of the bed was found out by dividing the drop in water surface along two points with their longitudinal distance of the channel. The bed slope was found out 0.001325 for smooth and 0.001 for the rough channel. It was kept constant for series of experiments.

3.7 Position of Measurement

The longitudinal velocity at purposed cross section points at different layers horizontally covering the full depth of flow measured through a Micro-Pitot static tube of outside diameter 4.77mm by means of placing the Pitot tube normal to the flow direction. To measure the simple straight channel, an even portion of the cross section was used for measuring the velocity at the bed as the section was symmetrical about the centre of the simple channel. The grid of measurement points with horizontal and vertical spacing for simple channel in fig.2

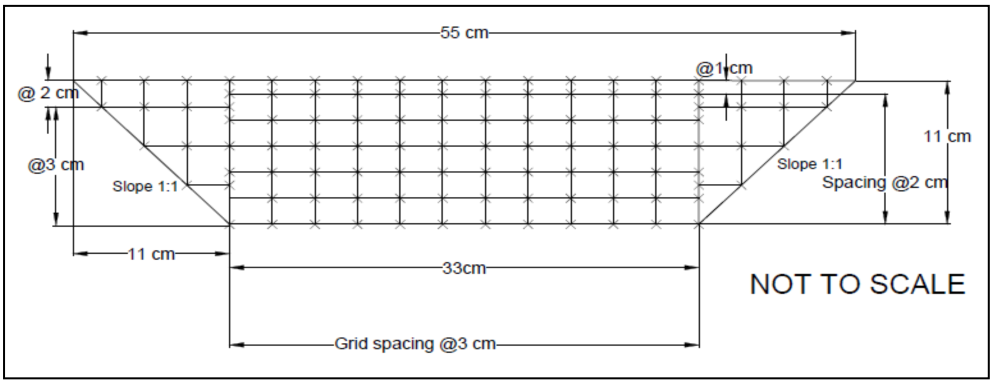


Figure: 3.6 Grid points for measurement of boundary shear distribution

3.8 Measurement of Depth of Flow and Discharge

To measure the depth of flow for experimental work, a point gauge of least count 0.1 mm is used which is attached to a traveling bridge and it was operated manually. For discharge measurement a volumetric tank arrangement at the downstream side of the channel and it measured at the end of the each experiment. Depending upon the rate of flow, the collection of water in volumetric tank varies with time i.e. for higher depth of flow time is less and vice versa. To know the volume of water collected in the volumetric tank and with respect to the time of rising, discharge was calculated for each run of the experiment.

3.9 Measurement of Boundary Shear Stress

Estimation of boundary shear stress in open channel flow helps to understand the transport of bed load, migration of channel, momentum transfer etc. Bed shear force can help to study of the transfer of bed load where as shear force give the general idea about the mitigation of channel pattern.There are several method used to estimate the wall and bed shear stress, Preston-tube technique is an indirect method for shear stress measurements and widely used in experimental channels.

3.10 Preston Tube Technique

Preston (1954) was developed a technique for measuring of local shear stress on the smooth boundaries using pitot tube by contact with the surface. This method was based on assumption the velocity distribution near the wall can be empirically related to the differential pressure between dynamic and static pressures, Preston presented a non-dimensional relation between differential pressure ΔP and the boundary shear stress, τ_0:

$$\left(\frac{\tau d^2}{4\rho v^2}\right) = F\left(\frac{\Delta P d^2}{4\rho v^2}\right) \tag{3.1}$$

Where d is the outer diameter of the tube, ρ is the density of the flow, ν is the kinematic viscosity of the fluid and F is an empirical function. (Patel 1965) future extended the research and gave two non-dimensional parameter x* andy* wich are used to convert pressur readind to boundary shear stress, where

$$x^* = \log_{10}\left(\frac{(\Delta P)d^2}{4\rho v^2}\right) \text{ and} y^* = \log_{10}\left(\frac{\tau d^2}{4\rho v^2}\right) \qquad (3.2)$$

$$y^* = 0.50x^* + 0.037, \qquad 0 \le y^* < 1.50 \qquad (3.3)$$

$$\text{Or,}0 \le x^* \le 2.90$$

$$y^* = -0.0060x^{*3} + 0.1437x^{*2} - 0.1381x^* + 0.8287 \qquad 1.50 \le y^* < 3.50 \qquad (3.4)$$

$$\text{Or,}2.90 \le x^* \le 5.60$$

And

$$x^* = y^* + 2\log_{10}(1.95y^* + 4.02), \qquad 3.50 \le y^* < 3.50 \qquad (3.5)$$

$$\text{Or}5.60 \le x^* \le 7.60$$

In the present study, all shear stress measurements are taken at the boundary of the channel. The pressure readings are taken using pitot tube along the predefined point across the section of the channel along the bed and wall. An inclined manometer was attached to the pitot tube for providing the head difference between the dynamic and static pressures. The differential pressure is calculated by using:

$$\Delta P = \rho g \Delta h \sin\theta$$

Where Δh is the difference between the dynamic and static head, g is the acceleration due to gravity, ρ is the density of water and Θ is the angle between horizontal and inclined surface. Here the coefficient of tube taken as unit and error due to turbulence is considered negligible while measuring the velocity. Accordingly out of Eq.3.1-3.5, the appropriate one has chosen foe computing the wall shear stress based on a range of x* values. After that the shear stress value was integrated over the entire perimeter of the channel to compute the total shear force per unit length normal to flow cross-section carried by the channel

Chapter-4

Experimental Results and Discussions

4.1 Overview

Chapter 4 describe the procedure of the experiments that carried out in the channel. In this chapter experimental result of the distribution of boundary shear stress along the wetted perimeter of different flow depth has been given. The stage discharge relationship is given in fig4.1.

4.2 Stage Discharge Relationship

Stage discharge relationship for a straight simple smooth channel and small gravel roughed channel was represented by the H~Q curve in Fig 4.1. It was clearly observed that when flow depths are increases the discharge also increases in channel and relation was found to be power function with higher R^2 value.

$Q = 2.0161x^{1.95}$ (For smooth channel) (4.1)

$Q = 0.5311x^{1.69}$ (For gravel roughed channel) (4.2)

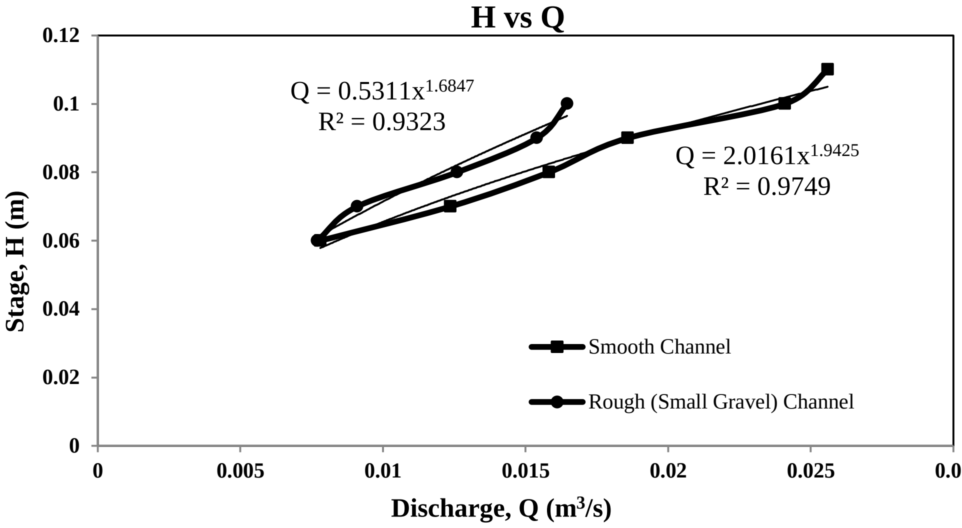


Figure:4.1 stage Discharge curve for straight smooth and small gravel roughed channel of NIT, Rourkela

The detail results of flow properties such as depth, area, wetted perimeter, hydraulic radiusand discharge of smooth and rough channels are given in table 4.1

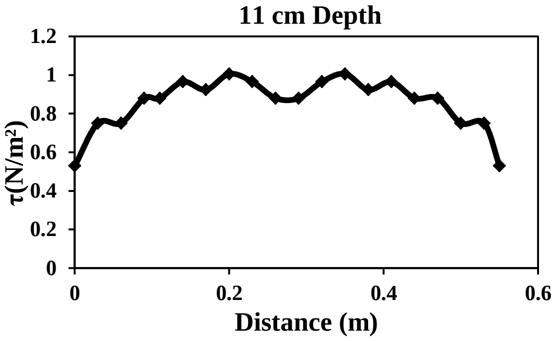
Table:2Detailed results of flow properties of the Experimental Channel

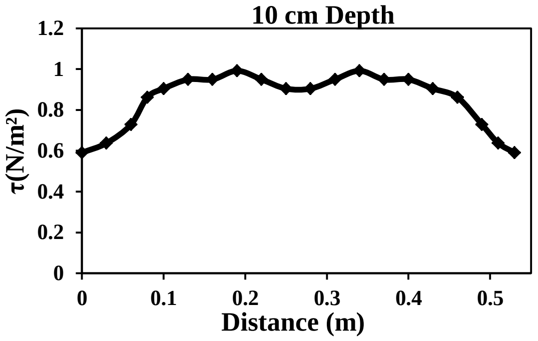
Material	Depth of Flow, H (m)	Area of Flow, A (m^2)	Wetted Perimeter, P (m)	Hydraulic Radius, R (m)	Discharge, Q (m^3/s)	Slope, S	Manning's n	Averaged n
Smooth Channel	0.06	0.023	0.499	0.047	0.008	0.001325	0.01229367	0.012085
	0.07	0.028	0.61	0.046	0.013	0.001325	0.01105269	
	0.08	0.033	0.566	0.059	0.016	0.001325	0.01192787	
	0.09	0.038	0.584	0.065	0.018	0.001325	0.01143169	
	0.1	0.043	0.613	0.07	0.024	0.001325	0.01163107	
	0.11	0.045	0.641	0.075	0.026	0.001325	0.01417449	
Rough Channel (Gravel)	0.07	0.028	0.61	0.046	0.006	0.001	0.02	0.02
	0.08	0.033	0.566	0.059	0.008	0.001	0.02	
	0.085	0.035	0.57	0.062	0.009	0.001	0.02	
	0.09	0.038	0.584	0.065	0.01	0.001	0.02	

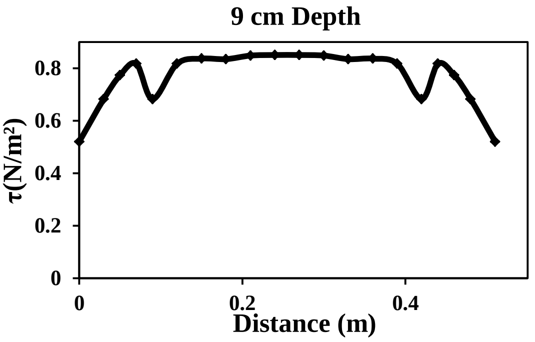
4.3 Boundary Shear Measurement

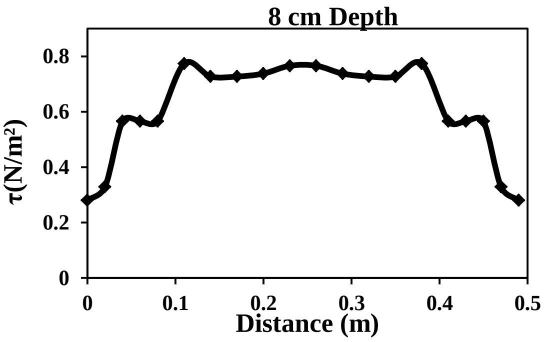
By using Preston tube technique, the boundary shear stresses along the wetted perimeter of the smooth and rough experimental channels have been presented below.

4.3.1 Smooth Channel









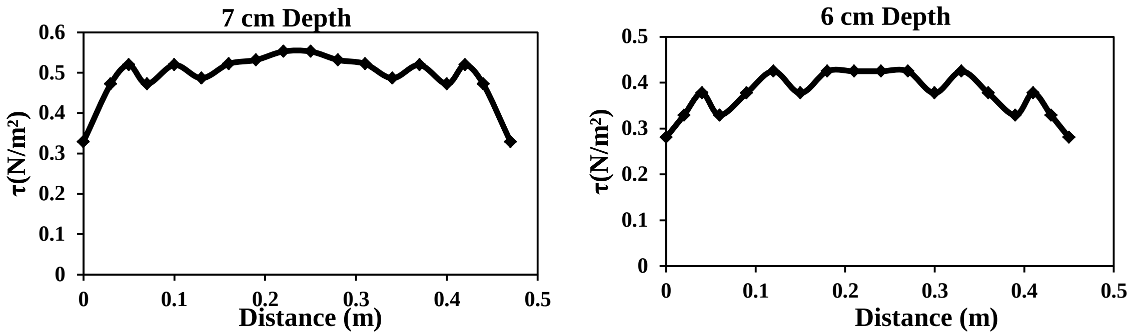


Figure:4.2 Shear stress distribution for smooth simple channel

From above Fig- 4.2 it was clearly observed that the boundary shear stress increases with the increase of flow depth in the channel. Highest shear stress for 11 cm depth is 1.0 N/m^2, for 10 cm depth 0.99 N/m^2, for 9cm depth 0.85 N/m^2, for 8 cm depth 0.76 N/m^2, for 7 cm depth 0.55 N/m^2 and for 6 cm depth 0.42 N/m^2.In the lower depth of flow the shear stress is not constant due to the higher friction between water and channel so that the difference in shear stress is high in transition zone i.e. wall and bed interface.

4.3.2 Rough Channel

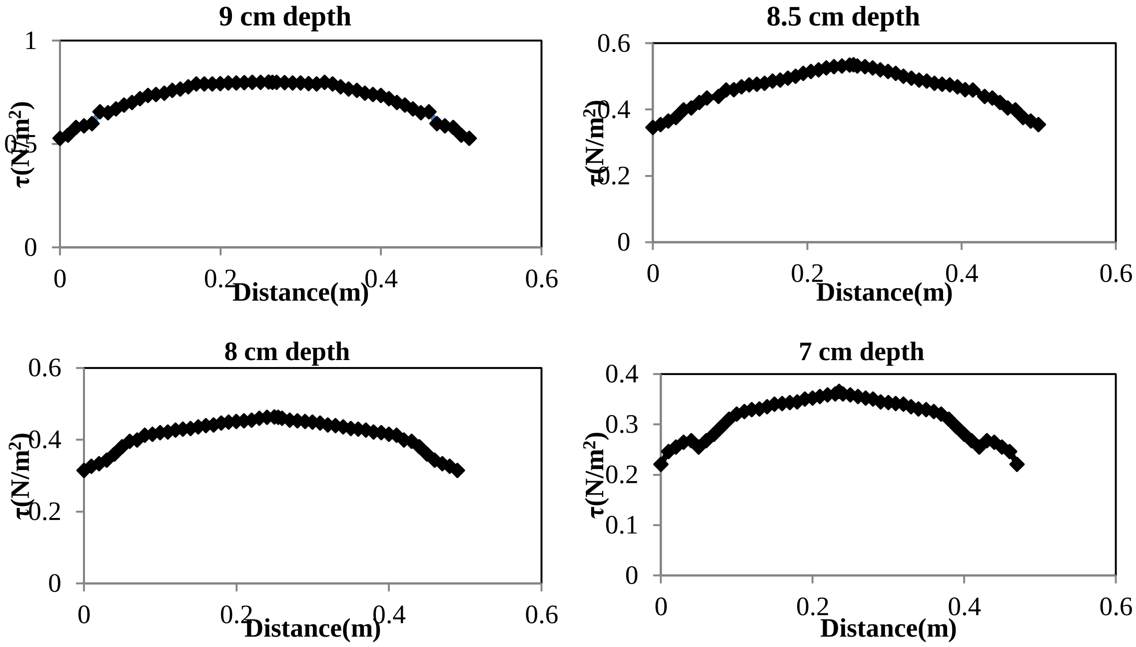


Figure:4.3Shear stress distribution forGravel Rough simple channel

From above Fig-4.3 it was clearly observed that the boundary shear stress increases with the increase of flow depth in the channel. Highest shear stress for 9cm depth is 0.95 N/m^2, for 8.5 cm depth 0.54 N/m^2, for 8 cm depth 0.46 N/m^2 and for 7 cm depth 0.36 N/m^2. Shear stress is not constant due to the higher friction between water and gravel surface of the channel so that the difference in shear stress is high in transition zone i.e. wall and bed interface of the channel.

4.4 Theoretical Analysis

4.4.1 Analytical Method For Computation of Boundary Shear Stress Distribution

Different methods for computation of boundary shear stress distribution and mean bed and shear stresses in prismatic open channel flows are compared with experimental data i.e. Vertical Depth Method (VDM), Normal Depth Method (NDM), Merged Perpendicular Method (MPM) and Yang and Lim Method (YLM).

4.4.2 Vertical Division Method (VDM)

- In Vertical Depth Method (VDM) method assumes that the local shear stress $\tau_i$on one wetted perimeter point is proportional to the local water depth hi as given by

$$\tau_i = \rho g h_i j \qquad (4.1)$$

Where ρ is the water density, g is the gravitational acceleration and j is the energy slope

- The VDM method can be applied to arbitrary cross-section shape, but in this secondary method currents and the momentum transfer between the main channel and its floodplains and the roughness distribution along the wetted perimeter is assumed to be homogeneous.
- Lundgren and Jonson (1964) identified that the concept of "vertical depth" is not adapted for calculation of boundary shear stress distribution, especially if the side slope is stepped.

4.4.3 Normal Division Method (NDM)

- They used another method to find the boundary shear distribution is called Normal Depth Method (NDM) in this method only h_i of equation (1) is replaced by h_{Ni} so equation will be

$$\tau_i = \rho g h_{Ni} j \qquad (4.2)$$

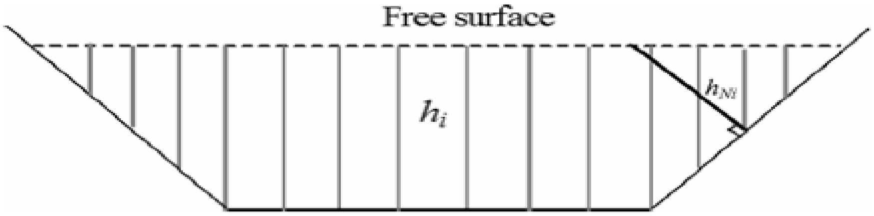


Figure:4.4 Schematic illustrations of the VDM and NDM(Lundgren and Jonson, 1964)

4.4.4 Merged Perpendicular Method (MPM)

- Geometric method was developed by Khodashenas and Paquier (1999) to compute the local shear stress in an irregular cross-section is called Merged Perpendicular Method (MPM, which is an "a cross-sectional region bounded by walls dividing into three sub-areas, corresponding to sidewalls and bed, respectively"

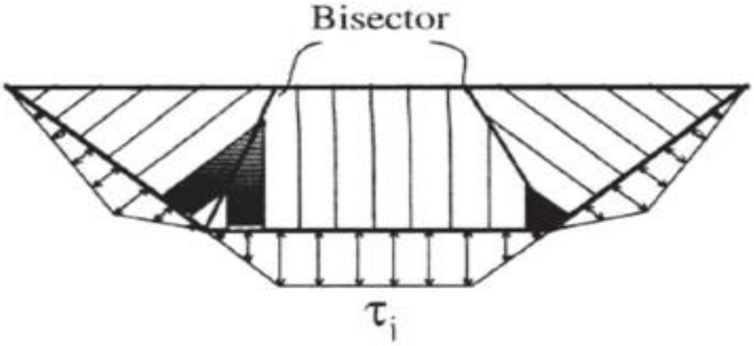


Figure: 4.5 boundary shear variations computed by MPM (Khodashenas and Paquier, 1999)

- **Procedure for computing boundary shear stress in MPM method:**

1. Divide the wetted perimeter into small segment

2. Draw the mediator of every segment

3. Every mediator that intersects the previous normal should be merged with it; the two normal will havethesame continuation. They join in a line of order 2. The direction of the new line is computed the by the weighted mean of the angles of the lines that intersect.

$$l_{j,j-1} = \frac{1}{2}(l_j + l_{j-1}) \tag{4.3}$$

4. Then, new lines can meet other normal and join into lines of higher order, the angle of which j weighted mean of the angle of the previous lines. The procedure continues to the water surface

$$l_{j,j-1,j-2} = \frac{1}{3}(2l_{j,j-1} + l_{j-2}) \tag{4.4}$$

5. The area between the final lines is computed and shear stress is computed by equation

$$\tau = \gamma . R_h . J_f \tag{4.5}$$

Where τ = boundary shear stress,γ = water specific weight,R_h = hydraulic radius computed as the ratio of the area between 2 line to length of corresponding segment, J_f = average energy slope.

