STAGE-DISCHARGE MODELING FOR MEANDERING CHANNELS

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

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In
Civil Engineering

SAINE SIKTA DASH

DEPARTMENT OF CIVIL ENGINEERING

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Submitted by

Saine Sikta Dash

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Under The Guidance of

Dr. K.K Khatua

Department of Civil Engineering
National Institute of Technology Rourkela
Orissa -769008, India
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NATIONAL INSTITUTE OF TECHNOLOGY ROURKELA,
ORISSA -769008, INDIA

This is to certify that the thesis entitled, "**STAGE-DISCHARGE MODELLING FOR MEANDERING CHANNELS**" submitted by **Saine Saikta Dash** in partial fulfillment of the requirement for the award of **Master of Technology** degree in **Civil Engineering** with specialization in **Water Resources Engineering** at the National Institute of Technology Rourkela is an authentic work carried out by her under our supervision and guidance. To the best of our knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any degree or diploma.

Research Guide

Place: Rourkela
Date:

Dr. K. K Khatua
Associate Professor
National Institute Of Technology

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ABSTRACT

Flow in meandering channel is quite ubiquitous for natural flow systems such as in rives. Rivers generally follow this pattern for minimization of energy loss. However, several factors such as environmental condition, roughness are responsible for generation of this path for rivers. Selection of proper value of Roughness coefficient is essential for evaluating the actual carrying capacity of Natural channel. An excessive value underestimates the discharge and a low value can over estimates. Suggested values for Manning's n are found tabulated in many standard articles. The resistance to the flow in a river is dependent on a number of flow and surface and geometrical parameters. The usual practice in one dimensional analysis is to select a value of n depending on the channel surface roughness and take it as uniform for the entire surface for all depths of flow. The influences of all the parameters are assumed to be lumped into a single value of Manning’s n .It is seen that Manning’s coefficient n not only denotes the roughness characteristics of a channel but also the energy loss in the flow. The larger the value of n, the higher is the loss of energy within the flow. Experimental investigations concerning the variation of roughness coefficients for a highly meandering channel for different flow condition, geometry are presented. The flow properties are found to be affected by different geometric, surface and flow parameters. In the present work, an attempt has been made to analyses the important parameters affecting the flow behavior and flow resistance in term of Manning’ n in a meandering channel. The factors influencing for predicting the roughness coefficient of a meandering channel are non-dimensionlised and its dependency with different parameters are studied. Further, a regression analysis has been done to formulate a mathematical model to predict the roughness coefficient. The equation can be suitably applied to predict the stage-discharge relationships of a meandering channel. The efficacy of the proposed equation has also been tested not only to the present data sets but also the data of other investigators.

KEYWORDS: Meandering channel, Manning’s n, Flow variables, Stage, Discharge.

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A	Area of channel cross section
a	Intercept
B	Meander channel top width
b	Bottom width of channel
b/h	Width depth ratio or aspect ratio
C	Chezy's channel coefficient
C_d	Coefficient of discharge
d_{84}	Size of the intermediate particles
e	Error
f	Darcy-Weisbach Friction factor
F_r	Froude's Number
g	Acceleration due to gravity
H_n	Height of water above the notch
H_w	Height of water in the volumetric tank
h	Height of channel
k	Von Karman's constant
L_c	Wave Length
L_m	Length of Meander
n	Manning's roughness coefficient
Q	Discharge
Q_a	Actual discharge
Q_{th}	Theoretical discharge
R^2	Coefficient of Determination
R	Hydraulic radius of the channel cross section
R_e	Reynolds Number
S_o	Bed Slope of the Channel
S_r	Sinuosity of the Channel

SS_y	Sum of Square Error
V	Mean flow velocity
X	Independent Variable
Y	Dependent Variable
ΔP	Dynamic Velocity
ρ	Density of flowing fluid
μ	Dynamic viscosity of water
α	Aspect ratio
σ^2	Variance
v	Kinematic viscosity
λ	Wave Length

CHAPTER 1

INTRODUCTION

Chapter 1

1.1 OVERVIEW

Water is perhaps the most fundamental and necessary resource available to mankind. It arrives on land in the form of precipitation and returns to the sea by means of river channels. For the most part, river channels adequately convey the water back to the sea but occasionally, under conditions of high rainfall and large flow rates, the river channel may overtop its banks and flow onto the flood plain with possible danger to life and property. Rivers are a natural aspect of our landscape and form an integral part of the water cycle. By default rivers are the effect of magnificence and the historic essence of a settlement. Also river are providing peace and serenity to the human beings. People have lived near to rivers for centuries due to the reason of mainly food, water, transport and protection. But sometimes, it may cause serious damage to people and the places in which they live even if it is a small, slow-flowing stream or gentle river. Normally river flow patterns are divided into two types such as (i) Straight river and (ii) Meandering river and (iii) Braid ed river. Discharge through straight type and meandering type are totally different from each other. According to the geometrical shape and other parameters flow through meandering channel are more complicated than straight channel. So In a meandering river, distribution of flow and velocity play a major role in relation to practical problems such as flood protection, flood plain management, bank protection, navigation, water intakes and sediment transport-depositional patterns. River flows in a meandering channel often inundate the adjacent plains at high discharges. Due to this it generates a complicated complex flow structure throughout the channel. There are two main issues involved in tackling such complex flow problems. The first is to collect the fundamental data for an internal structure under simple flow conditions as a bench mark. Without understanding the structure in a simple flow case one cannot proceed to more complex flow situations. Secondly an advanced tool is required to predict the accurate flow variables for complex flow structures. To predict such types of complex flow, experimental facilities, instrumentation and computer models have been gradually improved in the world. In fact, for the last 2 or 3decades, development of new velocity measuring devices, data collection systems and numerical models has made possible considerable advances in knowledge relating to water engineering problems. Extensive research has already been conducted not only in simple straight channels but also in complex meandering channels, such as the study was being carried out by Ikeda & Parker (1989) and Ozawa (1995), and compound channel flows by Ishigaki (2001).