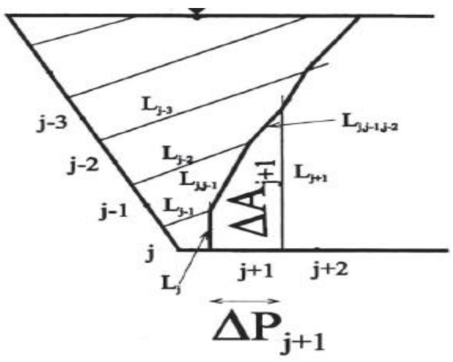


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Figure: 4.6 Area determined by M.P.M(Khodashenas and Paquier, 1999)

4.5 Velocity Profile Method for Computation of Boundary Shear Stress

One indirect method uses the graphical plotting of velocity distribution based on the work of Karman and Prandtl. Let *u1* and *u2* are the time-averaged velocities measured at *h'1* and *h'2* heights respectively from the boundary From the closely spaced velocity distribution observed in the vicinity of the channel bed and the wall we can take a difference of *u'* and *h'* between two points 1 and 2 close to each other.

$$u_* = \frac{1}{5.75}\frac{u_2-u_1}{log_{10\left(\frac{h'_2}{h'_1}\right)}} = \frac{M}{5.75} \tag{4.6}$$

Substituting$u_* = \left(\frac{\tau_0}{\rho}\right)^{0.5}$in equation (4.6) we can rewrite

$$\tau_0 = \rho\left[\frac{M}{5.75}\right]^2 \tag{4.7}$$

$M = \frac{u_{2-}u_1}{log_{10}\frac{h'_2}{h'_1}} = \frac{u_{2-}u_1}{log_{10}h'_2 - log_{10}h'_1}$ = the slope of the semi-log plot of velocity distributions near the channel bed and the wall.

4.6 Results and Comparison

In this chapter the experimental results of the smooth and rough channel are given and the results are compared with different convention method i.e. VDM, NDM, MPM and Velocity profile method are used toknow the behaviour of the boundary shear stress distribution in the channel with the depth of flow and surface condition of the channel. The convention method i.e. VDM, NDM, MPM and Velocity profile method results are compared with Preston tube technique to known the behaviour of boundary shear stress in channel gemotry.

4.6.1 Velocity Profile Method

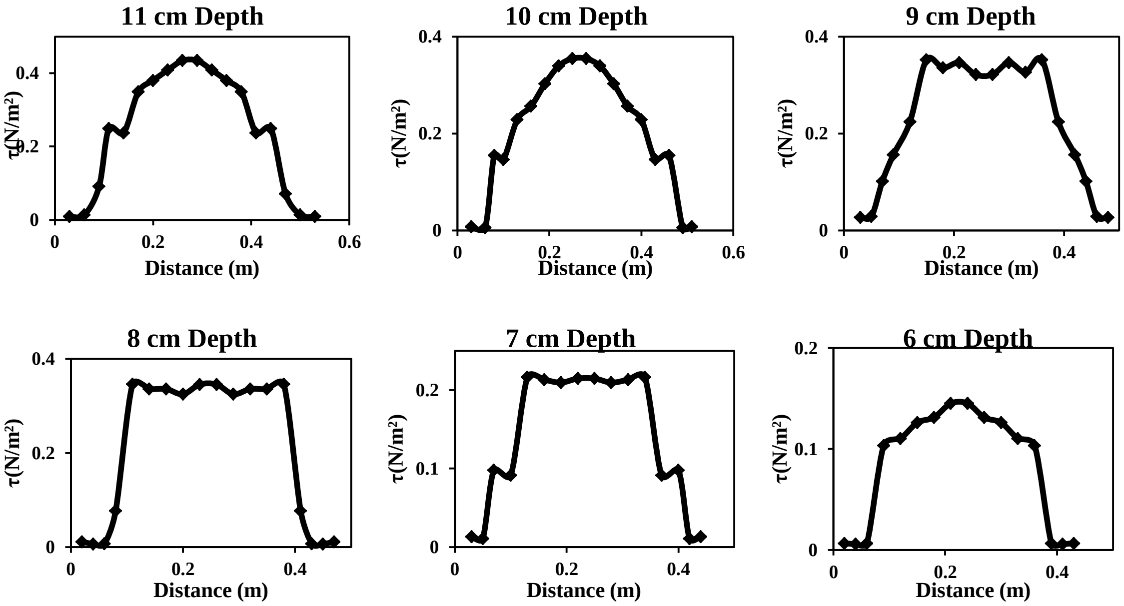


Figure: 4.7 Boundary shear distribution by Velocity profile method

4.7 Analytical Method

4.7.1 Vertical Division Method (VDM)

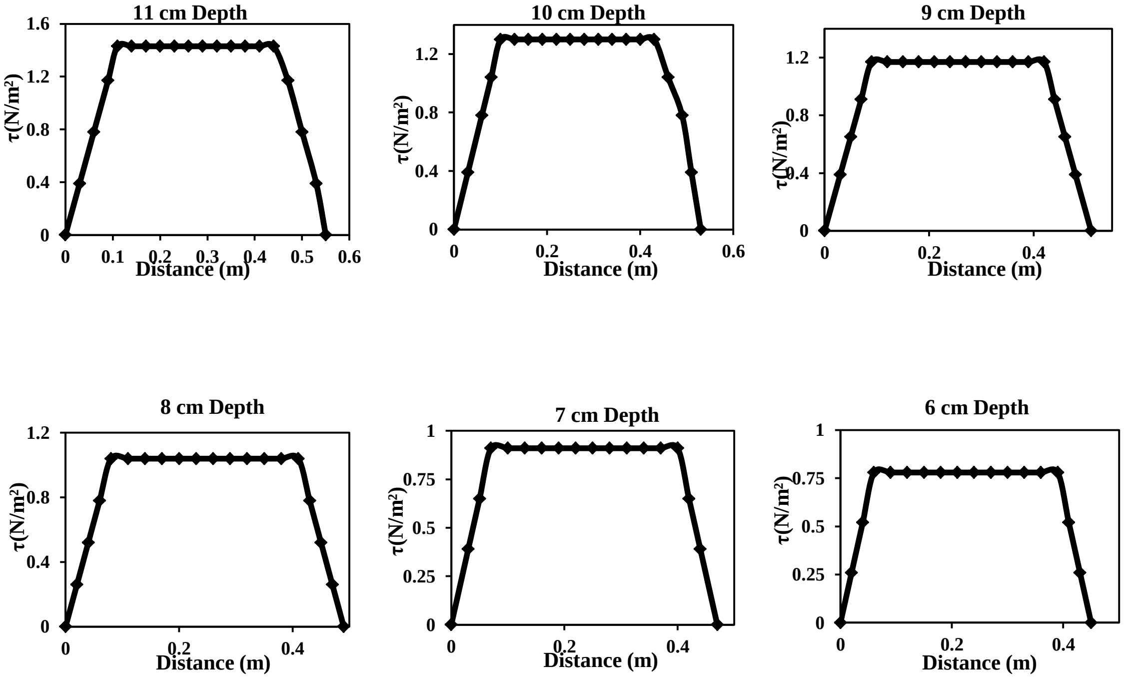


Figure: 4.8 Boundary shear distribution by VDM

4.7.2 Normal Division Method (NDM)

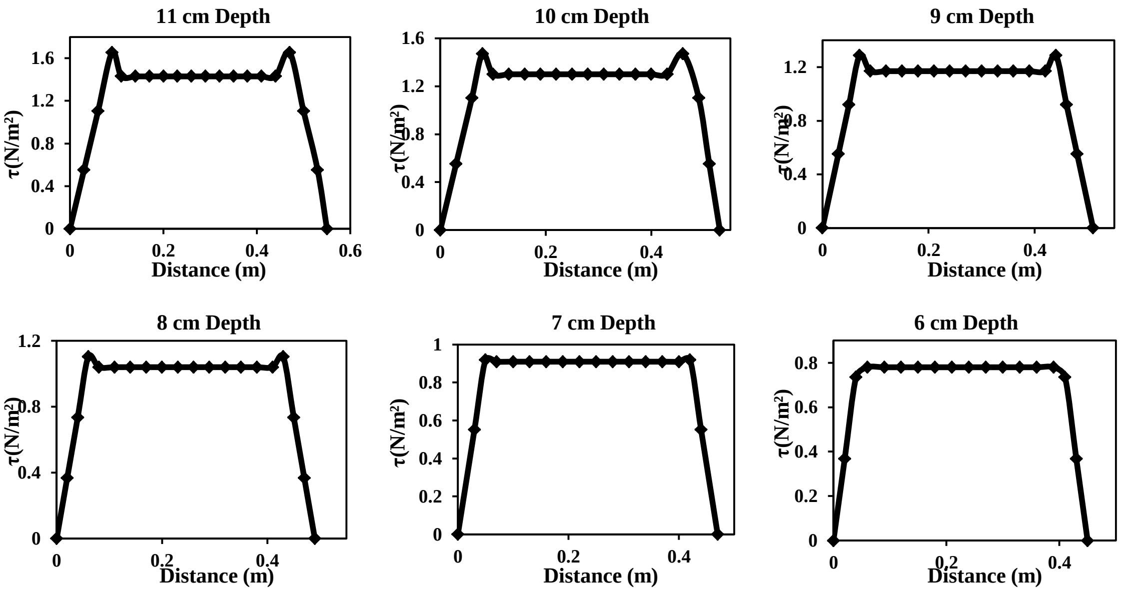


Figure: 4.9 Boundary shear distribution by NDM

4.7.3 Merged Perpendicular Method (MPM)

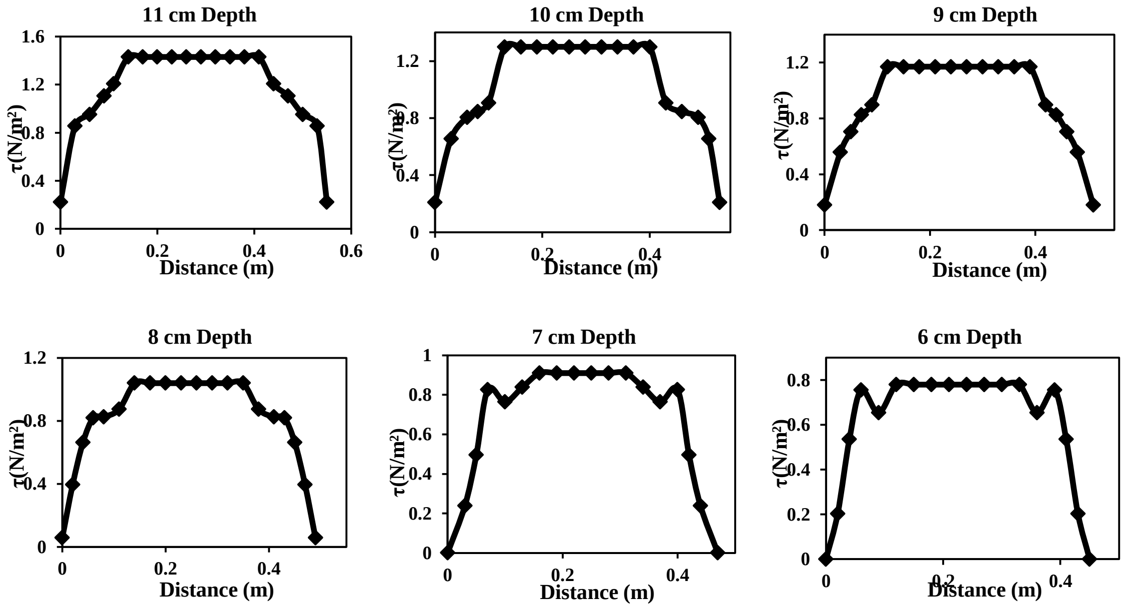


Figure: 4.10 Boundary shear distribution by MPN

4.8 Comparison of All Methods

All analytical methods are compared with the piston tube technique for estimation of boundary shear. Fig 4.11 shows the analytical method VDM,NDM,MPM are over predicting the boundary shear value as compared to that of values from piston tube technique however the velocity profile methodunder predicts the boundary shear for all data sets.

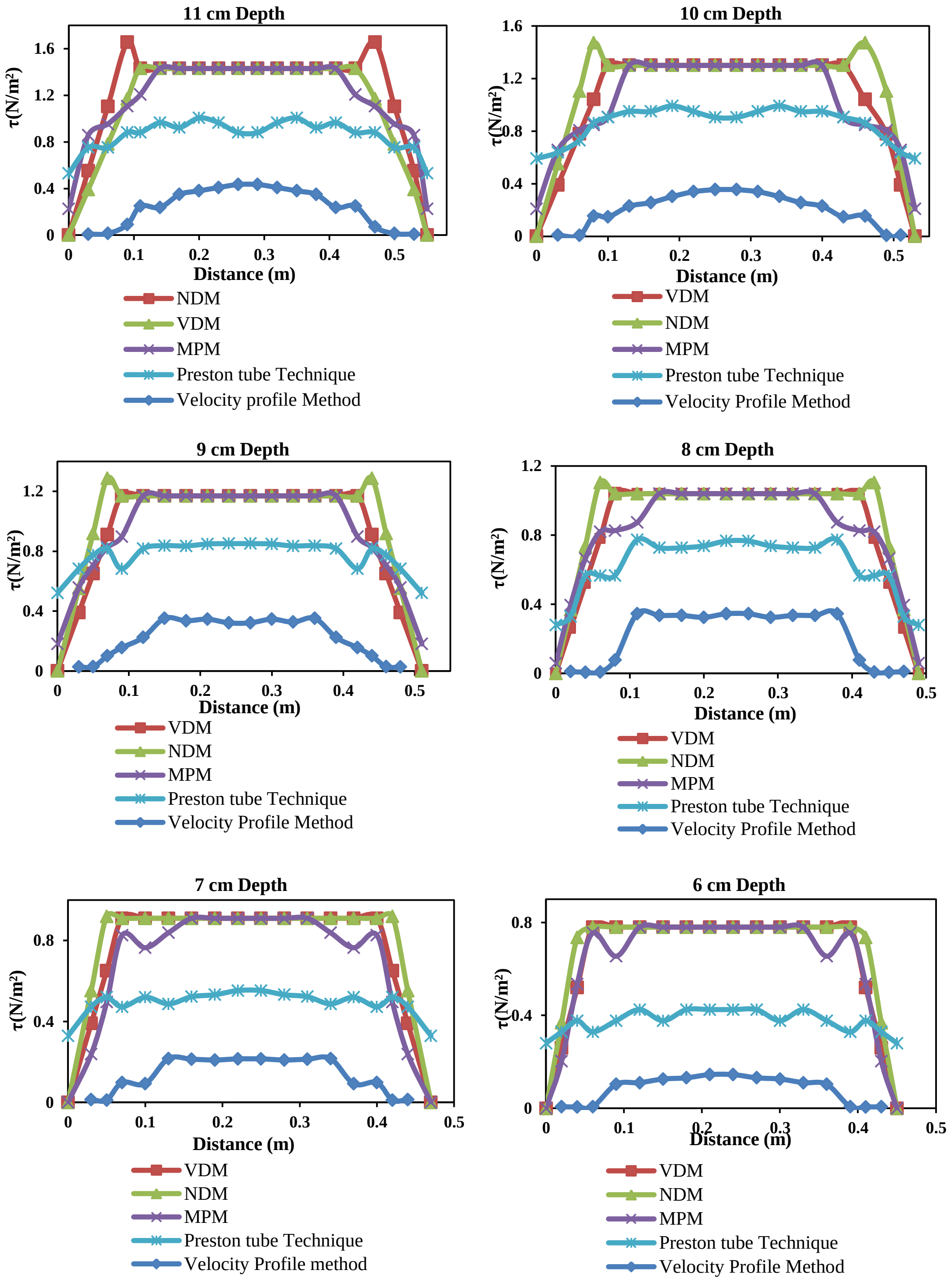


Figure: 4.11 Comparison of all Methods

Chapter-5

Model Development

5.1 Behaviour of Percentage of Shear with Hydraulic Parameters for Smooth Channels

The nature of dependency of shear force with geometric and hydraulic parameters varies from channel to channel, roughness and flow depth etc. The importance of these study needs to be investigated from many experimental data sets to know its influence on the smooth simple channel in terms of percentage.

5.1.1 Smooth Simple Channel Data:

Table 3 shows the details of details features of flow depth, flow aspect ratio, manning's roughness coefficient, the percentage of shear force carried by the wall and bed and the longitudinal slope of the channel of different researches.

Table: 3 Collection of data for Smooth Simple Channel of different researches

Author	Manning's *n*	*H*(mm)	*B/H*	*%Sw*	*%Sb*	*So*
Authors data(2016)	0.01	60-110	3-5.5	23.4-34.9	65.0-76.8	0.001325
Mohanty (2013)	0.008-0.015	30-65	5.07-11	10.5-17.2	82.8-90	1.1x10^-3
Lashkar et.al (2010)	0.009-0.0096	13-101	7.92-18.6	6.23-16.6	83.5-93.8	2.0x10^-3
Seckin et.al (2006)	0.0089-0.01	29.9-60.4	6.9-14.79	8.07-18.4	81.56-91.9	2.02x10^-3
Atbay(2001)	0.008-0.009	26.3-95	4.19-15.2	7.13-27.5	72.4-92.9	2.0x10^-3
FCF	0.0098-0.01	48.6-148	10.0-30.0	3.42-10.3	89.7-96.6	1.02x10^-3
Alhamid(1991) 1	0.0246-0.027	56.2-94	1.49-2.49	47.9-64.0	35.91-52.11	3.92x10^-3
Alhamid(1991) 2	0.021-0.0222	49.5-74.2	3.99-5.98	29.0-38.1	61.81-70.97	3.92x10^-3
Alhamid(1991) 3	0.021-0.024	57.0-95.3	1.51-2.51	49.1-63.0	37.1-51.0	3.92x10^-3
Alhamid(1991) 4	0.0217-0.023	44.1-58.8	7.49-9.98	18.0-24.1	75.87-81.91	4.03x10^-3
Yuen(1989)	0.009-0.010	50-150	1-3	50-72.5	27.53-55.7	1.0x10^-3
Knight et.al (1984) 1	0.009-0.010	103.8-224	0.31-.67	73.6-85.2	14.8-26.4	9.66x10^-3
Knight et.al (1984) 2	0.009-0.0104	76-153	0.99-2.0	47.5-67	33-52.5	9.66x10^-3
Knight et.al (1984) 3	0.009-0.0105	56.1-123	3.09-6.76	19.9-35.6	64.4-80.1	9.66x10^-3
Knight et.al (1984) 4	0.009-0.0106	31.9-90.2	6.8-19.12	6.9-19.6	80.4-93.1	9.66x10^-3
Flintham(1988) 1	-	-	0.92-6.36	23.6-71.1	28.9-76.4	-
Flintham (1988) 2	-	-	0.98-4.64	29-73.4	26.6-71	-
Noutsopoulos and Hadjipanos (1982)	-	-	2.1-23.73	5.6-44.5	53-94.4	-
Mayer(1978)	0.009-0.01	111-164	1.56-2.28	45-56.5	43.5-55.1	2.64x10^-3

5.1.2 Smooth Simple Channel

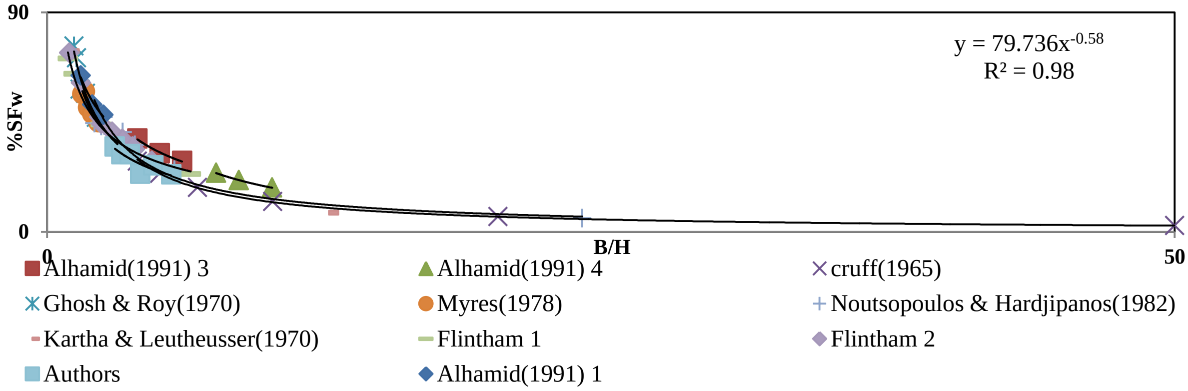


Figure: 5.1 Percentage of Shear Force on Wall versus B/H of Smooth Simple Channel

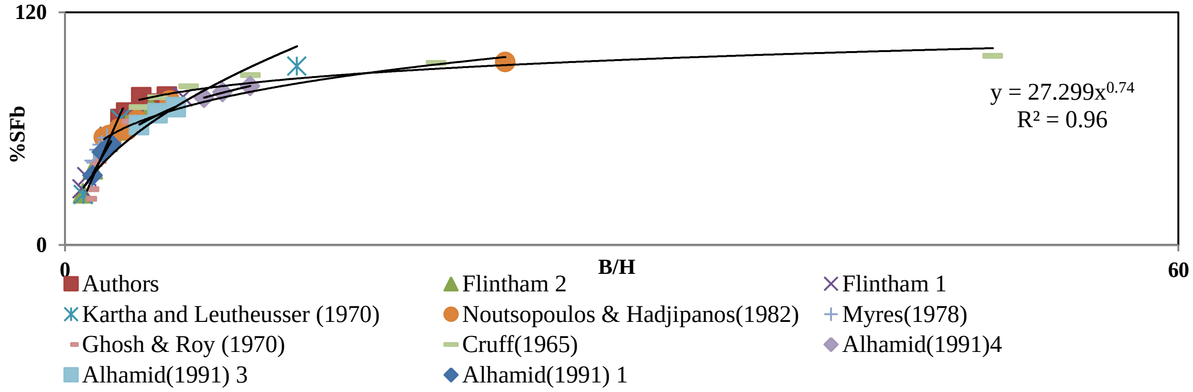


Figure: 5.2 Percentage of Shear Force on Bed versus B/Hof Smooth Simple Channel

The graphical presentation of boundary shear stress distribution for simple channels in terms of percentage shear on bed ($\%S_b$) and percentage shear on wall ($\%S_w$) against *B/H* has been done. Where, *B* is the bottom width of the channel and *H* is the flow depth. More data sets have been collected from other literatures for examining this distribution. Fig.5.1 and Fig.5.2 show the boundary shear stress distribution$\%S_b$ and $\%S_w$ for simple channel where the roughness of wall and bed are same. The distribution of shear on wall ($\%S_w$) provides falling trend where as distribution of shear on wall ($\%S_b$) provides a reverse trend of that. It is concluded that when flow increase the shear stress also increases on bed however decreases on wall.