Meander migration is a significant river engineering problem, which interferes with many human activities on and around the rivers, such as navigation, highway construction, flood control, and farming. There is a well-documented need (U.S. Army Corps of Engineers 1981) for guidelines for evaluating the problem, which is one of stability of river channel alignment. Guidelines are particularly needed to determine the extent to which a given channel alignment is prone to future changes. The meandering river system is characterized by recurrent river planform patterns, repeated with little variation from one river to the next irrespective of their magnitude and from one scale to another within each river. This consistency suggests that a higher level of processes forms by self-organization from the physical processes of deposition and erosion operating in the system. These physical processes may be described by continuum fluid mechanics. Although meandering dynamics can be simulated from models based on continuum mechanics, such models reveal little about the holistic, spatiotemporal properties of the meandering process, for example, the hierarchical, fractal geometry of the river planform. Present study attempts to justify the computational hydraulics analyses of meandering channel with formulation of equation for discharge. The natural flow mechanism was complicated and hence the calculation of discharge in meandering open channel flow is also complex and conventional methods cannot predict discharge with sufficient accuracy. A simple but reliable prediction technique for estimating roughness of a channel is highly necessary for field engineers, designers and researchers. However, with the recent development of soft computing, data mining and artificial intelligence, there is a choice of better techniques that can made easy to analysis the problems and can solve these problems to get the satisfactory results efficiently. When relationship between input and output is difficult to establish using numerical, analytical and mathematical methods and it becomes complicated and consumes the valuable time, therefore an easily implementable technique like a computing technique using a generalized Regression method can be adopted. The main advantage of this technique, it is totally a mathematical regression process Experiments are shown to examine the variation of roughness coefficients of a meandering channel with different hydraulic and geometric parameters. In addition to fresh experimental dataset, other data sets of meandering channels are collected to estimate the roughness coefficients of a meandering channel by Statistical system. The results validated by Statistical are compared with other well established and widely used traditional models Sellin (1960), Willet & Hardwick (1993), Shino & knight (1999), Glasgow (1997), Abreeden (1997), Myers (1957), Khatua(2007). Statistical error analysis is also carried to examine the performance of these models.

1.2 STAGE-DISCHARGE RELATIONSHIPS:-

Normally in river, for hydrological analysis continuous data measurement was needed but in practically data measurement in flowing condition was usually impractical. For stage we need data for analysis so it was observed continuously or at time intervals with relative ease and economy. Luckily, a relation occurs between stage and discharge at the river section. This relation is named a stage-discharge relationship or stage-discharge rating curve. This relationship occurs by making a number of concurrent observations of stage and discharge over a period of time covering the estimated range of stages at the river gauging section. This is conventional method for stage-discharge analysis.

Stage discharge rating curve is a very important device for open channel flow because the consistency of discharge data is highly dependent on a suitable stage-discharge relationship at the gauging station. Though the planning of rating curves appears to be an essentially task, a wide theoretical background is needed to create a reliable tool to switch from measured water height to discharge. The traditional and simple way to gather information on current discharge is then to measure the water level with gauges and to use the stage-discharge relationship to estimate the flow discharge. It is well known, in fact, that direct measurements of discharge in open channels is costly, time consuming, and sometimes impractical during floods. Prediction of stage-discharge relationship in a meandering river section is required in several river hydraulic problems such as river engineering, environmental engineering and intake designs. In a meandering river distribution of flow and velocity play a major role in relation to practical problems such as flood protection, Flood plain management, bank protection, navigation, water intakes and sediment transport-depositional patterns.

1.3 TYPES OF FLOW CHANNELS:-

In rivers, phenomena which may vary considerably in time and space, involve mainly two important subjects: open channel flow hydraulics and sediment transport. The boundaries in rivers are generally loose, and the problems are therefore complex. For a basic understanding of river morphology knowledge of sediment transport is obviously essential. Generally the natural rivers are of various kinds. Typical patterns in the plan geometry of streams correspond to characteristic of cross-sectional form, ability of bed load, downstream slope, and cross-valley slope, inclination to cut or fill, or position within the system. They can be classified on the basis of geometry of their flow path as follows,

1) STRAIGHT CHANNEL
2) MEANDERING CHANNEL
3) BRAIDED CHANNEL

1.3.1 Straight channels

If a channel no variation occurs it passage along its flow path. A straight channel, mainly unstable in nature and it’s developing along the lines of faults and joints, on steep slopes where hills closely follow the surface gradient. Flume experiments show that straight channels of uniform cross section rapidly develop pool-and-riffle orders.

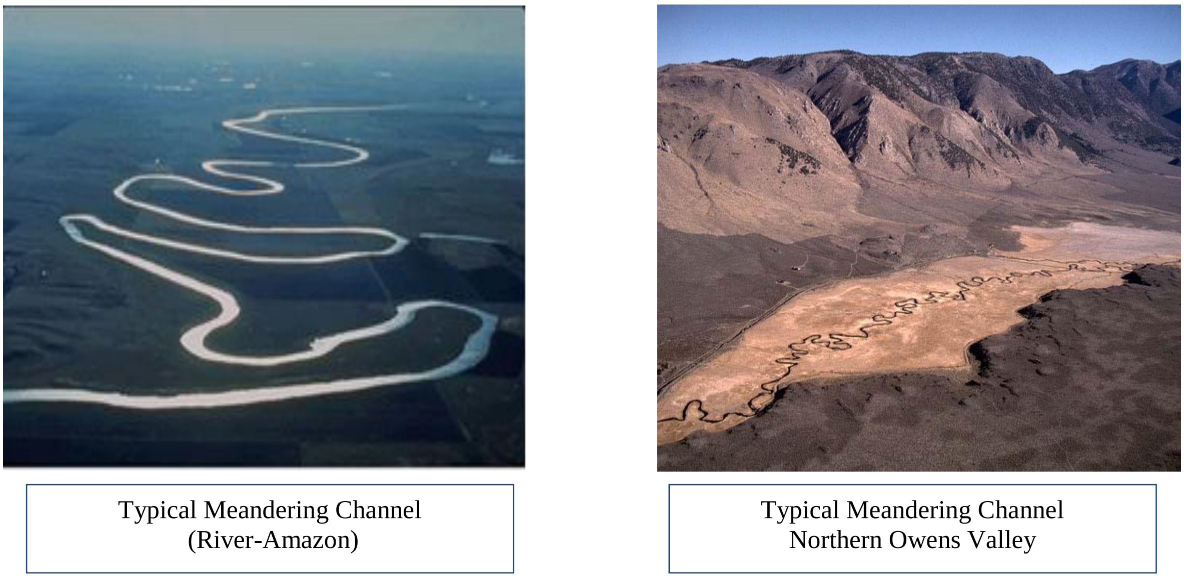
The Straight River in Owatonna

The Straight River Township Minnesota

Fig.1.1 Different types of straight channel

1.3.2 Meandering channels

If a channel deviates from its axial path and a curvature of reverse order is developed with short straight reaches. Meandering represents a degree of adjustment of water and sediment load in the river. Meandering channels are solo channels that are sinuous in geometry, but there is no principle, the degree of sinuosity essential before a channel is called meandering. The design of bends is measured by flow resistance. In meandering channel the flow reaches a minimum when the radius of the bend is between two and three times the width of the bed. Meandering channel is a bend in a sinuous river where single channels deviate and it becomes meander. It is basically formed by sediment erosion from the outer wall of bend and depositing them on the inside as results widens its valley. Natural channels never stop changing their geomorphic characteristics. The channel geometry, slope, degree of curvature, roughness and other concerning parameters are adjusted in such a way that the river fixes the least work in rotating, while carrying these loads. Flow in a meandering channel significances in geomorphic changes.



Typical Meandering Channel
(River-Amazon)

Typical Meandering Channel
Northern Owens Valley

Fig.1.2 Different types of meandering channel

Topographic high points and low points are count as pools and riffles correspondingly (Watson, et al. (2005)).The grain sizes found in riffles is greater than pools stated by Keller (1971). Fine sediments are removed from riffles during low flow velocity and shear stress and which get deposited in to pools. As a results the outer side of the bank became deeper than the inside bank where a point bar formation occurs. In addition to this the following features are seen in natural streams: point bars, middle bars, alternate bars and braiding. In meandering channel a helical flow (corkscrew shaped flow) is occurs, which is the water surface being raised on the outer bank of each curve, and return existing at depth directing the flow towards the opposite bank. The outer bank is eroded for this type situation and its gives a result of the higher flow velocity, for this deposition takes place on the inner side it forms a point bar.