5.2 Behaviour of Percentage of Shear with Hydraulic Parameters for Rough Channels

The nature of dependency of shear force with geometric and hydraulic parameters varies from channel to channel, roughness and flow depth etc. The importance of these studyneeds to be investigated from many experimental data sets to know its influence on rough simple channel in terms of percentage

5.2.1 Rough Simple Channel Data

Table 4 shows the details of details features of flow depth, flow aspect ratio, manning's roughness coefficient, the percentage of shear force carried by the wall and bed and the longitudinal slope of the channel of different researches.

Table:4 Collection of data for Rough Simple Channel of Different researches

Author	**Manning's *n***	***H*(mm)**	***B/H***	***%Sw***	***%Sb***	***So***
Authors data(2016)	0.012	70-90	3.6-4.71	25.6-34.2	65.7-74.4	0.001
Alhamid(1991) 1	0.018-0.021	43-126	1.85-2.49	84.6-94.7	5.3-15.3	3.92x10^-3
Alhamid(1991) 2	0.016-0.018	48-142	0.085-2.5	79.4-92.8	7.13-20.4	3.92x10^-3
Alhamid(1991) 3	0.013-0.014	54.5-90.8	2.9-4.99	64.4-74.7	25.3-35.6	3.92x10^-3
Alhamid(1991) 4	0.016-0.017	51.1-84.9	3.0-5.0	73.6-81.1	18.8-26.3	3.92x10^-3
Alhamid(1991) 5	0.012-0.013	40-66.7	5.9-9.98	56.3-67.8	32.1-43.6	3.92x10^-3
Alhamid(1991) 6	0.010-0.011	41.6-69.5	5.98-10.0	46.9-59.6	40.3-53.1	1.93x10^-3
Flintham& carling (1988) 1	-	-	0.73-3.63	30.8-75	25-69.2	-
Flintham& carling (1988) 2	-	-	1.13-5.35	19.1-58.6	41.4-80.9	-
Flintham& carling (1988) 3	-	-	1.05-5.05	15.2-45.6	54.4-84.8	-
Flintham& carling (1988) 4	-	-	0.8-8.872	5.5-51.2	48.8-94.5	-

5.2.2 Rough Simple Channel

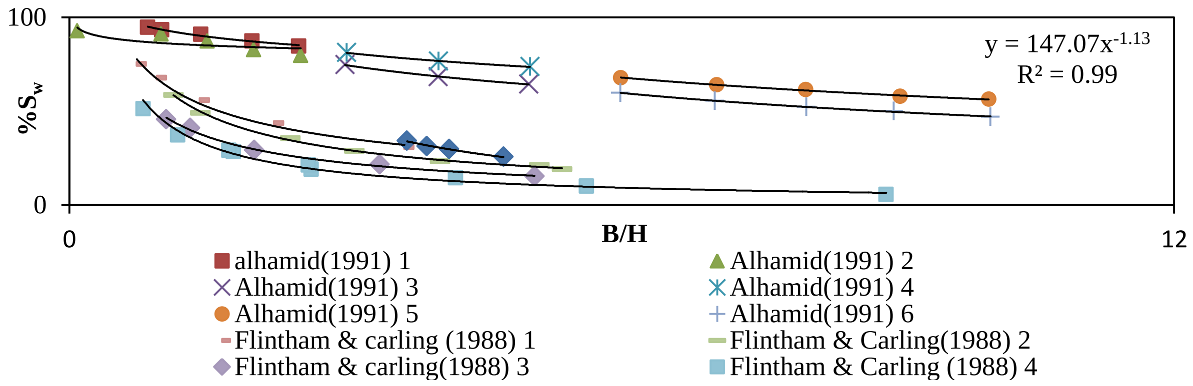


Figure: 5.3 Percentage of Shear Force on Wall versus B/Hof Rough Simple Channel

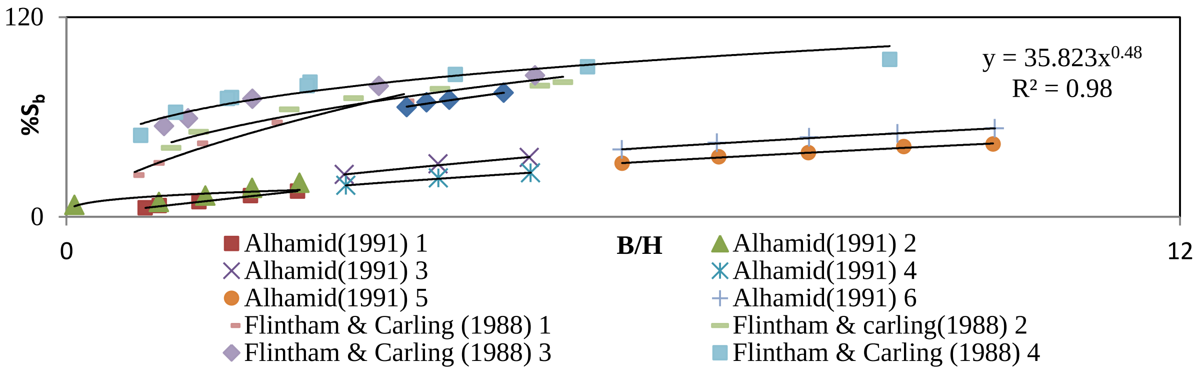


Figure: 5.4 Percentage of Shear Force on Bed versus B/Hof Rough Simple Channel

Fig.5.3 and Fig.5.4 demonstrate the variation percentage shear on bed$(\%S_b)$ and percentage shear on wall$(\%S_w)$ against *B/H* for the channels where the wall and bed having different roughness. The similar results of upward curve of $\%S_b$with $^B/_H$and down ward curve of $\%S_w$ with $^B/_H$have been observed for all data sets.But the distribution in different rough channels isnot identical with the magnitude of shear force as this distribution of shear greatly varies with different geometry and roughness.But one can observe that when the roughness of wall and bed are same, the variations of dependent parameters $(\%S_b, \%S_w)$ with independent parameters $(^B/_H)$are identical in shear force values. The percentage shear on bed$(\%S_b)$ and on wall$(\%S_w)$ of all the channels having same roughness are meeting at one place making one trend.

5.3 Behaviour of Percentage of Shear with Hydraulic Parameters for Smooth Compound Channels

The nature of dependency of shear force with geometric and hydraulic parameters varies from channel to channel, roughness and flow depth etc. The importance of these study needs to be investigated from many experimental data sets to know its influence on smooth compound channel and in terms of percentage

5.3.1 Smooth Compound Channel Data

Table 5 shows the details of details features of flow depth, flow aspect ratio, manning's roughness coefficient, the percentage of shear force carried by the wall and bed and the longitudinal slope of the channel of different researches.

Table: 5 Collection of data for Smooth Compound Channel of Different researches

Author	**Manning's *n***	**Width ratio(α)**	**Relative depth(β)**	**Aspect ratio(δ)**	***%Smc***	***%Sfp***	***So***
B.Rezaei (2006)	0.01	1.5-3.0	0.152-0.537	8	41.0-82.3	17.6-58.9	2.03x10^-3
K.K	001	3.67	0.15-0.36	1	24.1-58.9	41.1-75.9	0.0019

Khatua(2007)							
FCF-2	0.01	4.2	0.041-0.0479	10	58.1-89.5	10.5-41.8	0.0001027
FCF-3	0.01	2.2	0.041-0.0479	10	58.1-89.5	10.5-41.8	0.0001027
FCF-8	0.01	4	0.05-0.499	10	26.6-72.0	27.9-73.4	0.0001027
FCF-10	0.01	4.4	0.05-0.463	10	36.1-82.4	17.6-63.9	0.0001027

5.3.2 Smooth Compound Channel

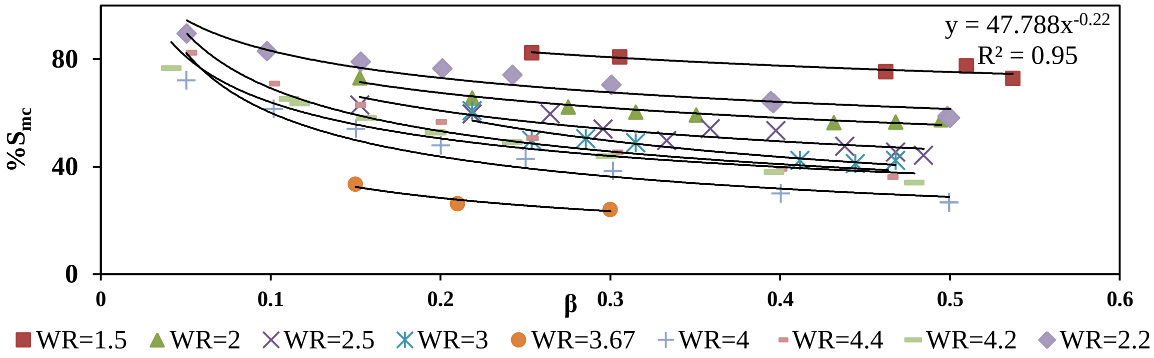


Figure: 5.5 Percentage of Shear Force on %Smc versus β of Smooth Compound Channel

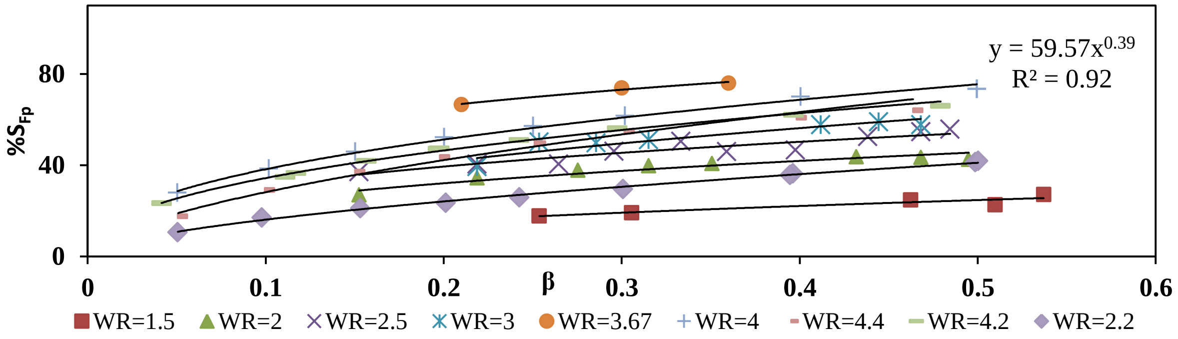


Figure: 5.6 Percentage of Shear Force on %Sfp versus β of Smooth Compound Channel

The dependency of percentage shear force in main channel $\%S_{mc}$ and percentage shear force in flood plain $\%S_{fp}$against relative flow depth$(\beta)$for smooth compound open channel flow have been presented in the Fig.5.5 and 5.6. The rising trends have been observed here and the clear dependence of both depended and independent variables obey power function with high regression coefficient of 0.92. The power functional relationship is presented by$\%S_{mc} and\ \%S_{fp} = a\beta^{b}$, where a and b are coefficient of regerssion.The trends observed for $\%S_{mc}$ with $\beta$are down in nature means when the flow depth rises, the boundary shear distribution on main channel decreases. But the reverse upward curve have been observed for flood plain cases. That means with increase in depth, the flood plain shear also increases causing reduction in main channel.

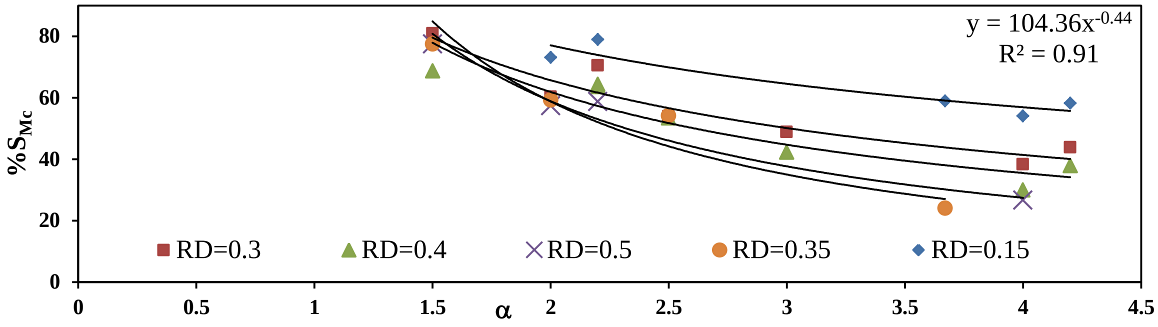


Figure: 5.7 Percentage of Shear Force on %Smc versus α of Smooth Compound Channel

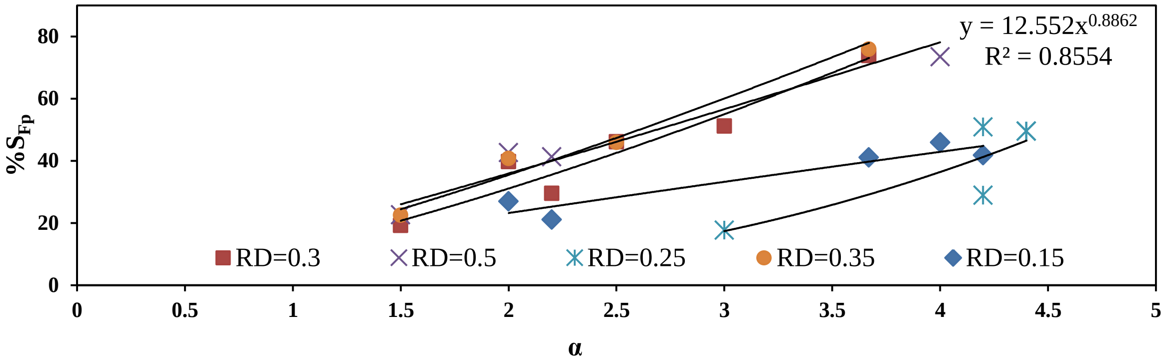


Figure: 5.8 Percentage of Shear Force on %Sfp versus α of Smooth Compound Channel

The graphical presentation of percentage shear force in main channel $\%S_{mc}$ andpercentage shear force in flood plain $\%S_{fp}$against width ratio(α) have been presented in the Fig.5.7 and Fig 5.8.The functional dependency of percentage shear force in main channel $\%S_{mc}$ and flood plain are also power in nature.It has been clearly observed that $\%S_{mc}$ decreases with increase of width ratio but $\%S_{fp}$ increases with increase of width ratio. That means when channel widens the boundary shear force is reducing on main channel leading to increase inshear on flood plain. The power functional relationship is presented by $\%S_{mc}\ and\ \%S_{fp} = c\beta^{d}$, where c and d are coefficient of regerssion.

5.4 Behavior of Percentage of Shear with Hydraulic Parameters for Rough Compound Channels

The nature of dependency of shear force with geometric and hydraulic parameters varies from channel to channel, roughness and flow depth etc. The importance of these study needs to be investigated from many experimental data sets to know its influence on rough compound channel and in terms of percentage

5.4.1 Rough Compound Channel Data

Table 5 shows the details of details features of flow depth, flow aspect ratio, manning's roughness coefficient, the percentage of shear force carried by the wall and bed and the longitudinal slope of the channel of different researches.

Table: 6 Collection of data for Rough Compound Channel of Different researches

Author	Manning's *n*	Width ratio(α)	Relative depth(β)	Aspect ratio(δ)	*%Smc*	*%Sfp*	*So*
FCF-7	-	4.2	0.093-.504	10	64.9-76.9	23.1-35.1	0.0001027
FCF-11	-	4.4	0.096-0.505	10	97.5-100	0-2.524	0.0001027
N.Sahoo	0.00983	15.75	0.279-0.407	1.5	26.0-32.6	67.3-74.0	0.00311
	0.01097	15.75	0.288-0.41	1.5	28.6-37.0	63.0-71.3	0.00311
	0.01449	15.75	0.275-0.41	1.5	26.4-41.2	58.8-73.5	0.00311

5.4.2 Rough Compound Channel

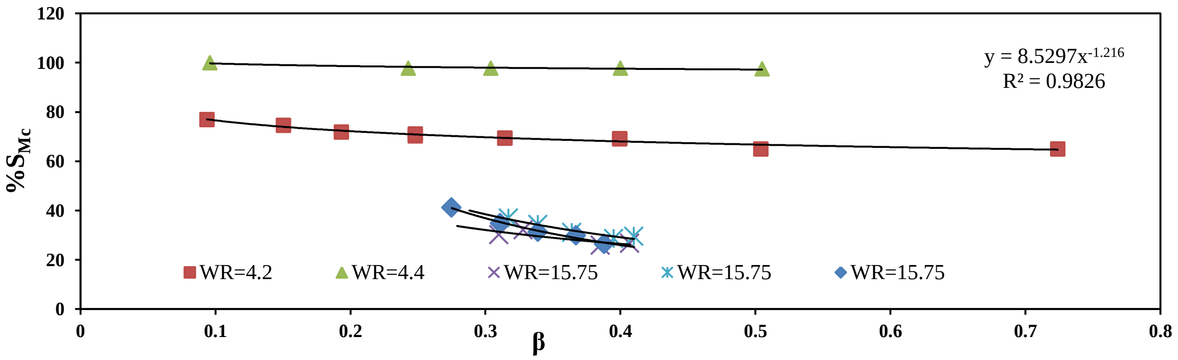


Figure: 5.9 Percentage of Shear Force on %Smc versus β of Rough Compound Channel

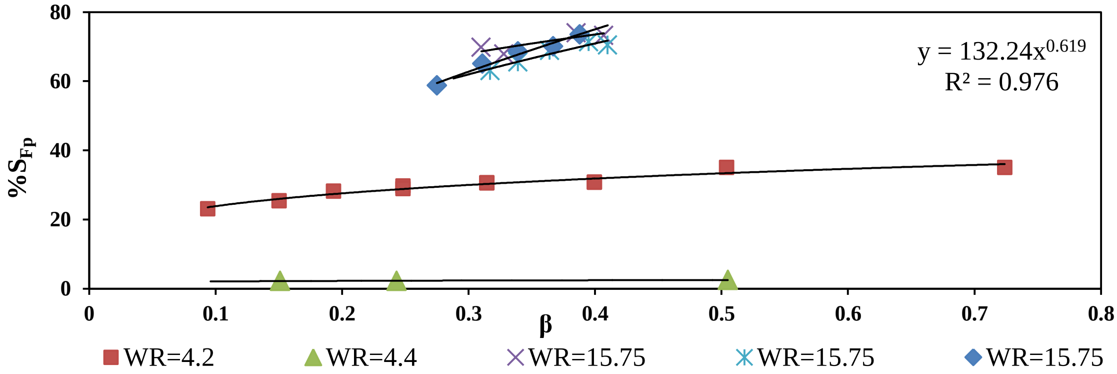


Figure: 5.10 Percentage of Shear Force on %Sfp versus β of Rough Compound Channel

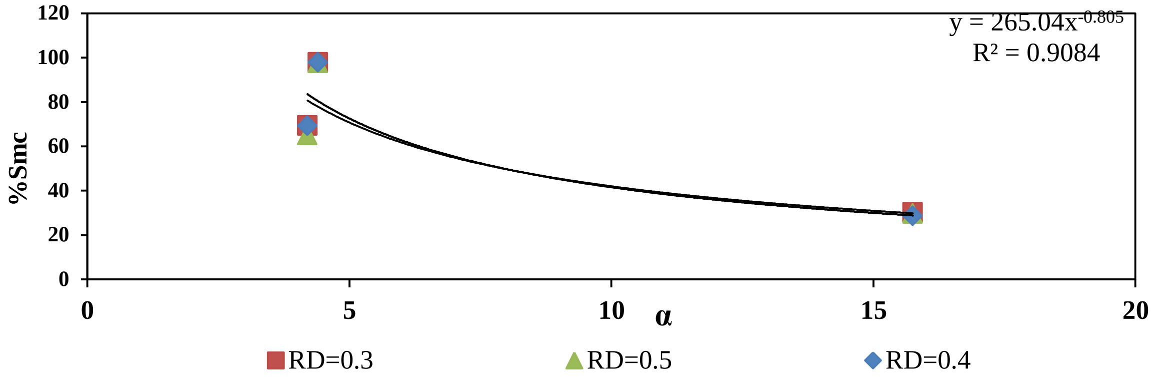


Figure: 5.11 Percentage of Shear Force on %Smc versus α of Rough Compound Channel

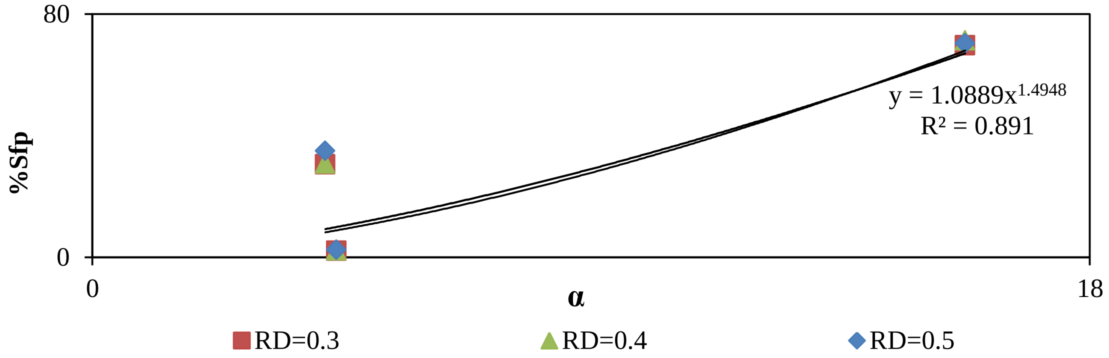


Figure: 5.12 Percentage of Shear Force on %Sfp versus β of Rough Compound Channel

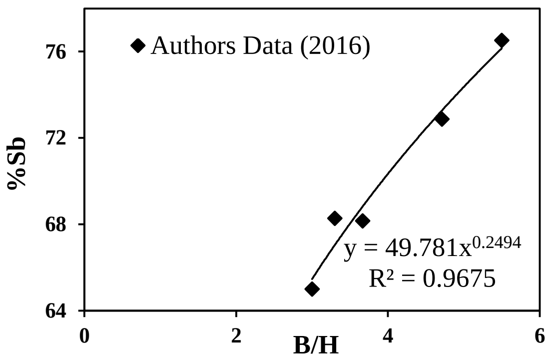
The dependency of percentage shear force in main channel $\%S_{mc}$ and percentage shear force in flood plain $\%S_{fp}$against relative flow depth(β) and width ratio$(\alpha)$for rough compound open channel flow have been presented in the Fig.5.9,Fig.5.10, Fig.5.11 and Fig.5.12. The channels , used here are of different roughness in main channel and flood plain. Mainly the main channels are smooth and flood plains are having various roughness. The similar identical trends as smooth compound channel have been observed for rough cases. The trends for $\%S_{mc}$ with $\beta$are down in nature means when the flow depth rises, the boundary shear distribution on main channel decreases. But the reverse upward curve have been observed for flood plain cases. That means with increase inan depth, the flood plain shear also increases causing reduction in main channel.The best functional relationships of both depended and independent variables show power in nature with high regression coefficient of 0.9. It has also been clealy observed the same natures of trend of $\%S_{mc}$and$\%S_{fp}$ with width ratio are noticed as found for smoothy open channel cases. That means when channel widens the boundary shear force is reducing on main channel leading to increase inshear on flood plain.

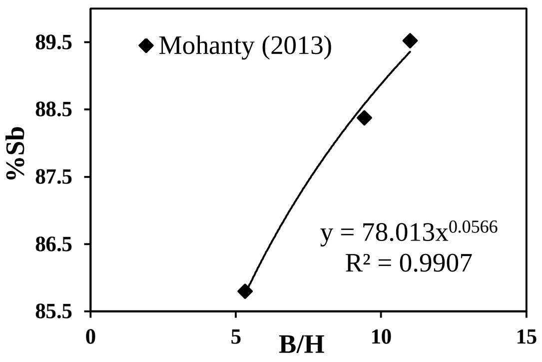
5.5 Collection of Data for Model Development

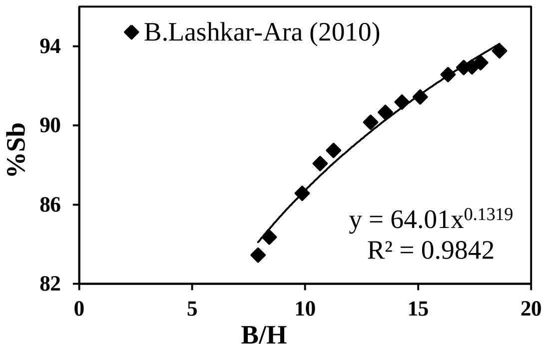
5.5.1 Smooth Channel

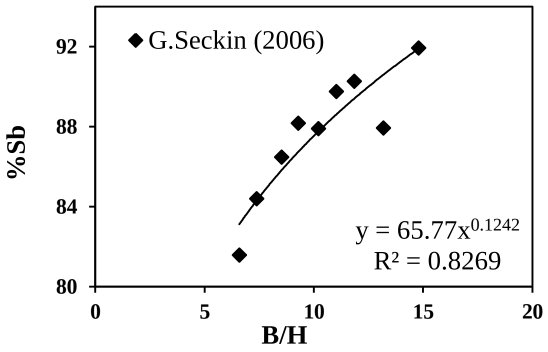
The variation of percentage of boundary shear force at bed $(\%S_b)$with non-dimensional parameter i.e., aspect ratio$\left(B/_H\right)$, Reynolds no (Re) and Froude no (Fr) have been observed and presented graphically for different researchers data sets.

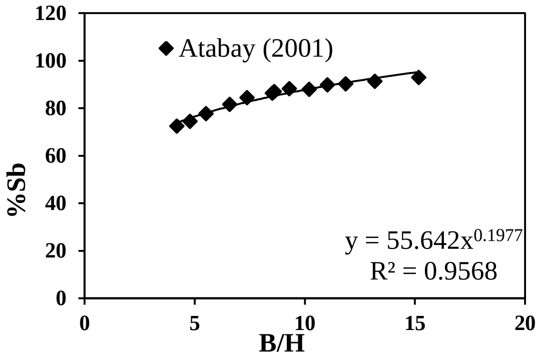
- **Influence of flow aspect ratio $\left(B/_H\right)$on percentage of shear force $(\%\boldsymbol{S_b})$**

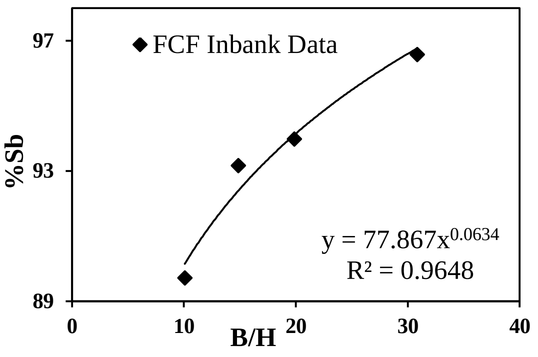


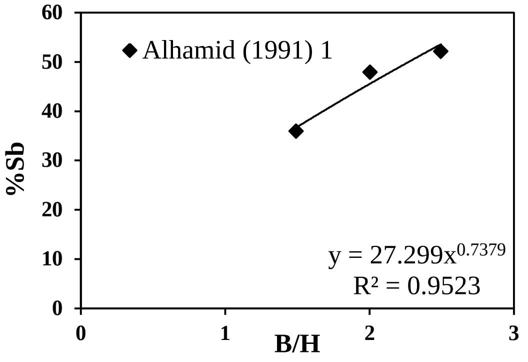


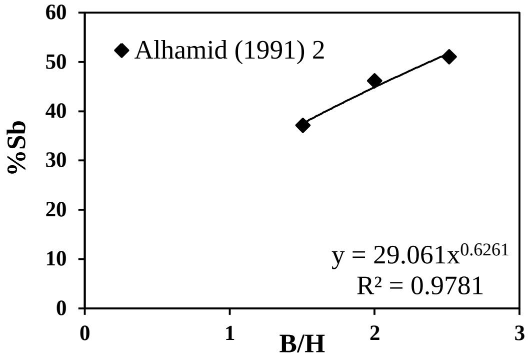


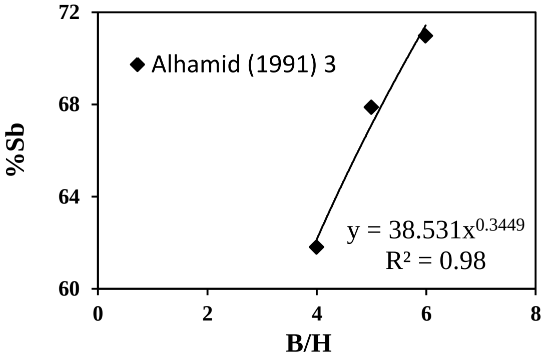


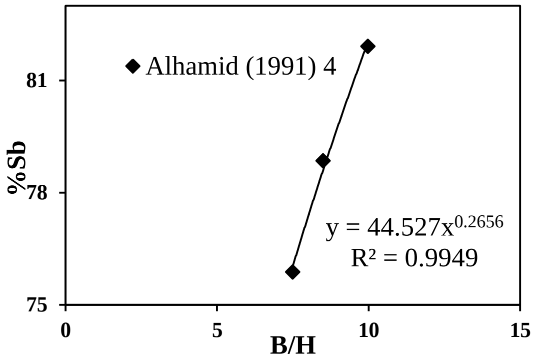


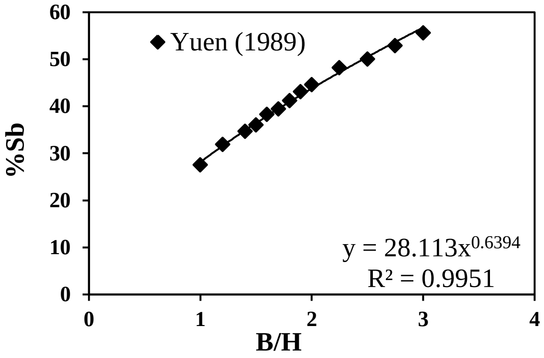


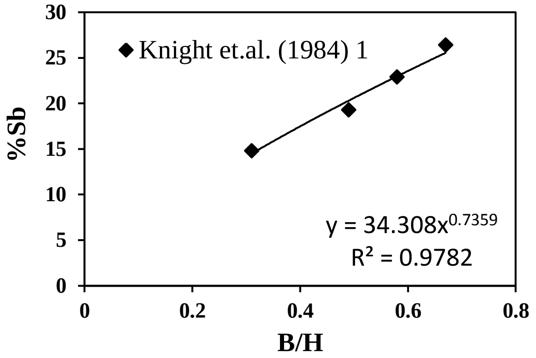

◆ Alhamid (1991) 1
%Sb
B/H
y = 27.299x^0.7379
R² = 0.9523
0
10
20
30
40
50
60
0
1
2
3

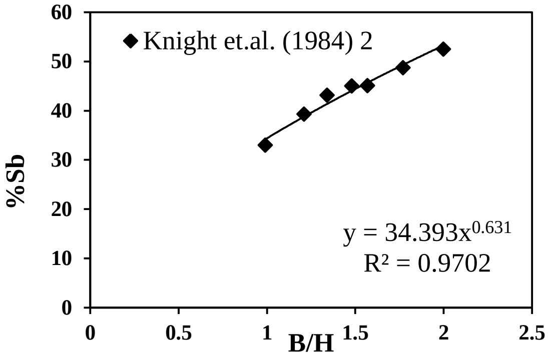

◆ Alhamid (1991) 2
%Sb
B/H
y = 29.061x^0.6261
R² = 0.9781
0
10
20
30
40
50
60
0
1
2
3

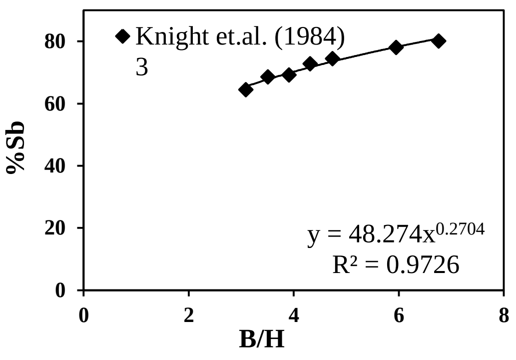

◆ Alhamid (1991) 3
%Sb
B/H
y = 38.531x^0.3449
R² = 0.98
60
64
68
72
0
2
4
6
8


◆ Alhamid (1991) 4
%Sb
B/H
y = 44.527x^0.2656
R² = 0.9949
75
78
81
0
5
10
15


◆ Yuen (1989)
%Sb
B/H
y = 28.113x^0.6394
R² = 0.9951
0
10
20
30
40
50
60
0
1
2
3
4


◆ Knight et.al. (1984) 1
%Sb
B/H
y = 34.308x^0.7359
R² = 0.9782
0
5
10
15
20
25
30
0
0.2
0.4
0.6
0.8


◆ Knight et.al. (1984) 2
%Sb
B/H
y = 34.393x^0.631
R² = 0.9702
0
10
20
30
40
50
60
0
0.5
1
1.5
2
2.5


◆ Knight et.al. (1984) 3
%Sb
B/H
y = 48.274x^0.2704
R² = 0.9726
0
20
40
60
80
0
2
4
6
8

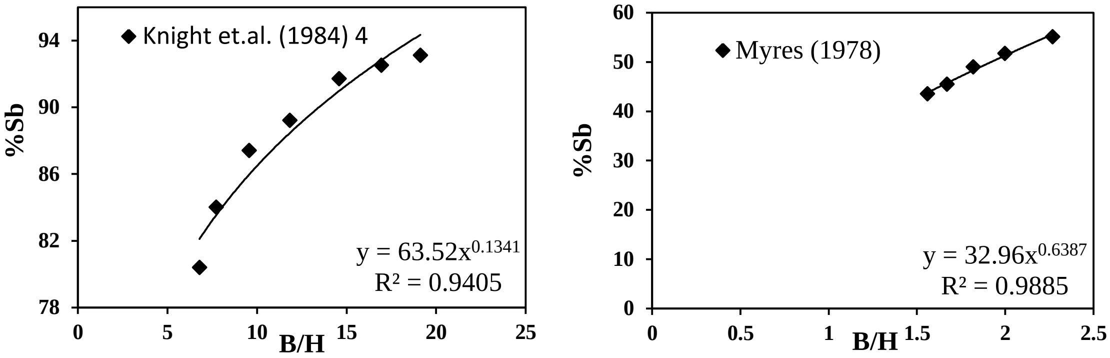
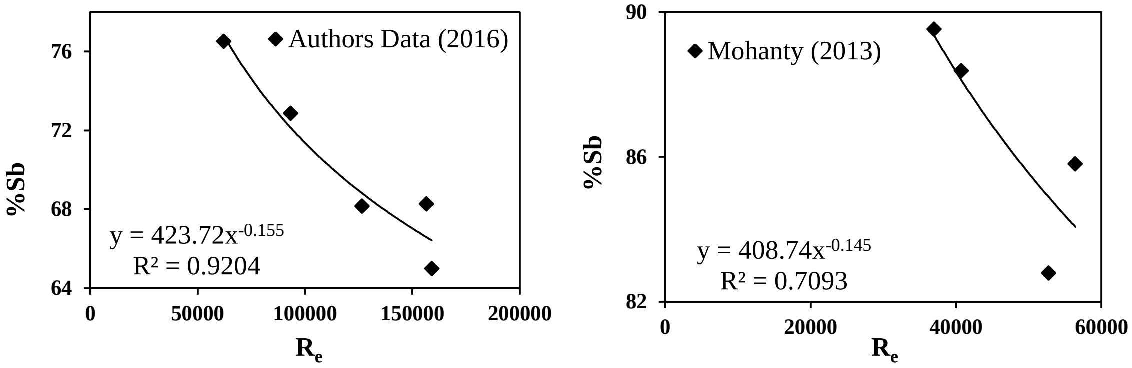


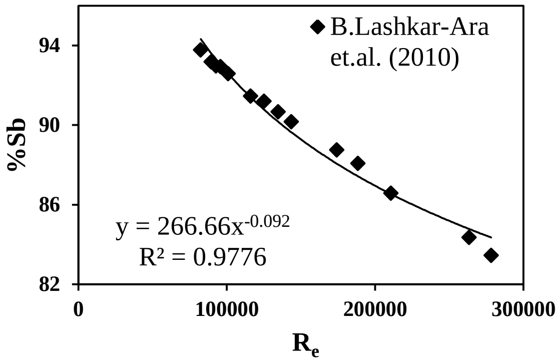
Figure: 5.13 Percentage of Shear Force on Bed versus B/H of Smooth Channel

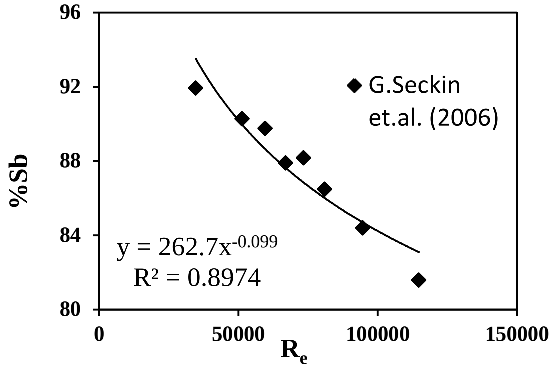
This finding from the Fig-5.13 show that the Percentage of shear force $(\%S_b)$ increases with rise in flow aspect ratio$({}^{B}/_{H})$. It's due to the rise in bed width that increases the bed shear due to a large contacting area.Percentage of shear force $(\%S_b)$ increases with increase in width of the channel and decreases with decrease in depth of the flow. The increase is high for higher flow depth and for low flow depth increase is less. The variation of percentage of shear force $(\%S_b)$ are found to be power function with a higher R^2 value.

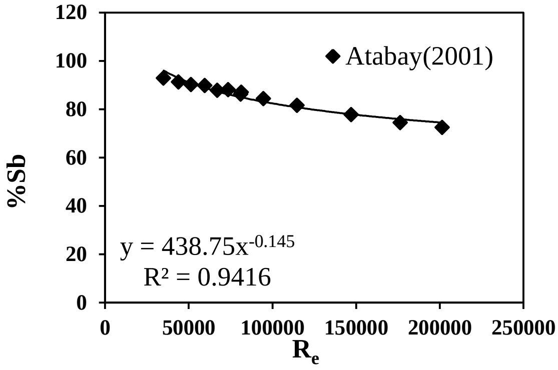
- **Influence of Reynolds no (R_e) on Percentage of shear force $(\%S_b)$**

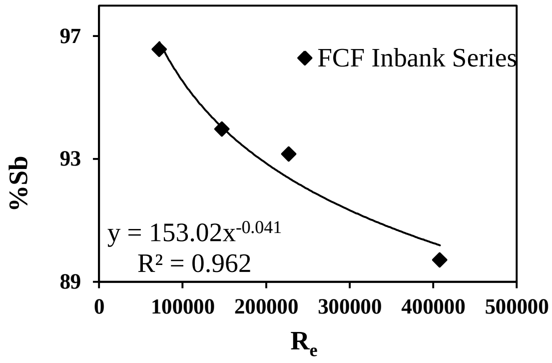
Fig 5.14 depicts the variation of percentage of shear force $(\%S_b)$ with the Reynolds number(R_e). It is clearly demonstrated in these figures that the $\%S_b$ decreases with increase in Reynolds number.

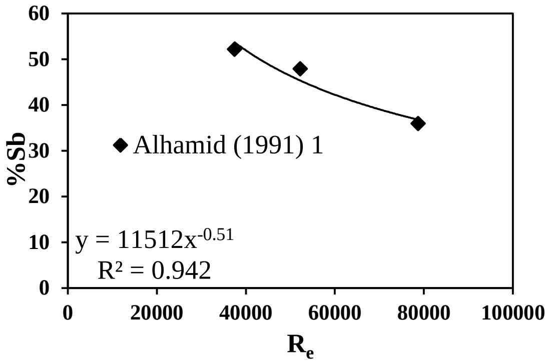


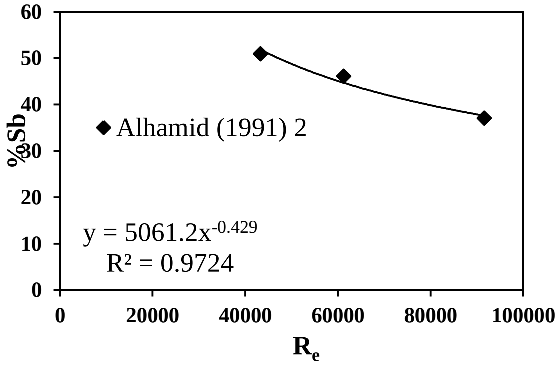

◆ B.Lashkar-Ara et.al. (2010)
y = 266.66x^-0.092
R² = 0.9776
%Sb
94
90
86
82
0
100000
200000
300000
Re

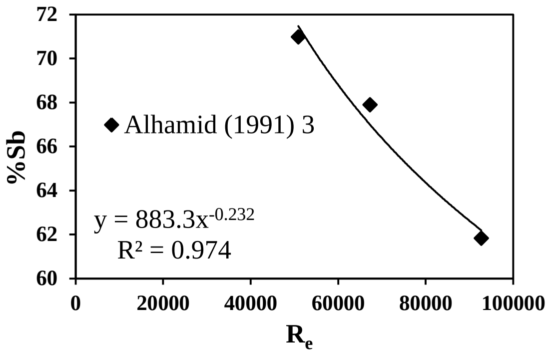

◆ G.Seckin et.al. (2006)
y = 262.7x^-0.099
R² = 0.8974
%Sb
96
92
88
84
80
0
50000
100000
150000
Re

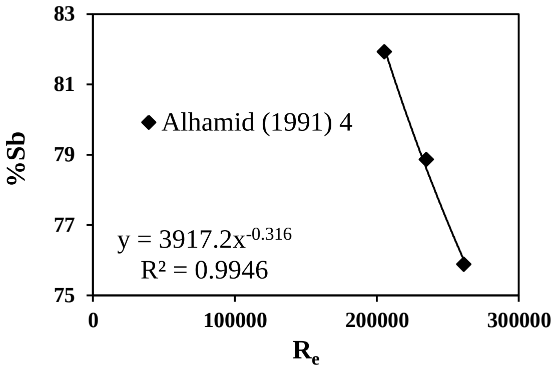

◆ Atabay(2001)
y = 438.75x^-0.145
R² = 0.9416
%Sb
120
100
80
60
40
20
0
0
50000
100000
150000
200000
250000
Re


◆ FCF Inbank Series
y = 153.02x^-0.041
R² = 0.962
%Sb
97
93
89
0
100000
200000
300000
400000
500000
Re


◆ Alhamid (1991) 1
y = 11512x^-0.51
R² = 0.942
%Sb
60
50
40
30
20
10
0
0
20000
40000
60000
80000
100000
Re