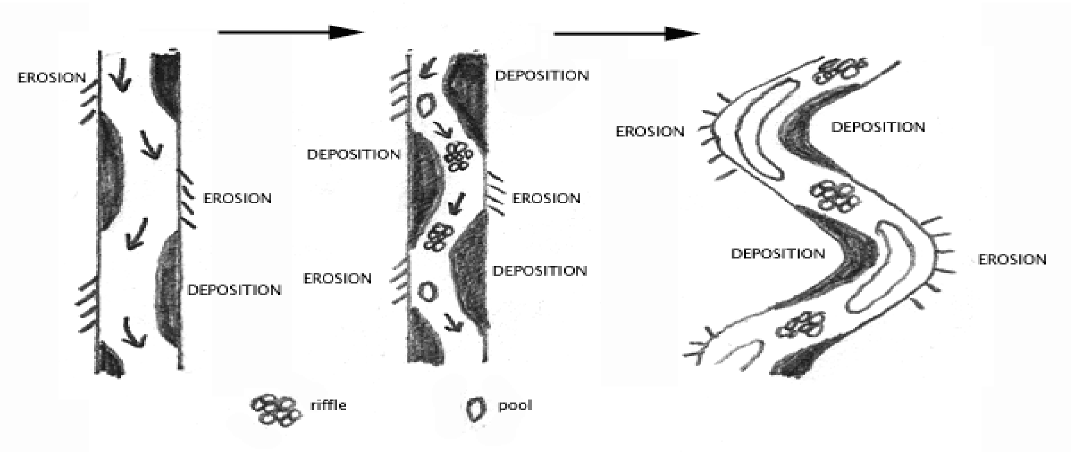


Fig.1.3 A simple illustration of Meandering Channel formation

There are two methods available to analyze meander geometry (Knighton, 1998). The first method focused on the individual bend statistics and the second method is a series approach method that treats the stream trace as a differential change of flow direction (Knighton 1998). An over view of geometry of meandering channel Watson et al. (2005) is shown below

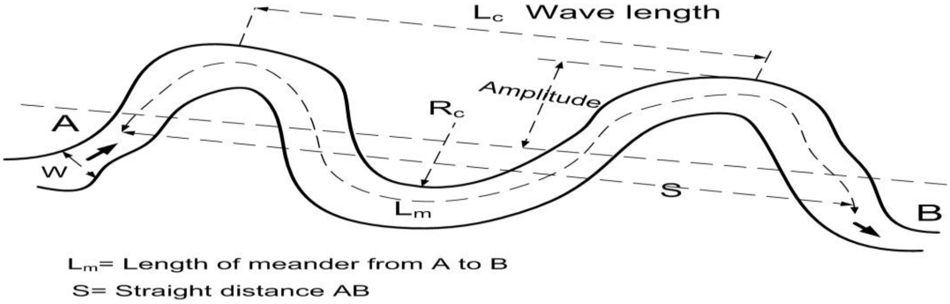


Fig.1.4 Geometry of Meandering Channel

1.3.3 Braided Channel

A braided river has a channel that consists of a network of small channels. Water courses which are divided by Small Island into multiple channel but term doesn't describes the multiple channel of an Ana-branching river. It is a section of a river or stream that diverts from the main channel or stem of water course and rejoins the main stem downstream.

Typical braided Channel
(Waimakariri River)

Typical braided Channel
(white river)

Fig.1.5 Different types of braided channel

1.4 Estimation of Stage-Discharge:-

For estimating a suitable rating curve in a natural channel the flow is considered steady and uniform and the discharge is estimated using traditional open channel flow formulations such as, Manning's formula, Chezy's formula and Darcy's Weisbach formula etc. are used. Normally discharge is calculated by area and velocity.

$$Q=A.V \tag{1.1}$$

In previously our scientist such as Manning's, Chezy's, Darcy's weisbach gives some formula to calculate velocity for straight channel. These are given below:-

Manning's equation $v=\frac{1}{n}R^{2/3}S^{1/2}$ (1.2)

Chezy's equation $v=C\sqrt{RS}$ (1.3)

Darcy-Weisbach's equation $v=\sqrt{\frac{8gRS}{f}}$ (1.4)

In above equation were traditional formulas for calculating velocity. The equation fails to predict the flow in meandering channels because of many variability and irregularities in geometry, flow and surface conditions. For this type of situation we need to create a mathematical modeling for calculating roughness and hence the stage-discharge relationships for meandering channel for a generalised conditions of flow and geometry.

CHAPTER 2

LITERATURE REVIEW

CHAPTER 2

2.1 OVERVIEW

An attempt has been made in this chapter to draw together various aspects of past research in hydraulic engineering concerning the behavior of rivers and channels during in bank and overbank flow. Prior to the early Sixties, very little was known of the complex flow patterns which exist between a channel and its associated flood plains, but more recent developments have led to a clearer understanding of the hydraulic mechanisms involved, at least at the level of model studies. An important step in receiving a better understanding of river systems is to study its velocity distribution with maximum accuracy. The flow prediction of river flows is vital information for flood control, channel design, channel stabilization and restoration projects and it affects the transport of pollutants and sediments. However, natural river channels are neither straight nor uniform somewhat typical curved or meandering channel forms. Flow in meandering channels is increasing interest because this type of channel is common for natural rivers, and research work regarding flood control, discharge estimation and stream restoration need to be conducted for this type of channel. It has exposed from investigators that the flow structure of meandering channels is unpredictably more complex than straight channels due to its velocity distribution. There are limited studies available in literature concerning the flow in meandering channels. Rivers are observed to meander, as may readily be seen from maps or aerial photographs (such as the well-known view of the Thames through London). Meandering effectively lengthens the channel path, within the existing valley or flood plain. The degree of meandering may be measured by the term sinuosity, which is defined as the ratio of channel length to valley length. Chow (1959) described the degree of meandering as follows:

Table 2.1:-Degree of meandering

Sinuosity ratio	Degree of meandering
1.0 - 1.2	Minor
1.2 - 1.5	Appreciable
1.5 and greater	Severe

In rivers, phenomena which may vary considerably in time and space, involve mainly two important subjects: open channel flow hydraulics and sediment transport. The boundaries in rivers are generally loose, and the problems are therefore complex. For a basic understanding of river morphology knowledge of sediment transport is obviously essential. In this research, experiments have been carried out in a meandering channel or compound channel and the results from these different channel configurations compared. This chapter is therefore divided into two sections: the hydraulics of open channel flow with either meandering or compound channels. These two sections briefly explain the necessary information concerning flow structure, two-phase flow and sediment transport. The prediction of the flow characteristics in meandering channels is a challenging task for rivers engineers due to the nature of flow. The dominant feature consists of the effect in the fast moving flow in meandering channel. Some of the extension literature are studied and presented below.