◆ Alhamid (1991) 2
y = 5061.2x^-0.429
R² = 0.9724
%Sb
60
50
40
30
20
10
0
0
20000
40000
60000
80000
100000
Re


◆ Alhamid (1991) 3
y = 883.3x^-0.232
R² = 0.974
%Sb
72
70
68
66
64
62
60
0
20000
40000
60000
80000
100000
Re


◆ Alhamid (1991) 4
y = 3917.2x^-0.316
R² = 0.9946
%Sb
83
81
79
77
75
0
100000
200000
300000
Re

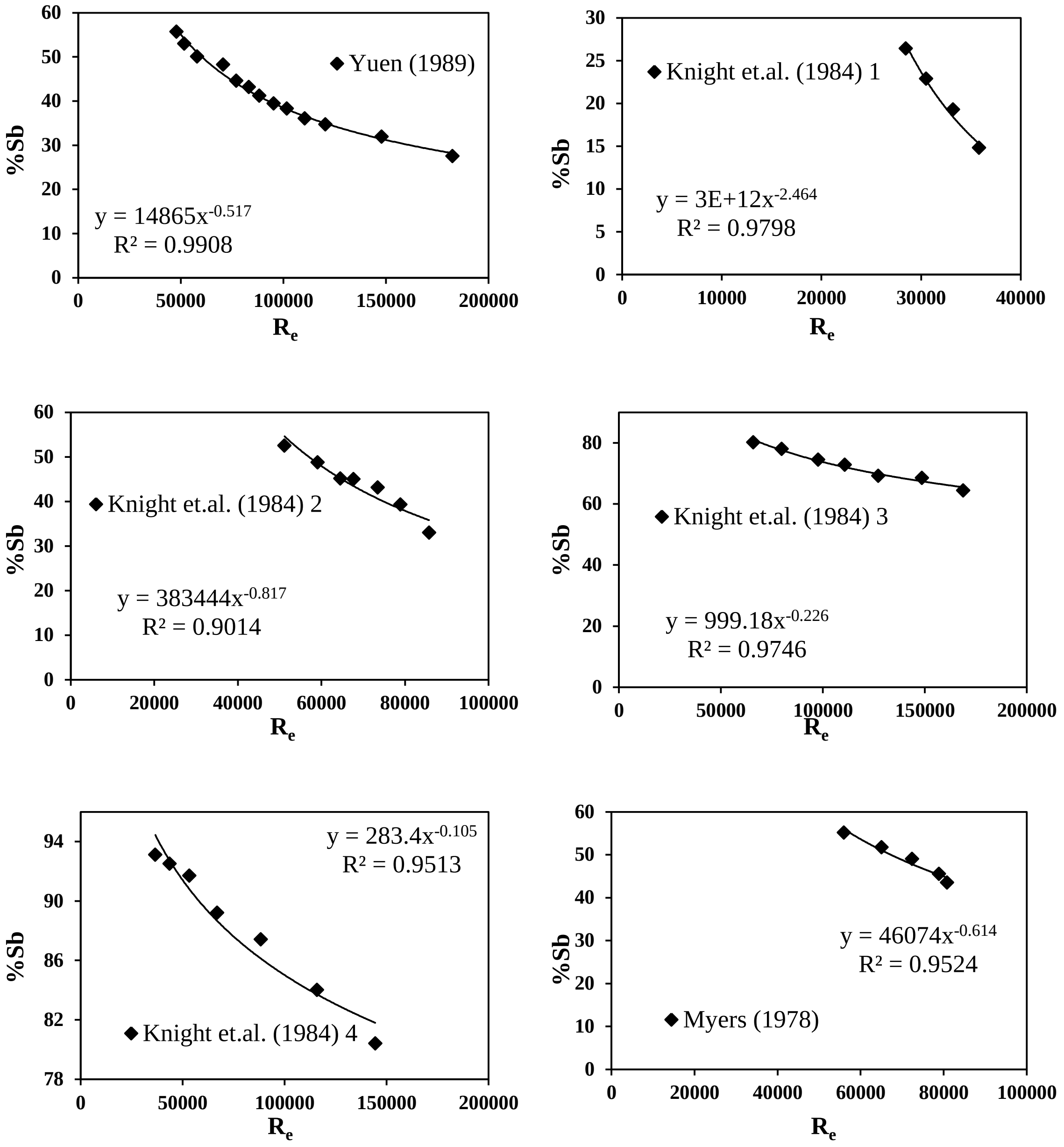
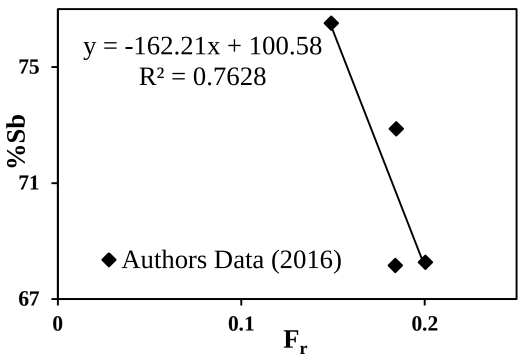
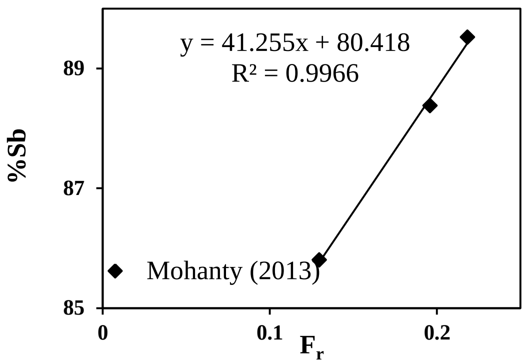


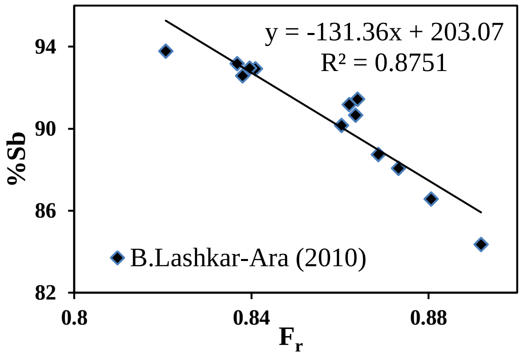
Figure: 5.14Percentage of Shear Force on Bed versus R_e of Smooth Channel

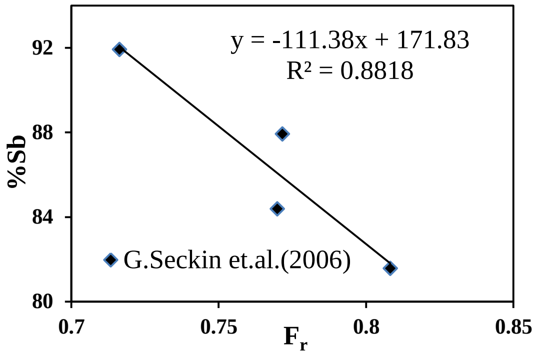
Percentage of shear force ($\%S_b$)in the bed decrease with increase in Reynolds number (R_e) and their relationship found as a power function with higher R^2 value. This is because when depth of flow increases the Reynolds number (R_e) increases for higher depths the contribution of Percentage of shear force ($\%S_b$) on bed is more as compare to walls of channel. the The magnitude of Reynolds number (R_e) is depends upon the velocity of flow so when the depth of flow is high itincreases the velocity of flow.

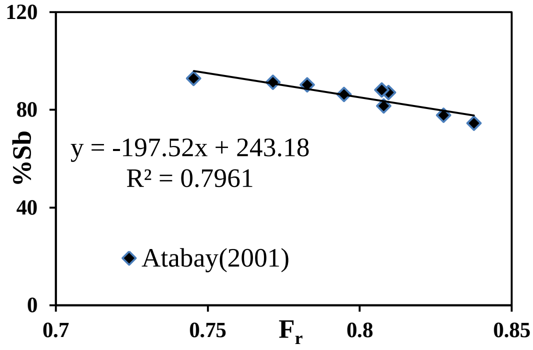
➢ Influence of Froude no (F_r) on Percentage of shear force ($\%S_b$)

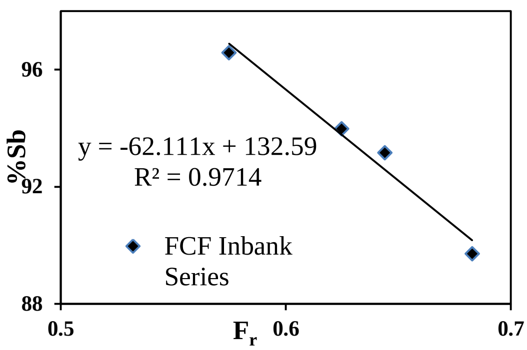


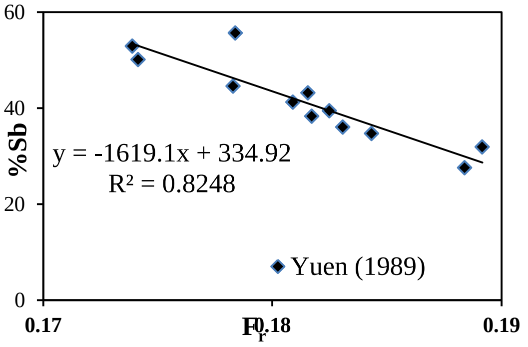


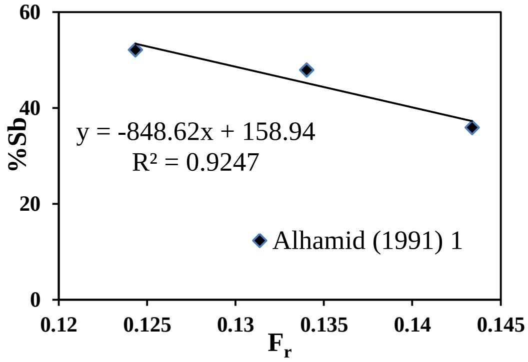












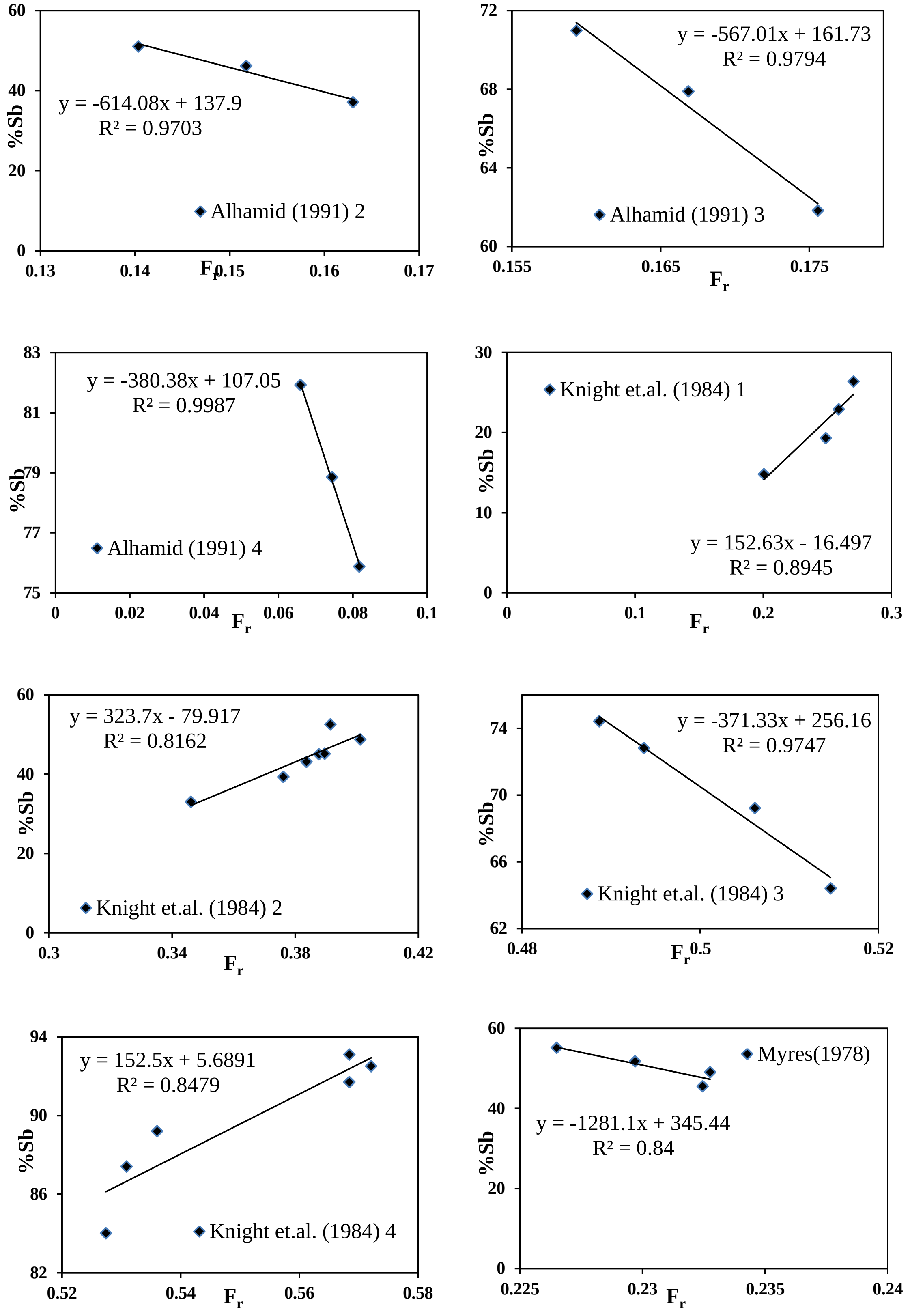


Figure: 5.15Percentage of Shear Force on Bed versus F_r of Smooth Channel

Percentage of shear force $(\%S_b)$ on the bed decrease with increase in Froude's number (F_r) and their relationship found as a linear function with higher R^2 value. This is because when the depth of flow decreases the Froude's number(F_r) is increases. This all factors are depended upon the flow depth of the channel; when the depth of flow increases, velocity is also increases that lead to increase of shear stress on bed of a the channel and vice versa.

5.5.2 Rough Channel

The variation of percentage of boundary shear force at bed $(\%S_b)$ with non-dimensional parameter i.e., aspect ratio$\left({}^{B}/_{H}\right)$, Reynolds no (Re) and Froude no (Fr) have been observed and presented graphically for different researchers data sets.

- **Influence of flow aspect ratio $\left({}^{B}/_{H}\right)$on Percentage of shear force $(\%S_b)$**

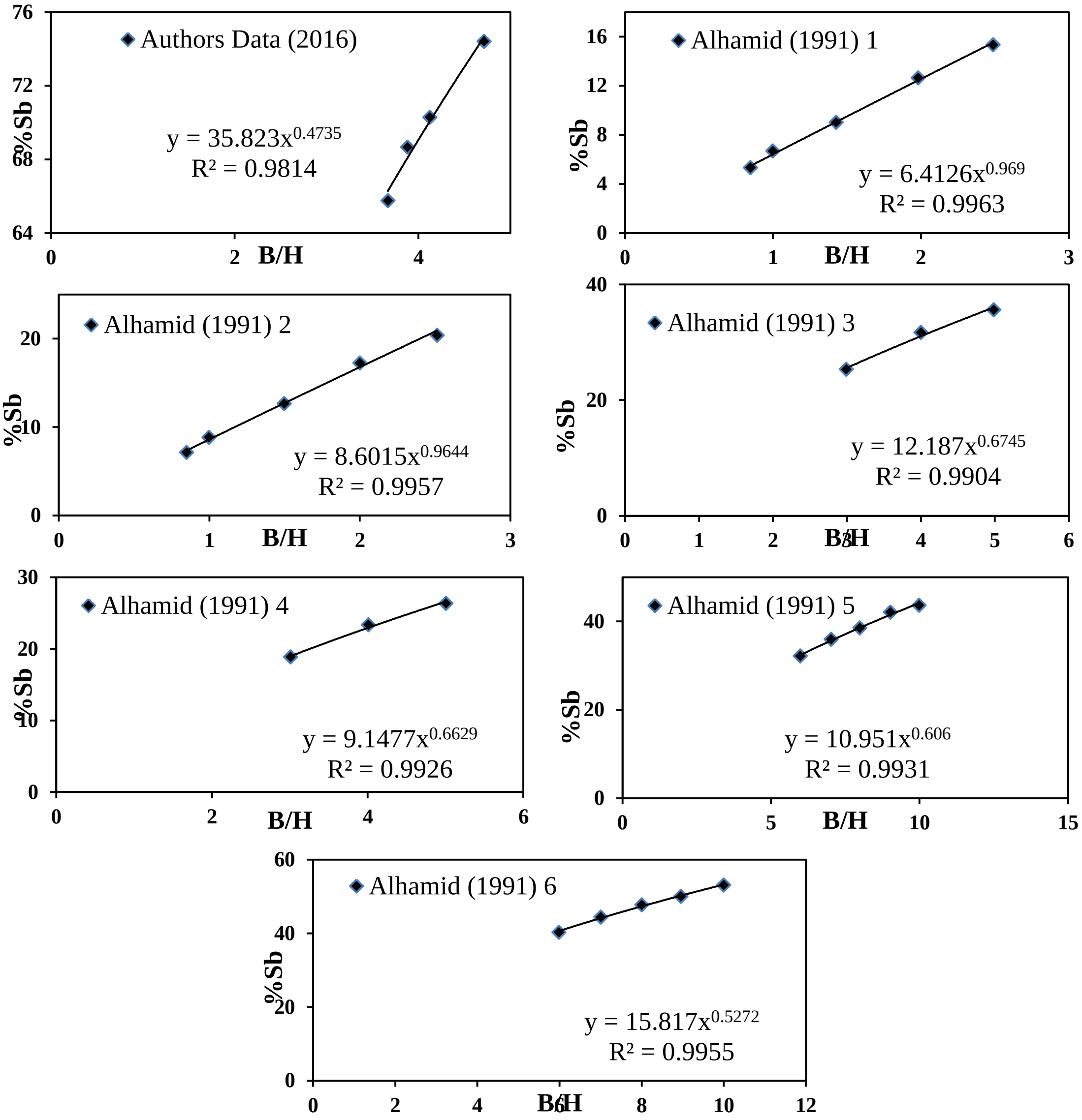
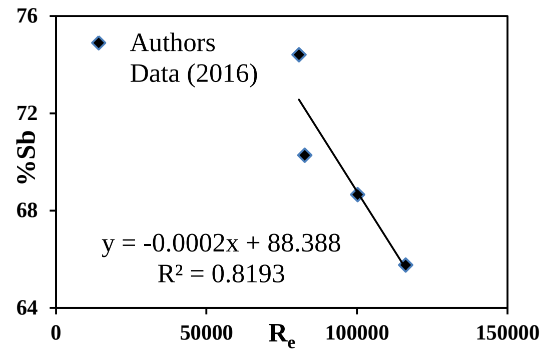
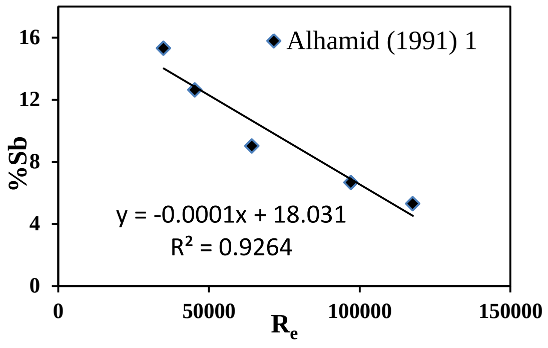


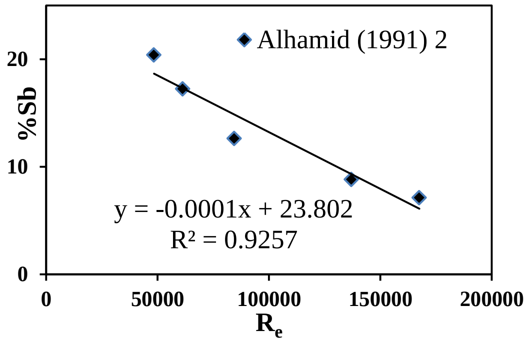
Figure: 5.16Percentage of Shear Force on Bed versus B/H of Rough Channel

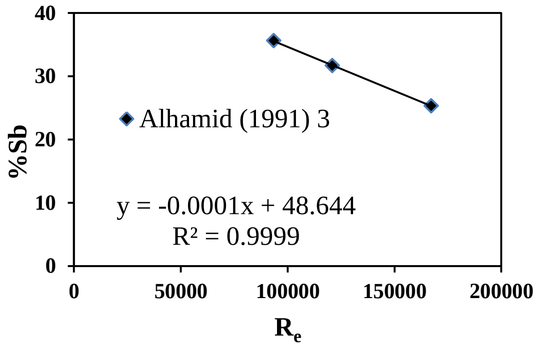
Fig.5.16 demonstrate the variation percentage shear on bed$(\%S_b)$ against *B/H* for the channels where the wall and bed having different roughness. The similar results of upward curve of $\%S_b$with $^B/_H$ have been observed for all data sets. But the distribution in different rough channels is not identical with the magnitude of shear force as this distribution of shear greatly varies with different geometry and roughness. But one can observe that when the roughness of wall and bed are same, the variations of dependent parameters $(\%S_b)$ with independent parameters $\left(^B/_H\right)$are identical in shear force values. The percentage shear on bed$(\%S_b)$ of all the channels having same roughness are meeting at one place making one trend.