2.2 LITERATURE ON ROUGHNESS ,DISCHARGE AND VELOCITY PROFILE

Thomson (1876) studied the characteristic spiral motion of the flow in a channel bend. He also dedicated much research work to both clarifying the flow structure and explaining its mechanism. It was observed that the source of this phenomenon was the centrifugal force generated due to the curved flow path, and resulting spiral motions, i.e. secondary flows, have a significant effect on engineering matters such as flow resistance, sediment transport, erosion and deposition.

Bhowmik and Demissie (1932) studied data from two rivers in the United States and it is observed the rating curves obtained from these two rivers. It can be seen that, for both rivers there is a significant reduction in the main channel velocity during overbank flow.

Shukry (1950) observed regarding the entrance of the bend and gave the information about the path deviates from its normal course towards the inner bank and called this phenomenon an "adjusting process". Due to this the maximum primary velocity occurs along the inner bank in the first half of bend. After advance proceeding into bend, secondary flows begin to act on the distribution of the primary flow, driving the faster moving fluid to the outer bank. From the exit of the bend onward the maximum forward velocity lies near the outer side of the bend. Also Francis & Asfari (1971), Kalkwijk & De Vriend (1980) and Johannesson & Parker (1989b) analysed about the distribution of the primary velocity in channel bends theoretically, taking into account the advective effect of secondary flows.

Shukry (1950), Rozovskii (1961) and Onishi et at. (1976) conducted experimental work to identify both the main sources of extra energy losses in channel bends and the parameters which will affect such energy losses. Also it is concluded that the major sources of energy loss in channel bends can be attributed to: a) skin friction along the channel boundaries; b) increased bed friction caused by secondary flows and c) internal fluid friction due to secondary flows. The parameters on which energy loss in a channel bend is deemed to depend are: a) geometrical conditions, such as bend radius r c, bend angle 8 and the channel cross section shape; b)hydraulic conditions, such as flow depth h, Reynolds number Re and Froude number Fr; and c) roughness condition, i.e. friction factor *j*, n, C etc.

Prandtl (1952) divided secondary flows into three categories. According to him, the secondary flows in a channel bend are skew induced and are of the first kind. On the other hand, secondary flows of the second kind, stress induced ones; appear in straight ducts or channels. In this paper the growth and decay of secondary flows are described. The analysis that, after entering a bend, secondary flows start to develop until they become fully developed at some middle point on the bend. It is seen that the rotation of the flows is that the currents at the water surface move towards the outside of the bend, whereas they move inwards near the bed. At the fully developed point single cell type circulation of the flow can be observed and then secondary flows maintain their conditions uniformly until the exit of the bend. They initiate to decay when they leave the bend and enter the downstream straight reach. A much longer distance is necessary to weaken the flow than that for the development. The results show that both geometrical and hydraulic conditions are essential parameters.

The U.S. Army Corps of Engineers (Hydraulic 1956) studied a series experiments in meandering channels at the Waterways Experiments Station in Vicksburg. This paper investigates the stage-discharge and the effect of geometric parameters like radius of curvature of the bends, sinuosity of the channel, depth of flow, channel roughness on conveyance capacity in meandering channels.

Cowan (1956) discusses a procedure for estimating the effects of some factors to determine the value of n for a channel. This paper provides much more flexibility and accuracy than can be achieved using Chow (1959) in isolation.

Chow (1959) shows the tables specifying roughness coefficients for natural channels with constant roughness characteristics along a full river reach. However in any one reach these characteristics may vary considerably.

Sellin (1960) also presented the similar work at the University of Bristol. This paper investigates in a 6.1 meters long, 0.457 meters wide flume with symmetrical flood plains constructed from fiber glass. The consequential bank full depth was 0.0445 m. Preliminary tests indicated depressions on the water surface caused by large scale vortices transporting momentum from regions of high velocity to regions of slower flow on the flood plain. Based on the experiments it is attempted to quantify the extent of these vortices by using two similar photographic techniques. Thus the Schlieren principle can be used as a method of photographing the depressions on the water surface, generated by the vortices mechanism.

Spitsin (1962) explained about the behaviour of a trapezoidal channel with a channel bed width of 1.66 meters during overbank flow. To compare the flow in the main channel under interacting and isolated conditions, a glass wall at the channel/flood plain junction is inserted. Also he was able to calculate the energy existing in the channel and flood plain under isolated and interacting conditions.

The original Soil Conservation Service (SCS) (1963) method is also used for selecting roughness coefficient values for meandering channels. It is consisted of an empirically-based model which incorporates the extra flow resistance resulting from the influence of a channel sinuosity by adjusting the roughness coefficients that are used in the standard resistance formulae.

Sellin (1964) discusses about the existence of vertical vortices at the junction using a flow visualization technique. He also explained that momentum is exchanged between the main channel and the flood plain through these vortices.

Cruff (1965) studied the use of the Preston tube technique as well as the Karman - Prandtl logarithmic velocity-law to estimate the boundary shear stress resulting from uniform flow in a rectangular channel. A Preston tube is traversed around the boundary of a rectangular channel and an estimation of the boundary shear stress distribution obtained. From considerations of the longitudinal force equilibrium Equation, an apparent shear force, which is essentially an "out of balance" force, could be calculated to act on any vertical plane in the flow. Although he did not measure boundary shear stresses in a channel with overbank flow, his work recognized a method to enable investigators to calculate the apparent shear stress and hence momentum transfer between a channel and its flood plain. Also Wright and Carstens used the Preston tube technique to measure boundary shear stresses in a closed conduit aerodynamic model 6 meters long.

Posey (1967) shows the problems associated with the use of the hydraulic radius in estimating discharges in rivers with overbank flow. The hydraulic radius is distinct as the cross-sectional area of a channel divided by its wetted perimeter. As a flood inundates the flood plain, there is a sudden increase in the wetted perimeter with only a small increase in the total channel cross-sectional area. It shows that at just above bank full level, the hydraulic radius, as commonly calculated, is suddenly reduced and if conventional relationships are used to estimate discharge (such as Chezy’s or Manning) then the predicted discharge will also be reduced, since the discharge is a function of the hydraulic radius. Since the actual discharge is not reduced, better methods of estimating the discharge in compound channels are required. He suggested four possible methods which might be used in situations described above: (i) consider the whole cross-sectional area of the compound channel and divide it by the total wetted perimeter. (ii) Divide the channel and flood plains by imaginary walls at the channel/flood plain junction and compute the discharge for each section including the vertical imaginary walls for the calculation of the hydraulic radius for each section. The disadvantage of this method is that no allowance is made for the turbulent shear interaction and momentum transfer which occurs across each division line. Neglecting of this channel/flood plain interaction will lead to overestimation of

discharges at low flood plain depths. (iii) Method (iii) is similar to method two except that the imaginary walls are exceeded in the calculations of the hydraulic radius for each section. (iv) Method (iv) is perhaps the most complicated approach and involves the introduction of imaginary walls inclined towards the center of the channel from the channel bank. The hydraulic radius is then weighted by considering the area of the section it represents, against the total cross-sectional area. It is concluded that method (ii) was the most accurate method at low flood plain depths, whereas at greater depths, method (i) became more accurate.

Toebes and Sooky(1967) conducted an experiment from which the roughness, slope and channel depth on the discharge capacity of a meandering channel was investigated. A sinuosity of 1.09 was set for all the models which meant that the key parameters of these models were dissimilar to the key parameters in natural river channels. They observed the insight into general flow behavior and the dependency of meandering channels on longitudinal slope and channel aspect ratio.

Townsend (1967) conducted an experimental programmer using a 9-10 meter long Perspex flume of width 0.61 meters. This paper discussed the measurement of turbulence intensities in the longitudinal and transverse directions. The results of two tests illustrate a distinct lateral distortion of the maximum velocity, filament away from the interaction region.

Limerions's (1970) discusses an equation for natural alluvial channels. It is only valid for a particular range of flow volume. The vary from 6 – 430 m^3/s, and $n/R^{0.17}$ ratios up to 300 although it is reported that little change occurs over R > 30.limits of discharges

Muramoto & Endo (1970) presented the experimental work and measured longitudinal velocity in 1800 curved open channels by means of a propeller current-meter and studied turbulent intensity, autocorrelation coefficients and energy spectra.

Ghosh and Jena (1972) shows the distribution of boundary shear stress for rough and smooth walls in a compound channel. The experiment is conducted in an 8*5 meter long flume with a main channel width of 0.203 meters flanked by two flood plains, each of width 76 mm. Also they obtained the boundary shear distribution along the wetted perimeter of the total channel for various depths of flow using the Preston tube technique combined with the Patel calibration. It is observed that the maximum shear stress on the channel bed occurs approximately midway between the center line and corner, and the maximum shear in the flood plain always occurs at the channel/flood plain Junction. Also they prepared no direct reference to the interaction between &-channel and its flood plain, but results obtained can be used to calculate the extent of any interaction which was taking place during their tests. From the experimental results of the shear distribution it is possible to calculate Tc' the average shear stress in the- channel during interaction. It is observed that by roughening the total periphery of the channel and flood plain the boundary shear in the channel could be redistributed with the maximum shear in the channel bed now occurring at the channel center line.

Yen and Overton (1973) suggested the inadequacies of the methods proposed for discharge estimation in rivers with overbank flow. They projected a method which involved the selection of division lines across which; the net momentum transfer was zero. These lines would therefore be excluded in the calculation of the hydraulic radius since by definition, no shear stress exists on division lines through which no momentum is transferred.