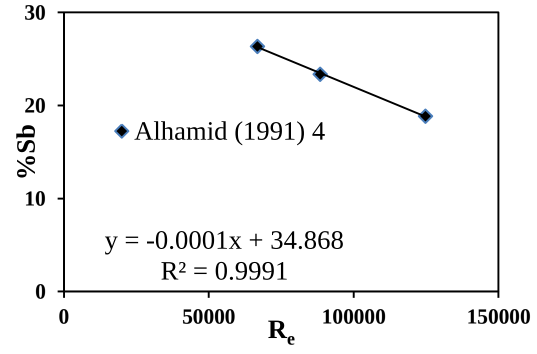
- **Influence of Reynolds no $(\boldsymbol{R_e})$ on Percentage of shear force $(\%\boldsymbol{S_b})$**

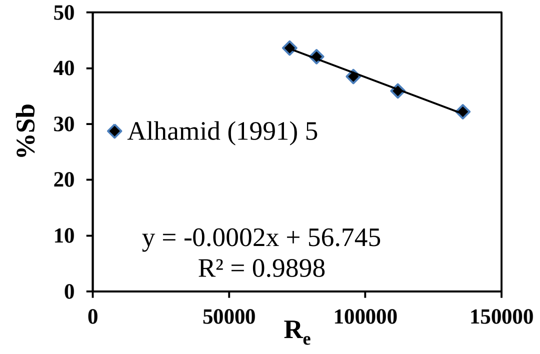












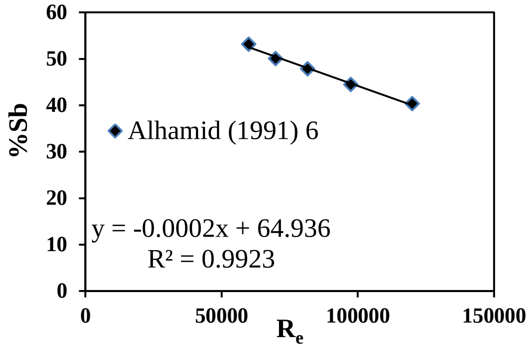
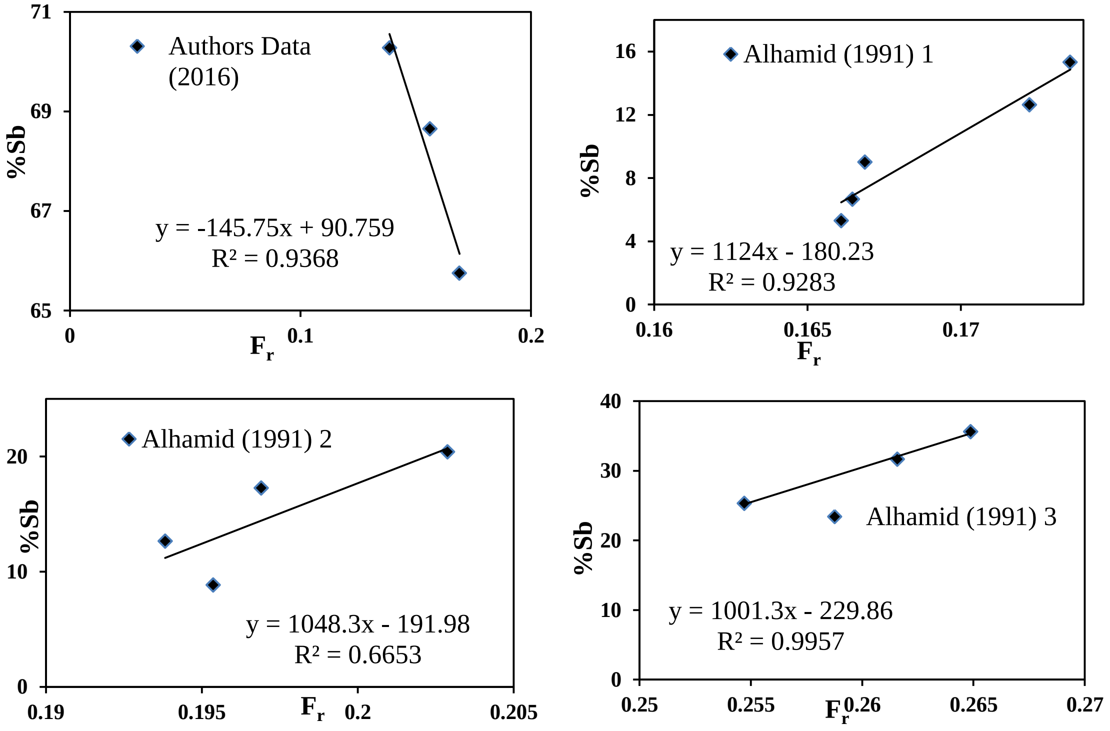


Figure: 5.17Percentage of Shear Force on Bed versus R_e of Smooth Channel

Fig.5.17 demonstrate the variation Percentage of shear force $(\%S_b)$ in the bed decrease with increase in Reynolds number (R_e) and their relationship found as a linear function with higher R^2 value. This is because when depth of flow increases the Reynolds number (R_e) increases for higher depths the contribution of Percentage of shear force $(\%S_b)$ on bed is more and for lower depth the contribution of Percentage of shear force $(\%S_b)$ on bed is less as compare to walls of the channel.

- **Influence of Froude no (F_r) on Percentage of shear force $(\%S_b)$**



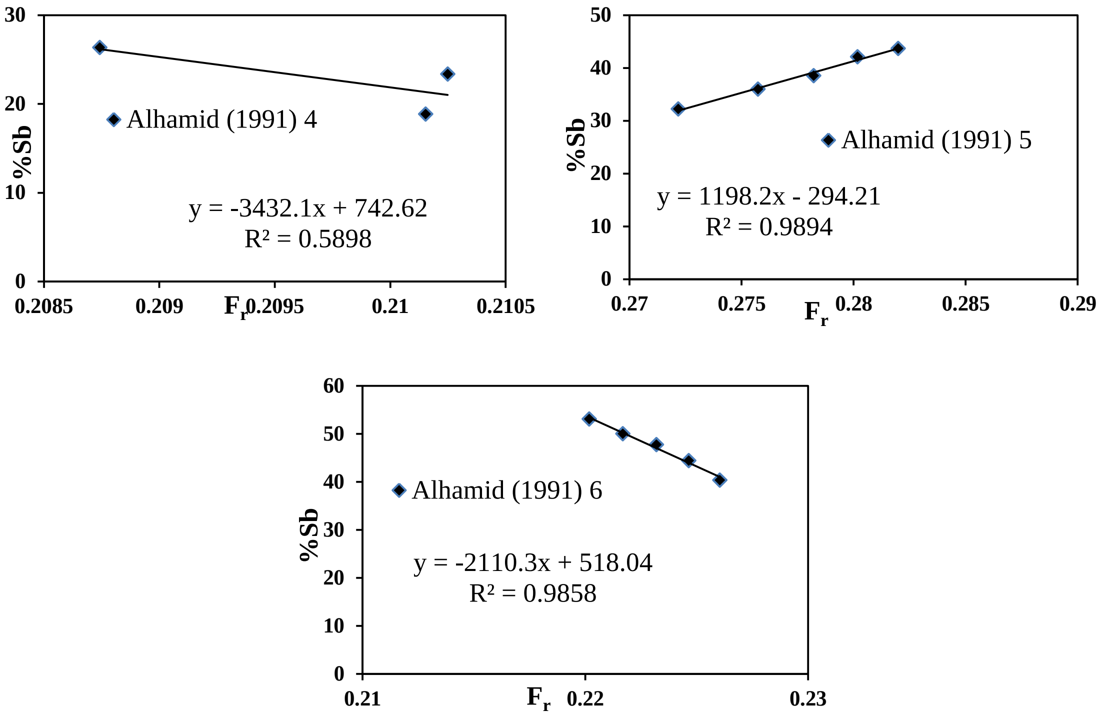


Figure: 5.18 Percentage of Shear Force on Bed versus F_r of Smooth Channel

Fig.5.18 demonstrates the variationPercentage of shear force $(\%S_b)$ on the bed decrease with increase in Froude's number (F_r) and their relationship found as a linear function with higher R^2 value. This is because when the depth of flow decreases the Froude's number(F_r) is increases. This all factors are depended upon the flow depth of the channel; when the depth of flow increases, velocity is also increases that lead to increase of shear stress on bed as compare to walls of the channel and vice versa.

5.6 Multi Linear Regression Analysis

Multi linear regression analysis is an extension of simple regression analysis. The term was first used by Pearson 1908. This process is used;when we need to anticipate the estimation of a variable in view of its estimations of two or more other variables. Which is going to predict is known as the dependent variable and the variables are utilized to predict the estimation of the dependent variable are known as the independent variables..

It incorporates numerous methods for demonstrating and assessing the variables,when the consideration is on the relationship between a dependent variable and one or more independent variables. Regression analysis can see how the estimation of ward variable changes when one of the free variables is varied,while other autonomous variables are kept settled. Typically, relapse investigation assesses the needy variable given the autonomous i.e. the normal of estimation of ward variable when the free variable is altered. In all cases ,the estimation target is an element of the free variable called the relapse capacity.

Regression examination is generally utilized for estimating and anticipating, where its utilization has a generous cover with the field of machine learning. Relapse investigation is additionally comprehended the which among the free variables are identified with the reliant variable and to break down the type of these connections. In restricted circumstances,regression investigation can be utilized to construe causal connections between the autonomous and ward variables.Different systems for complete the relapse examination have been developed.suitable technique, for example, straight relapse and customary slightest square relapse are parametric, in that the relapse capacity is characterized as far as a limited number of obscure parameters that the assessed from the information. Non parametric relapse alludes to systems that permit the relapse capacity to lie in a predefined set of capacities, which might be vast dimensional

The capacity of regression analysis technique by and by relies on upon the type of the information producing procedure, and how it identifies with the regression approach bring utilized. After all valid from of the information producing procedure is for the most part not know, regression analysis regularly depends on to some degree on making an assumption about this procedure. Statement are at some point testable if a sufficent amount of information is accessible.

5.6.1 Regression Models

Regression models involve the following variables:

- Unknown parameters, denoted as β, which may represent a vector or scalar quantity
- Independent variables, X
- Dependent variables, Y

In the various field of application different terminologies are used in place of dependent and independent variables.

A regression model relates Y to a function of X and β

$Y \approx f(X, \beta)$

In this reaches work independent variables as (Width ratio ($\frac{B}{H}$), Reynolds number(R_e), Froude's number (F_r) and dependent variable as (shear force on bed ($\%S_b$))

Using different types of data sets from various investigators and compiling the effects of percentage shear on three independent parameters, two expressions for smooth channel and rough channel have been derived. Equations have been developed by utilisingmulti linear regression analysiswhere the indispensible independent variables are Flow aspect ratio $(\frac{\mathrm{B}}{\mathrm{H}})$, Reynolds number$(\mathrm{R_e})$ and Froude's number$(\mathrm{F_r})$. So the shear force in terms of percentage shear on bed $(\%\mathrm{S_b})$ for smooth as well as for rough channels are depicted in equation 3.6 and 3.7

For smooth channel

$$\%\mathrm{S_{bs}} = 5.0899 + 29.697 * (\mathrm{B}/\mathrm{H})^{0.3923} + (3.92 * 10^{-4}) * (\mathrm{R_e})^{0.8489} + (0.1514 * \mathrm{F_r}) \quad (3.6)$$

For rough channel

$$\%S_{\mathrm{br}} = 50.6812 + 13.4218 * \left(B/H\right)^{0.8294} + (0.0002047 * R_e) - (390.12 * F_r) \quad (3.7)$$

Where, $\%\mathrm{S_{bs}}$= percentage of shear force on bed for Smooth channel

$\%S_{\mathrm{br}}$= percentage of shear force on bed for Rough channel

$\frac{\mathrm{B}}{\mathrm{H}}$ = Flow aspect ratio

Chapter - 6

Application of Model for Discharge Assessment

6.1 Application of Model for Discharge Assessment:

For a model to be considered as successful, if it is capable of providing good discharge prediction. To apply the present approach in assessing the discharge, following steps are to be adopted. The present model is to prophecy the percentage shear on bed($\%S_b$).So for finding the discharge from percentage shear on bed one has be clear about the composite roughness in channels. Some rules are followed to link up the $\%S_b$ results with flow.

We know the percentage shear force on bed depend upon boundary shear force on bed perimeter and given by

$$\%S_b = \frac{\tau_b P_b}{\rho g A S} \times 100 \qquad (6.1)$$

Where τ_b = boundary shear stress on bed, P_b =wetted perimeter of bed, ρ =density of water, g =acceleration due to gravity, A = total area of the channel, S = longitudinal slope of the channel

For calculation percentage of shear on wall($\%S_w$), the termτ_b, P_b of equation (6.1) are replaced by τ_w, P_w so equation will be

$$\%S_w = \frac{\tau_w P_w}{\rho g A S} \times 100 \qquad (6.2)$$

τ_w= boundary shear stress on wall and P_w= wetted perimeter of wall

Also the magnitude of $\%S_w$ can be found out directly by subtracting the $\%S_b$ value from 100

$$\%S_w = 100 - \%S_b \qquad (6.3)$$

By back calculation the boundary shear on bed and wall (τ_b and τ_w) are computed from the equation given in (6.1&6.2)

$$\tau_b = \frac{\%S_b \times \rho g A S}{100 P_b} \text{and} \qquad \tau_w = \frac{\%S_w \times \rho g A S}{100 P_w} \qquad (6.4)$$

We know the relationship between$f$andτi.e.,

$$\tau_b = \frac{f_b}{8} \times \rho {U_m}^2 \quad (6.5)$$

Where U_m=mean velocity of the channel, f_b= Friction factor of bed

The mean velocity of the channel can be obtained by using uniform flow formula i.e., Manning's equation and given by

$$U_m = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}} \quad (6.6)$$

Where, n = manning's roughness coefficient, R= hydraulic radius of the channel

From equation (6.5) friction factor of bed(f_b) is calculated

$$f_b = \frac{\tau_b \times 8}{\rho {U_m}^2} \quad (6.7)$$

We know the relation for friction factor of bed(f_b) and manning's roughness coefficient of bed (n_b) i.e.

$$f_b = \frac{8 {n_b}^2 g}{{R_b}^{\frac{1}{3}}} \quad (6.8)$$

Where,$\mathrm{R_b}$ = hydraulic radius at the bed of the channel.

Knowing the value of f_b and solving equation (6.8), we can find out the value of $\mathrm{n_b}$

$$\mathrm{n_b} = \sqrt{\frac{\mathrm{f_b} \times \mathrm{R_b}^{\frac{1}{3}}}{8\mathrm{g}}} \quad (6.9)$$

By using similar method the manning's roughness coefficient at wall (n_w) can be determined.

After finding out the value of manning's roughness coefficient at bed(n_b) and manning's roughness coefficient at wall(n_w) , composite manning's roughness coefficientn_c value can be calculated by using different researches formula. Different expressions are given by various researchers for compositen_c. Some of them are given below

6.1.1 Horton (1933) and Einstein (1934)

Total cross-sectional mean velocity is equal to subarea mean velocity.

$$n_c = \left[\frac{1}{p} \sum ({n_i}^2 P_i)\right]^{\frac{2}{3}} \quad (6.10)$$

6.1.2 Lotter(1933)

Total discharge is sum of subarea discharge

$$n_c = \frac{P R^{\frac{5}{3}}}{\sum \frac{P_i}{n_i} {R_i}^{5/3}} \quad (6.11)$$

6.1.3 Ida (1960) and Engelund (1964)

Total discharge is sum of subarea discharge.

$$n_c = \frac{\sum P_i R_i^{\frac{5}{3}}}{\sum \frac{P_i}{n_i} R_i^{\frac{5}{3}}} \tag{6.12}$$

6.1.4 Yen 1 (2002)

Total shear velocity is weighted sum of subarea velocity

$$n_c = \frac{\sum (n_i P_i)}{P} \tag{6.13}$$

6.1.5 Yen 2 (2002)

Total shear velocity is a weighted sum of subarea velocity.

$$n_c = \frac{\sum \left(\frac{n_i P_i}{R_i^{\frac{1}{6}}} \right)}{P / R^{\frac{1}{6}}} \tag{6.14}$$

Discharge $Q = \frac{1}{n_c} \times R^{\frac{2}{3}} \times S^{\frac{1}{2}} \times A$ (6.15)

By using different model equations (6.10, 6.11, 6.12, 6.13&6.14) value of composite manning's roughness coefficient $(n_c)$are computed and put in the equation (6.15) for finding out the discharge value (Q) for different models results are given below

6.2 For Smooth Channel

Theproposed model can estimate the individual roughness on the bed and wall for a given channel geometry and flow condition. So using the models of previous investigators, the composite roughness value can be calculated for a respective channel. After finding the value of composite roughness, the discharge can be found out for different channels. Here for validation purpose, channels ofNITR, Alhamid (1991) 1,Alhamid (1991) 2,Alhamid (1991) 3 and Yuen (1989) are considered. The results of composite roughness by different model along with the corresponding discharge for individual channels having different flow depths have been calculated and given in table 7. The comparison results also given for to distinguish the type of model gives the predicated discharge which having minimum error

Table: 7 Composite roughness and discharge of Different Smooth Channels

Models	Depth , H (m)	Actual Discharge, Q (m3/s)	n_w	n_b	n_c				Predicted, Q (m3/s)			
					Horton (1933) and Einstein (1934)	Ida (1960) and Engelund	Yen 1 (2002)	Yen 2 (2002)	Horton (1933) and Einstein (1934)	Ida (1960) and Engelund	Yen 1 (2002)	Yen 2 (2002)
NITR	90	0.018	0.0116	0.0133	0.0111	0.0133	0.01	0.0105	0.020	0.0167	0.0221	0.021
	80	0.0158	0.0112	0.0125	0.0105	0.0125	0.0097	0.0102	0.0173	0.0144	0.0186	0.0177
	70	0.0123	0.0116	0.0125	0.0104	0.0125	0.0100	0.0106	0.0138	0.0115	0.0144	0.0136
	60	0.0078	0.0144	0.0151	0.0124	0.0150	0.0123	0.0131	0.0089	0.0074	0.0090	0.0084
Alhamid(1991) 1	94	0.008	0.0246	0.0309	0.0258	0.0309	0.0188	0.0193	0.0076	0.0064	0.0105	0.0102
	70	0.0044	0.0262	0.0299	0.0249	0.0299	0.0201	0.0212	0.0046	0.0038	0.0057	0.0054
	56.2	0.0028	0.0281	0.0303	0.0252	0.0303	0.0217	0.0232	0.0030	0.0025	0.0035	0.0033
Alhamid(1991) 2	0.0953	0.0095	0.0216	0.0274	0.0229	0.0309	0.0309	0.0170	0.0090	0.0064	0.0064	0.0121
	0.0717	0.0053	0.0231	0.0267	0.0222	0.0299	0.0299	0.0188	0.0055	0.0038	0.0038	0.0065
	0.057	0.0033	0.025	0.0271	0.0224	0.0303	0.0303	0.0206	0.0036	0.0025	0.0025	0.0039
Alhamid(1991) 3	0.0742	0.0118	0.021	0.0228	0.0191	0.0229	0.0177	0.0188	0.0130	0.0108	0.0139	0.0131
	0.0596	0.0078	0.022	0.0229	0.0191	0.0230	0.0186	0.0198	0.0089	0.0074	0.0091	0.0086
	0.04954	0.0055	0.0228	0.0232	0.0193	0.0233	0.0195	0.0207	0.0064	0.0053	0.0064	0.0060
Yuen(1989)	0.05	0.0035	0.0098	0.0104	0.0087	0.0105	0.0078	0.0083	0.0039	0.0032	0.0043	0.0040
	0.05455	0.004	0.0101	0.0109	0.0091	0.0109	0.0080	0.0085	0.0043	0.0036	0.0049	0.0046
	0.06	0.0046	0.0101	0.0112	0.0093	0.0112	0.0079	0.0084	0.0050	0.0041	0.0058	0.0055
	0.06665	0.006	0.0094	0.0107	0.0089	0.0107	0.0074	0.0078	0.0062	0.0052	0.0076	0.0072
	0.075	0.007	0.0099	0.0116	0.0097	0.0117	0.0077	0.0081	0.0071	0.0059	0.0089	0.0085
	0.07895	0.0078	0.0097	0.0117	0.0097	0.0117	0.0076	0.0079	0.0078	0.0065	0.0100	0.0096

- ➢ **Proposed Model**

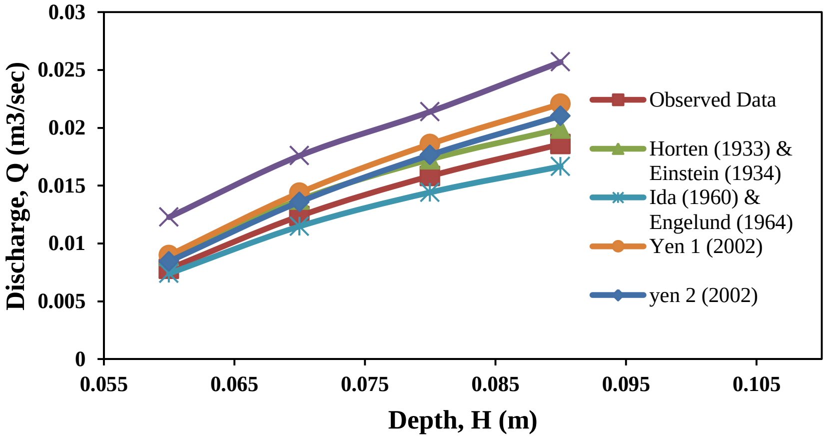


Figure: 6.1 (a) Comparison of discharge by different models for NITR data set

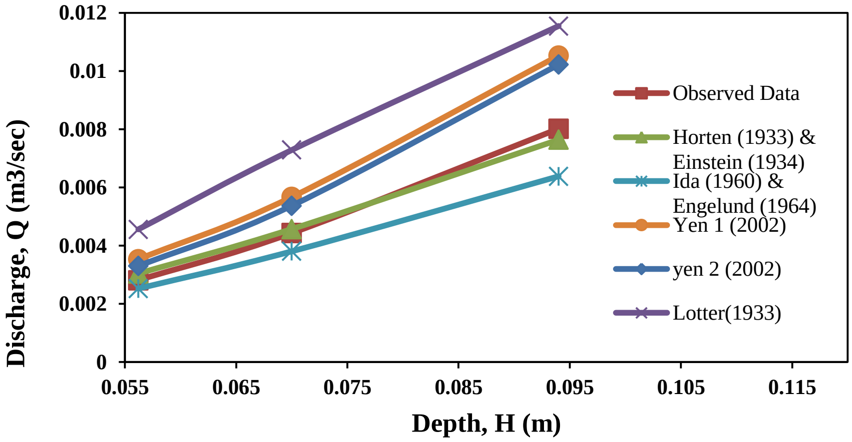


Figure: (b) Comparison of discharge by different models for Alhamid (1991) 1 data set

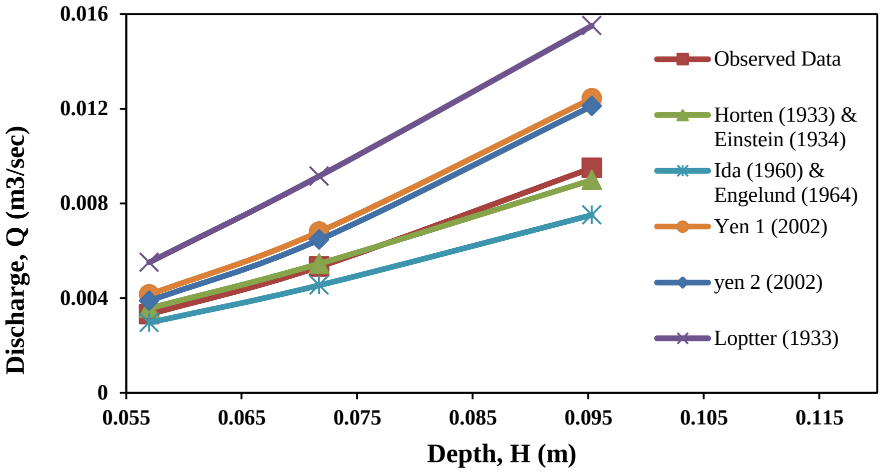


Figure: 6.1 (c) Comparison of discharge by different models for Alhamid (1991) 2 data set

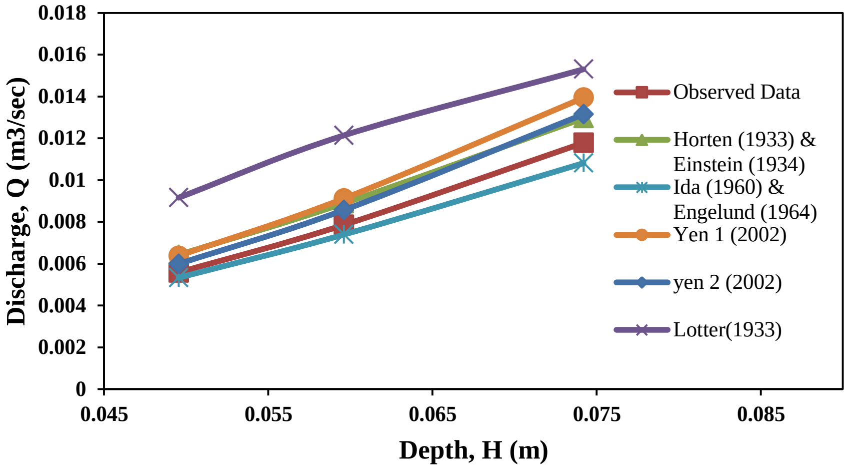


Figure:.6.1 (d) Comparison of discharge by different models for Alhamid (1991) 3 data set

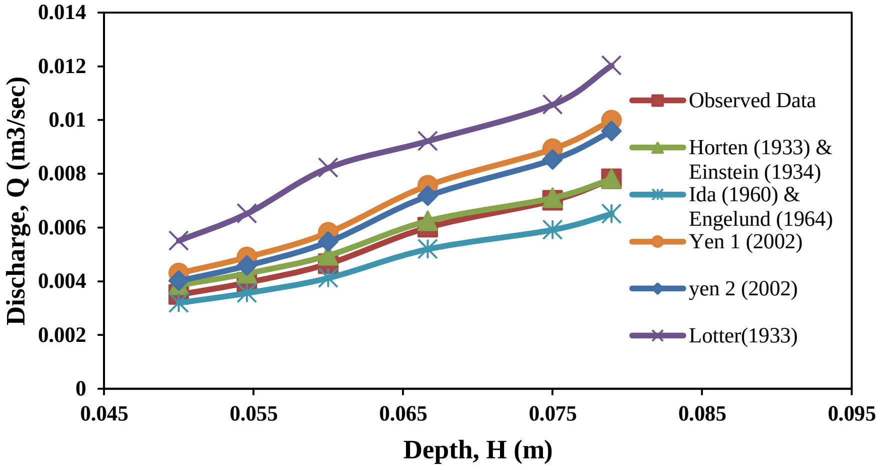


Figure: 6.1(e) Comparison of discharge by different models for Yuen (1989) data set

Figure: 6.1(a)-6.1(e) comparison of discharge by proposed model

From Fig 6.1(a)-6.1(e) shows comparison between the actual discharges by applying different composite roughness (n_c) model of different investigator. The discharge of Horten (1933) and Einstein (1934) composite roughness model gives the more accurate with the actual discharge and percentage of error is less as compare to other model. For a model to be considered as successful, if it is capable of provide good discharge prediction in this proposed model in a new technique gives the prediction of discharge which gives more accurate and nearer to the actual discharge for any simple smooth channel geometry.

6.2.1 Comparison Of Discharge With Other Model

- **By using model Knight et.al (1984)**

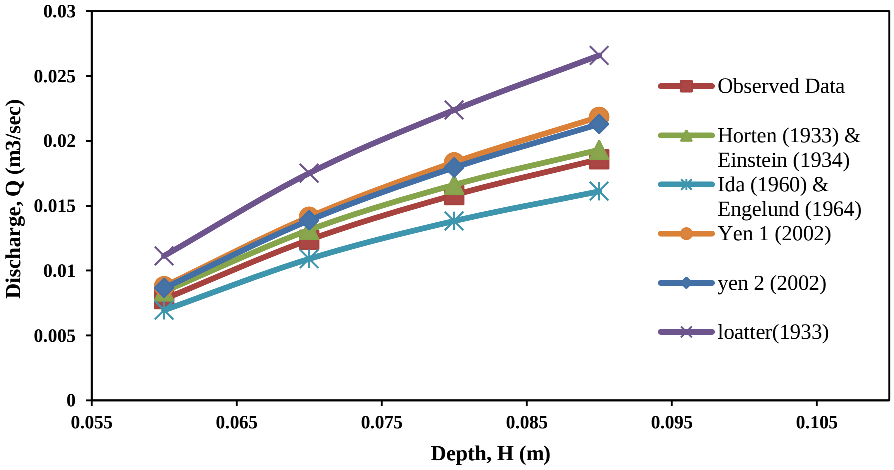


Figure: 6.2 (a) Comparison of discharge by different models for NITR data set

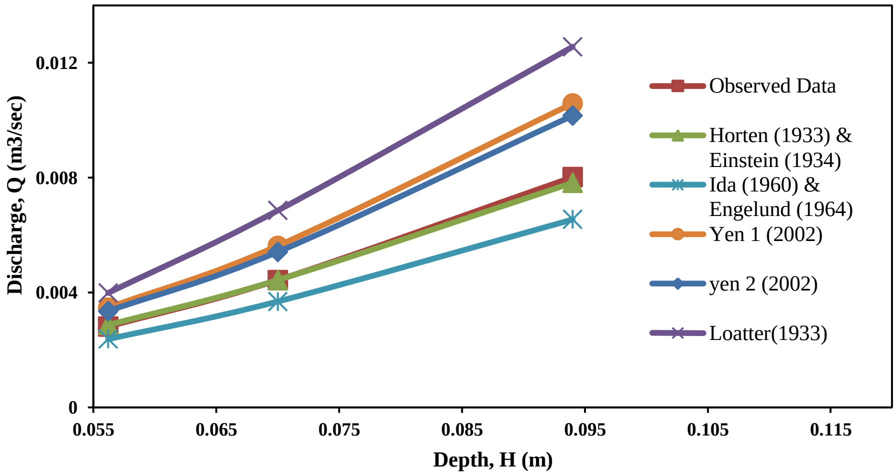


Figure: 6.2 (b) Comparison of discharge by different models for Alhamid (1991) 1 data set

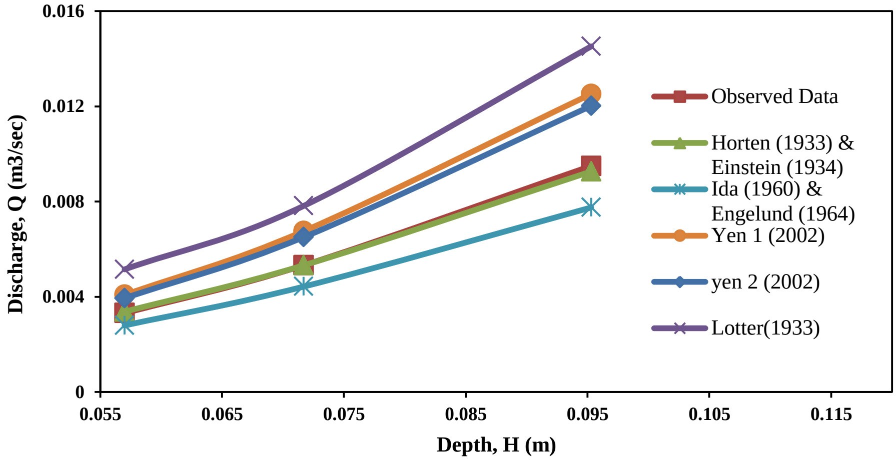


Figure: 6.2(c) Comparison of discharge by different models for Alhamid (1991) 2 dataset

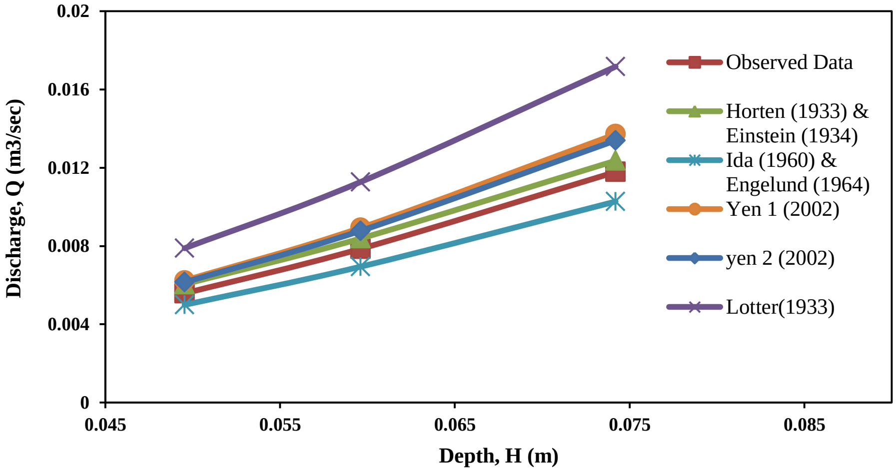


Figure: 6.2 (d) Comparison of discharge by different models for Alhamid (1991) 3 data set

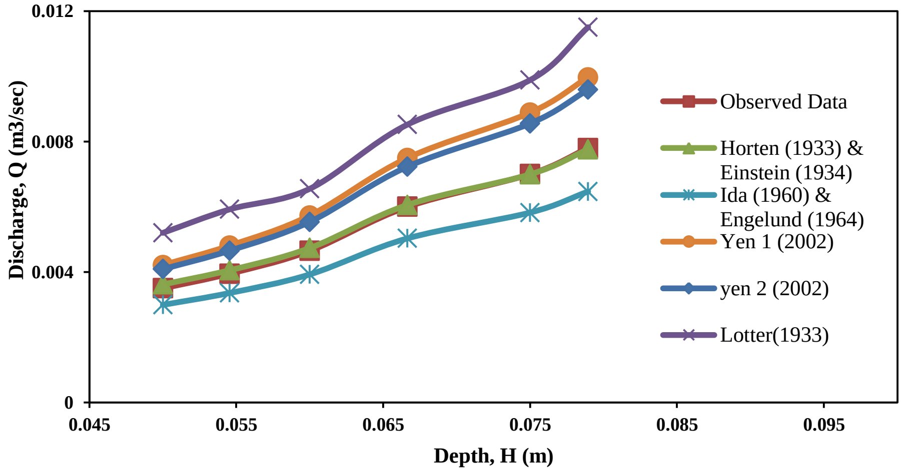


Figure: 6.2 (e) Comparison of discharge by different models for Yuen (1989) data set

Fig 6.2(a)-6.2 (e) comparison of discharge by Knight et.al (1984)

From Fig 6.2(a)-6.2(e) shows comparison between the actual discharges by applying different composite roughness (n_c) model of different investigator. The discharge of Horten (1933) and Einstein (1934) composite roughness model gives the more accurate with the actual discharge and percentage of error is less as compare to other mode in the Knight et.al (1984) model. The predicted discharge is approximately equal to the actual discharge. But in the Lotter(1933) composite n model predicts the higher value of all channel and the Ida (1960) &Engulend (1964) predicts the lower discharge value for all data set

- **By using model Seckin et.al (2006)**

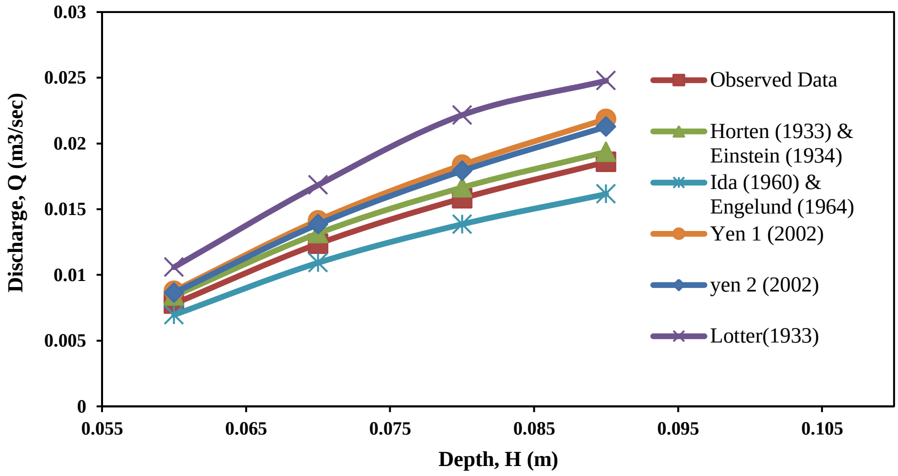


Figure:.6.3 (a) Comparison of discharge by different models for NITR data set

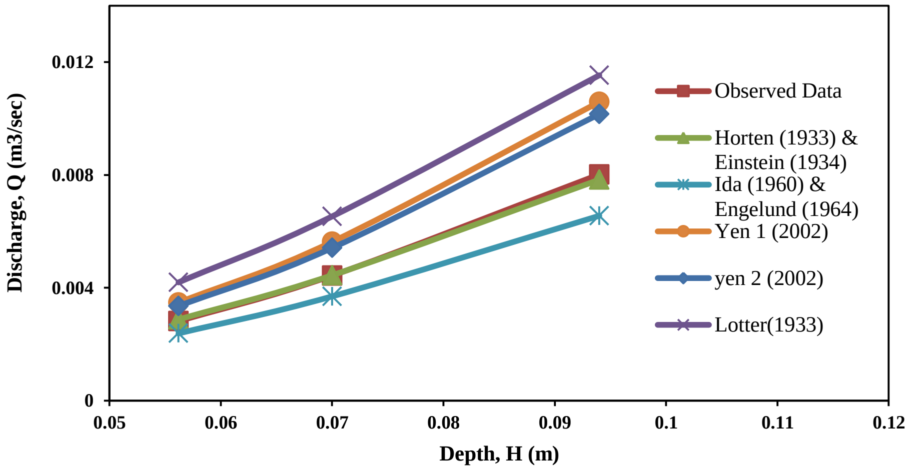


Figure: 6.3 (b) Comparison of discharge by different models for Alhamid (1991) 1 data set

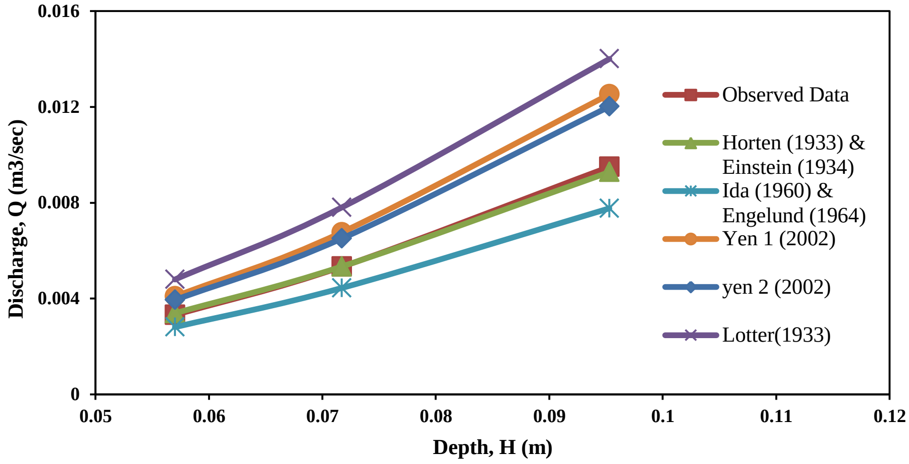


Figure: 6.3(c) Comparison of discharge by different models for Alhamid (1991) 2 data set

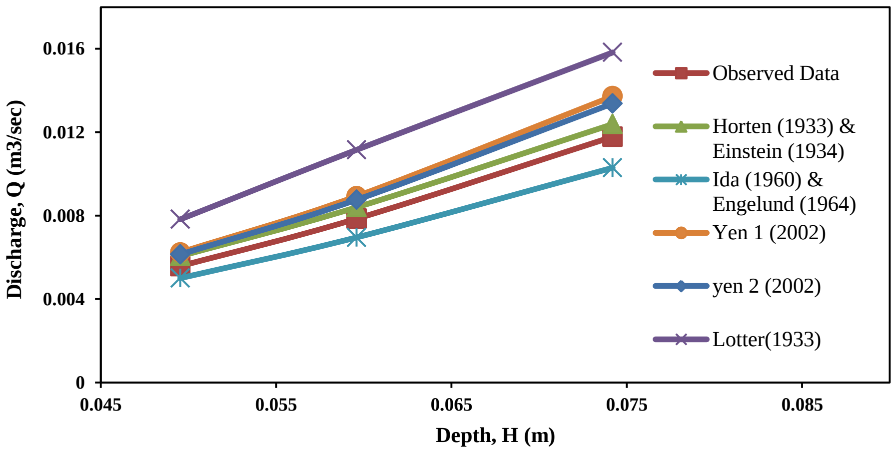


Figure: 6.3 (d) Comparison of discharge by different models for Alhamid (1991) 3 data set

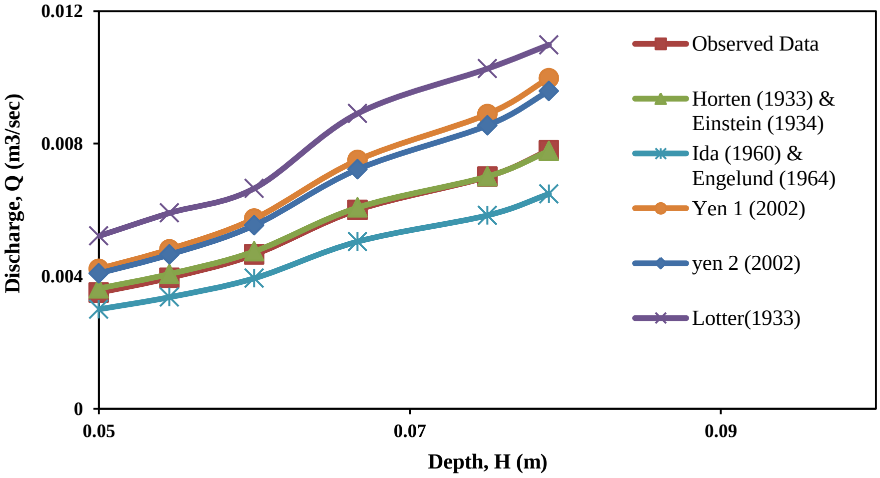


Figure:.6.3 (e) Comparison of discharge by different models for Yuen (1989) data set

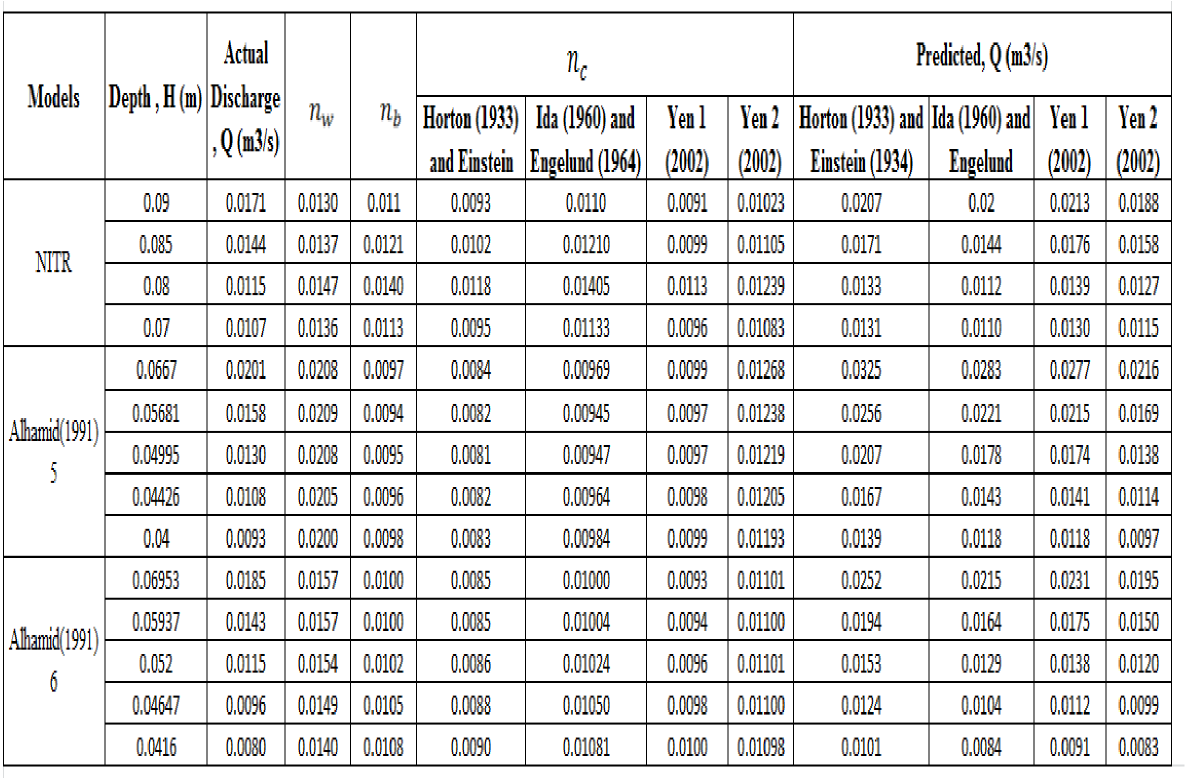
Figure: 6.3 (a) - 6.3 (e) comparison of discharge by Seckin et.al (2006)

From Fig 6.3(a)-6.3(e) shows comparison between the actual discharges by applying different composite roughness (n_c) model of different investigator. The discharge of Horten (1933) and Einstein (1934) composite roughness model gives the more accurate with the actual discharge and percentage of error is less as compare to other mode in the Seckin et.al (1984) model.But in the Lotter(1933) composite n model predicts the higher value of all channel and the Ida (1960) &Engulend (1964) predicts the lower discharge value for all data set.