Myers and Elsawy (1975) studied the effects of the existence of a flood plain on the boundary shear distribution of a channel. They used the Preston tube technique and Patel's calibration to determine the magnitude and distribution of boundary shear in a compound channel. It is seen that the average shear in the main channel is reduced during channel/flood plain interaction. It is found that this average shear stress could be reduced by as much as 20% at very low flood plain depths. At greater flood plain depths the reduction in shear stress decreased.

Leeder & Bridges (1975) give the information about the flow separation in meander bends and it is expressed as a function of bend tightness r *clB* and Froude number Fr. This paper shows that even at modest Froude numbers, say, 0.27-0.42, flow separation is likely to occur. This implies that many bends in rivers could be expected to induce separation zones.

James and Brown (1977) conducted an extensive study into the nature of the turbulent shear interaction between a channel and its flood plain. The experiment is carried out in a flume 26.82 meters long, 1-52 meters wide and 0.457 meters deep. Tests were conceded out on asymmetric and symmetric cross sections of varying channel and flood plain widths. Since the main channel was trapezoidal in shape, there was a less rapid change in the depth of flow across the channel. However the investigators did note some interaction between the channel and flood plain and suggested an empirical adjustment to the Manning resistance Equation applied to the total cross section.

Bathurst et al. (1979) presented the field measurements for the bed shear stress in a curved river and it is reported that the distribution of bed shear stress is affected by both the position of the core of the main velocity and the structure of secondary flows.

Rajaratnam and Ahmadi (1979) conducted experimental work in a channel 18.29 meters long, 1.22 meters wide and 0.9 meters deep. A main channel 0.2032 meters wide, flanked by two flood plains, each 0.508 meters wide is used to exhibit the Interaction mechanism in a symmetrical compound channel. Velocity traverses and boundary shear stresses were recorded. Analysis of velocity profiles revealed that the lateral velocity profiles at different depths in the main channel exhibited similarity.

Crory (1980) studied extensive tests in a flume described in Section 2-3i2. The analysis consist a model of an asymmetric compound channel, i. e. a channel flanked by only one flood plain. By inserting a moveable Perspex wall, it is able to test 4 different main channel widths and use was made of a laser Doppler anemometry system to give instantaneous point velocities and turbulence levels throughout the channel/flood plain cross-section. The point velocity measurements are integrated over the whole cross-sectional area giving a mean total channel discharge within 0.7% of the measured discharge, thus demonstrating the usefulness of the laser system. He also plotted isovel contours of the cross-sections and found that the maximum velocity filament in the channel was depressed below the water surface and away from the centre line of the channel, towards the non-interacting side of the main channel. It is observed at low flood plain depths, the maximum velocity filament occurred at the channel/flood plain.

Donald W. Knight, *et. al.* (1983) conducted experiments on flood plain and main channel flow interaction.The discharge characteristics, boundary shear stress and boundary shear force distributions in a compound section comprising of one rectangular main channel and two symmetrically disposed flood plains are obtained from experimental results. Equations are formed giving the shear force on the flood plains as a percentage of the total shear force in terms of two dimensionless parameters. The l Shear force results from experiments are used to derive ancillary equations for the lateral and vertical transfer of momentum within the cross section. The apparent shear force acting on the vertical interface between one flood plain and the main channel is shown to increase rapidly for low relative depths and high flood plain widths. Equations are modeled also giving the proportion of the total flow which occurs in the various sub areas. The division of flow based on linear proportion of the areas is shown to be inadequate on account of the interaction between the flood plain and main channel flows.

Chang (1984) conducted an experiment on the meander curvature and other geometric features of the channel using energy approach. It directly accounts for variations in bend radius along the length of a channel. The modified Chang (1984) method is based on the assumption that the channel is widecompared to its depth. This paper shows that it is difficult to apply this method to natural channels because of their variable configuration. In some of the instances the modified Chang method will give physically justifiable results however in most of the circumstances the simple LSCS method will be more appropriate than this method.

Jarrett (1984) studied a model to determine Manning’s *n* for natural high gradient channels having stable bed flow without meandering coefficient. This paper shows an mathematical equation which gives the value of Manning`s *n* is developed. The equation is meant for natural channels having stable bed and bank materials (boulders) without bed rock. It is intended for channel gradients from 0.002 – 0.04 and hydraulic radii from 0.15 – 2.1m.

Booij (1985) presented the experimental work and measured of the various shear stress components in a mildly curved flume. The analysis considered a 2-component LOA which was set up a unique configuration of the laser beams to obtain lateral and vertical components. This paper calculated the eddy viscosity coefficients in three directions: 1'yx -'-I (*a.---uv -8yx -J+ b-*

Tl) -8yax.Jp 0/ & 0/ and so on. It is shown that the assumption of isotropic eddy viscosities was not justified in the curved channel.

Anwar (1986) carried out a field measurement of three velocity components in a river bend using a two-component electro-magnetic current meter. The analysis considered

(a) The velocity profile in the mean flow direction in the bend did not obey the logarithmic law

(b) The Reynolds shear stress and normal stresses had their maxima near the outer bank.