6.3 Rough Channel

The proposed model can estimate the individual roughness on the bed and wall for a given channel geometry and flow condition. So using the models of previous investigators, the composite roughness value can be calculated for a respective channel. After finding the value of composite roughness, the discharge can be found out for different channels. Here for validation purpose, channels ofNITR,Alhamid (1991) 5 and Alhamid (1991) 6 are considered. The results of composite roughness by different model along with the corresponding discharge for individual channels having different flow depths have been calculated and given in table 8.

Table: 8 Composite roughness and discharge of Different Rough Channels



Models	Depth , H (m)	Actual Discharge , Q (m3/s)	n_w	n_b	n_c				Predicted, Q (m3/s)			
					Horton (1933) and Einstein	Ida (1960) and Engelund (1964)	Yen 1 (2002)	Yen 2 (2002)	Horton (1933) and Einstein (1934)	Ida (1960) and Engelund	Yen 1 (2002)	Yen 2 (2002)
NITR	0.09	0.0171	0.0130	0.011	0.0093	0.0110	0.0091	0.01023	0.0207	0.02	0.0213	0.0188
	0.085	0.0144	0.0137	0.0121	0.0102	0.01210	0.0099	0.01105	0.0171	0.0144	0.0176	0.0158
	0.08	0.0115	0.0147	0.0140	0.0118	0.01405	0.0113	0.01239	0.0133	0.0112	0.0139	0.0127
	0.07	0.0107	0.0136	0.0113	0.0095	0.01133	0.0096	0.01083	0.0131	0.0110	0.0130	0.0115
Alhamid(1991) 5	0.0667	0.0201	0.0208	0.0097	0.0084	0.00969	0.0099	0.01268	0.0325	0.0283	0.0277	0.0216
	0.05681	0.0158	0.0209	0.0094	0.0082	0.00945	0.0097	0.01238	0.0256	0.0221	0.0215	0.0169
	0.04995	0.0130	0.0208	0.0095	0.0081	0.00947	0.0097	0.01219	0.0207	0.0178	0.0174	0.0138
	0.04426	0.0108	0.0205	0.0096	0.0082	0.00964	0.0098	0.01205	0.0167	0.0143	0.0141	0.0114
	0.04	0.0093	0.0200	0.0098	0.0083	0.00984	0.0099	0.01193	0.0139	0.0118	0.0118	0.0097
Alhamid(1991) 6	0.06953	0.0185	0.0157	0.0100	0.0085	0.01000	0.0093	0.01101	0.0252	0.0215	0.0231	0.0195
	0.05937	0.0143	0.0157	0.0100	0.0085	0.01004	0.0094	0.01100	0.0194	0.0164	0.0175	0.0150
	0.052	0.0115	0.0154	0.0102	0.0086	0.01024	0.0096	0.01101	0.0153	0.0129	0.0138	0.0120
	0.04647	0.0096	0.0149	0.0105	0.0088	0.01050	0.0098	0.01100	0.0124	0.0104	0.0112	0.0099
	0.0416	0.0080	0.0140	0.0108	0.0090	0.01081	0.0100	0.01098	0.0101	0.0084	0.0091	0.0083

- **Proposed Model**

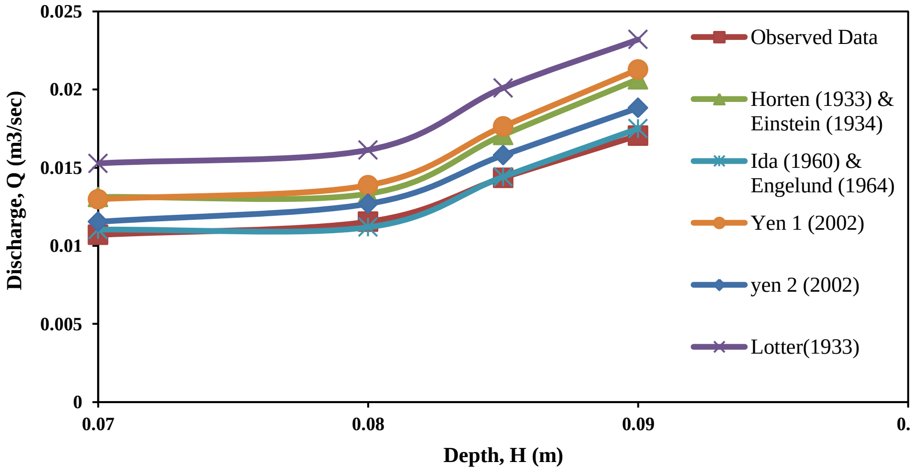


Figure:.6.4 (a) Comparison of discharge by different models for NITR data set

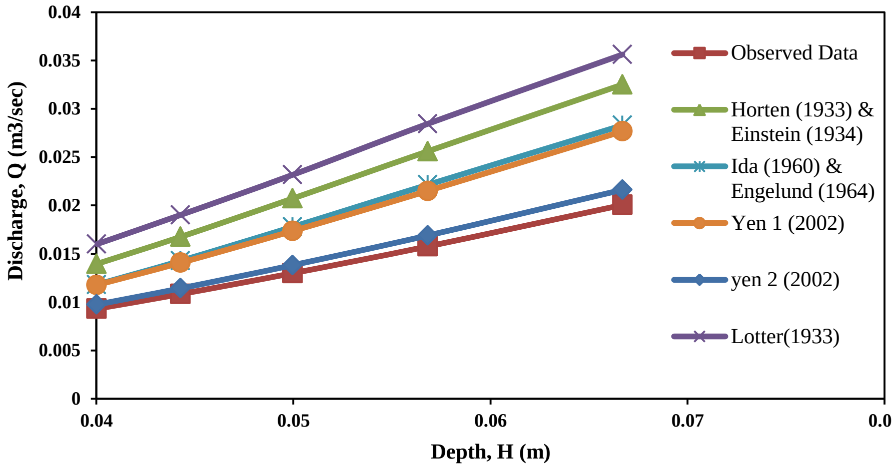


Figure: 6.4 (b) Comparison of discharge by different models for Alhamid (1991) 5 data set

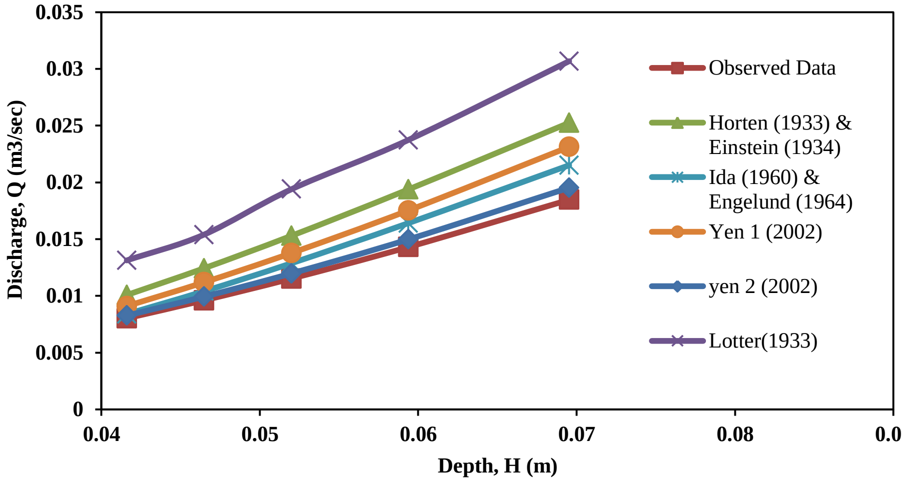


Figure: 6.4(c) Comparison of discharge by different models for Alhamid (1991) 6data set

Figure: 6.4 (a) - 6.4 (e) comparison of discharge by Proposed Model for rough channel

From Fig 6.4(a)-6.4(e) shows comparison between the actual discharges by applying different composite roughness (n_c) model of different investigator. For a model to be considered as successful, if it is capable of provide good discharge prediction in this proposed model in a new technique gives the prediction of discharge which gives more accurate and nearer to the actual discharge for any simple rough channel geometry. From fig 6.4 (a) shows that Ida (1960) &Engelund (1964) composite roughness model for prediction of discharge NITR channel is gives more accurate than other composite roughness model but for Alhamid(1991) channel Yen 2 (2002) composite roughness model gives good results than other models.

6.4 Comparison of $\%S_b$ Models

Many researchers gave different equation for prediction of boundary shear forces on bed and wall of the channel, but they are taking the independent variables as Width ratio (B/H). In this research work the number independent variable are taken more for study of behaviour of boundary shear forces on bed i.e. Width ratio (B/H) ,Reynolds number($\mathrm{R_e}$), Froude's number ($\mathrm{F_r}$).

- **Knight et.al (1984) model**

$$\log(\%SF_w) = -1.4026\log(B/H+3)+2 \qquad (6.15)$$

Or

$$SF_w = \exp(\propto) \text{ Where } \propto = -3.23\log(B/H+3)+6.146 \qquad (6.16)$$

- **Seckinet.al (2006) model**

$$\log(\%SF_w) = -1.382\log(B/H+3)+2.6563 \qquad (6.17)$$

Or

$$SF_w = \exp(\propto)\text{Where}\propto = -3.183\log(B/H+3)+6.1175 \qquad (6.18)$$

For the magnitude of $\%S_b$ can be found out directly by subtracting the $\%S_w$ value from 100

A comparison of result for proposed model with Knight et.al (1984) and Seckin et.al (2006) model given below

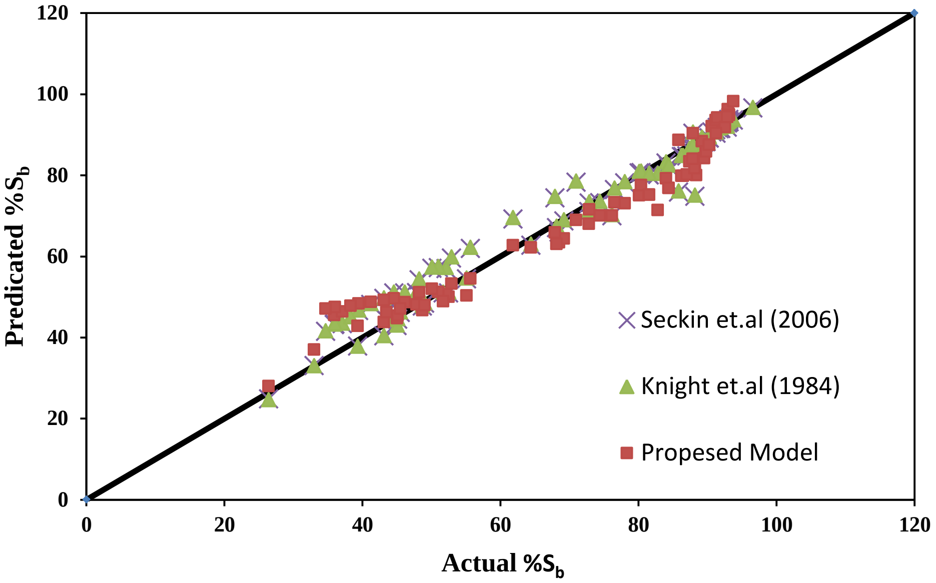


Figure: 6.18 Comparison of %S_b by different models

Fig.6.18 demonstrated the Percentage of shear force (%S_b) by proposed model along with other models and compared their results. The prediction from proposed model is well as the predicated values are on and near the line of good agreements. It shows that actual %S_b is well the predicated by the proposed model in a best fit line and error percentage is less as compare with the other models. Knight et.al (1984) and Seckin et.al (2006) models are also proving considerable prediction for %S_b estimation but the error in the proposed model is less as compared with the these models.

6.5 Application of Model to Field Data

The present model was validated with a natural river (main) which is in Northern Ireland.This river is almost straight and uniform cross-section, free from back water and tidal effect.Fig 6.19 shows the morphological cross-section of river main in which the main channel is almost straight and the banks are symmetrical.

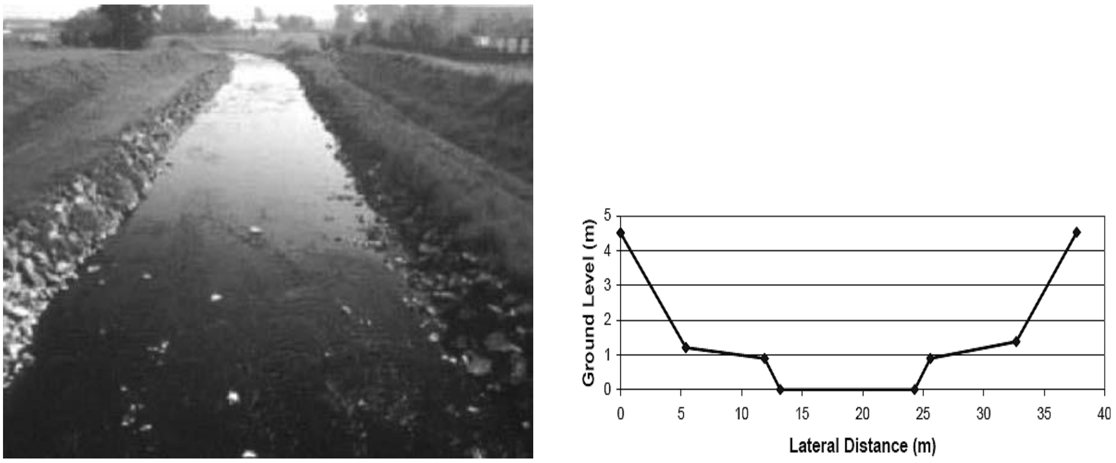


Figure: 6.19 Morphological and cross-section of River Main, Northern Ireland

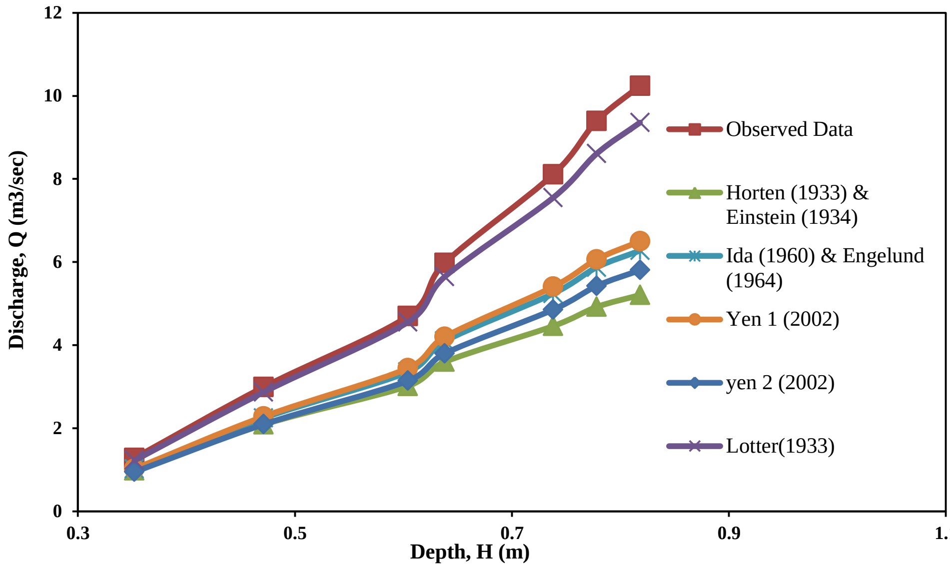


Figure: 6.20comparison of discharge by proposed model with River Main, Northern Ireland

The present model predicts the individual roughness value in term of manning's *n* for every sub perimeters. Then the composite roughness associated with different roughness values of subsections have been found out by applying different composite roughness models by previous investigators. Fig 6.20 shows comparison of discharges by applying different composite roughness (n_c) for River Main. The discharge predicted by of Horten (1933) and Einstein (1934), Ida (1960) &Engelund (1934), Yen 1(2002), Yen 2(2002) composite roughness models under predict the discharge in river, but Lotter (1933) model predicts a comparable good discharge for every depth of flow except three high flow depth. For first four depths, the predicated discharge is almost equal with the actual discharge of river main. But for last three flow depths, it under predicts the discharge but within an acceptable range error. We found that the Lotter (1933) method could give an overall good result with a minimum percentage of error for river main.

Chapter-7

Conclusions and Scope for Future Work

7.1 Conclusions

This present research followed by experimental data sets to observe the boundary shear stress distribution and percentage shear force on bed ($\%S_b$) and wall ($\%S_w$) in smooth and rough channel. Based on these observations, this research tries to compute the discharge which is the important task for every investigation. Based on this analysis, the following conclusions can be drawn.

- The experimental investigations are carried out in two different channels having different roughness. The measurements of percentage shear force on wall ($\%S_w$) and on bed ($\%S_b$)are taken. Percentage shear force on wall ($\%S_w$)in simple channel (bed and wall having same roughness) provides falling trend where as distribution of shear on wall ($\%S_b$) provides a reverse trend of that. It is concluded that when flow increase the shear stress also increases on bed however decreases on wall. The values of percentage shear on bed($\%S_b$) and on wall($\%S_w$) of all the channels having same roughness seems to make one trend.
- The similar results of $\%S_b$with $B/_H$ and $\%S_w$ with $B/_H$have been observed for channels where the wall and bed having different roughness all data sets. The distribution in different rough channels is not identical with the magnitude of shear force as this distribution of shear greatly varies with different geometry and roughness.
- The trends observed for $\%S_{mc}$ with relative flow depth (β) in compound channels are down in nature i.e., when the flow depth rises, the boundary shear distribution on main channel decreases. But the reverse upward curves have been observed for flood plain shear ($\%S_{fp} vs \beta$) cases. That means with increase in depth, the flood plain shear also increases causing reduction in main channel.

- It has been clearly observed that $\%S_{mc}$ decreases with increase of width ratio(α) but $\%S_{fp}$ increases with increase of width ratio (α). That means when channel widens the boundary shear force is reducing on main channel leading to increase in shear on flood plain. The similar identical trends as smooth compound channel have been observed for rough compound channel cases.
- A model has been derived for estimating the percentage shear on bed($\%S_b$) using multi linear regression analysis where the independent parameters are Reynolds no, Froude's no and flow aspect ratio. By using the proposed model for $\%S_b$ predicts good results and percentage error has been found minimum as compare to other models of previous investigators.
- By using different composite manning's roughness coefficient (n_c) model, the discharge for all data sets have been computed and found that the predicted discharge are approximately same as the measured value.
- Then the composite roughness associated with different roughness values of subsections have been found out by applying different composite roughness models and found that the Lotter (1933) method can give overall good result with minimum percentage of error for river main

7.2 Scope for Future Work

- The present research is restricted to channels with smooth boundary and rough boundary. So it can be extended to mobile bed cases.
- Only the straight prismatic sections are considered here, so it also extended to a meandering channel having a rough and mobile boundary.
- Incorporating a lot of data sets of various configurations, the accuracy of the present model can be improved.
- The study can also extend to overbank flows where the complex phenomenon is developed

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Dissemination

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