Arcement and Schneider (1989) studied the Cowan method discussed above. This paper relates specifically for selection of resistance factor in natural meandering channels. This is mainly performed for the U.S. Department of Transportation. In the modified equation each variable values are selected from tables in Arcement and Schneider (1989).The equation is verified with flow depths from 0.8-1.5 m.

James and Wark (1992) studied the step function defined above with a linear function to avoid the discontinuity at the certain limits of the defined sinuosity ranges with consequent ambiguity. To overcome from this difficulty the existing equation was further linearised known as the Linearised SCS (LSCS) Method [1992] and this method was easy to apply and yields a significant result.

D. A. Ervine, *et.al*. (1993) shows the factors affecting conveyance in meandering compound flows. This paper accumulates together recent data from the large-scale flood channel facility, Wallingford, England, with other model studies to study the main parameters affecting conveyance in meandering compound river channels. Parameters measured include sinuosity, boundary roughness, main channel aspect ratio, width of meander belt, and flow depth above bank-full level as well as the cross-sectional shape of the main channel. The effect of each parameter is quantified through a non-dimensional discharge coefficient F*. Possible scale effects in modeling such flows are also investigated.

Willets and Hardwick (1993) conducted an experiment to study flow in a small laboratory flume where meandering channels of different sinusitis and geometry were utilized. It was found that the conveyance of channel vary with sinuosity. In other words, the flow resistance increases substantially with an increase in channel sinuosity. The flow interaction responsible for the flow resistance was also found to be dependent on channel cross section geometries.

Genadii A. Atanov, *et.al.* (1999) conducted an experimental work to measure estimation of roughness profile in trapezoidal open channels. In de Saint Venant equations, it is difficult to measure the bed roughness-coefficient directly and therefore needs to be estimated. The estimation process is referred to as ‘‘parameter identification,’’ which is a mathematical process depending on the difference between the solution of the model equations and the measured system response. This paper shows an approach for solving the parameter identification problem in the de Saint Venant equations. The method proposed herein is widely used in gas dynamics; but it is not used before for unsteady problem identification of open channel flow parameters. The assumed solution is also used for other parameters, e.g., cross-sectional area, bed width, etc. Starting with an initial guess of the roughness coefficient, the algorithm iteratively improves the guesses in the direction of the gradient of the least square criterion. The gradient is obtained by means of a variation approach, while the conditions of the criterion minimum are identified by the general method of indefinite Lagrangian multiplier.

Maria and Silva (1999) studied friction factor of meandering channel by conducting experiments in two meandering channels of different sinuosity and expressed that it is a function of sinuosity and position. This expression was found to compute vertically averaged flows that were in agreement with the flow pictures measured for both large and small values of sinuosity.

Shiono, *et.al.* (1999) studied the effect of bed slope and sinuosity on discharge estimation of a meandering channel. Conveyance capacity of a meandering channel was derived using dimensional analysis and consequently helped in finding the stage-discharge relationship for meandering channels. Ta paper shows that discharge increased with an increase in bed slope and decreased with increase in sinuosity for the same channel.

Kahnu C. Patra and Srijiv k. kar (2000) studied on the flow interaction of meandering river with floodplains. A series of laboratory test results are conducted about the boundary shear stress, shear force, and discharge characteristics of compound meandering river sections composed of a rectangular main channel and one or two floodplains disposed of to its sides. Five dimensionless parameters are used to form equations representing the total shear force percentage carried by floodplains. A set of smooth and rough sections is studied with an aspect ratio varying from 2 to 5. Apparent shear forces on the assumed vertical, diagonal, and horizontal Interfacial plains are found to be different from zero at low depths of flow and change sign with an increase in depth over the floodplain. Here a variable-inclined interface is proposed for which apparent shear force is calculated as zero. This paper shows equations related to proportion of discharge carried by the main channel and floodplain. The equations concur well with experimental and river discharge data. Using the variable-inclined interface, the error between the measured and calculated discharges for the meandering compound sections is found to be the minimum when compared with that using other interfaces.

Patra, Kar and Bhattacharya (2004) shows that the flow and velocity distributions in meandering channels are strongly governed by flow interaction. By taking adequate care of the interaction affect, they proposed equations that are found to be in good agreement with natural rivers and also the experimental meandering channel data obtained from a series of symmetrical and unsymmetrical test channels with smooth and rough sections.

Patra and Khatua (2006) observed that Manning's roughness coefficient not only denotes the roughness characteristics of a channel but also the energy loss in the flow.

Jana (2007) assumed the stage-discharge relationship in meandering channels of low sinuosity using dimensional analysis. For meandering channel Manning's roughness co-efficient is described as a function of aspect ratio, sinuosity and bed slope.

Khatua (2008) studied that distribution of energy is an important aspect needs addressed adequately. It is resulted from the variation of the resistance factors Manning's n, Chezy's C, and Darcy –Weisbach's f with flow depths. He found out Stage-discharge relationship ranging from in-bank to the over-bank flow, channel resistance coefficients for meandering channel. It is stated that Flow distribution becomes more complicated due to interaction mechanism as well as with sinuosity.

Lai Sat Hin *et. al*. (2008) measured the estimation of discharge capacity in river channels with variations in geometry and boundary roughness. It is shown that the findings afield study including the stage-discharge relationships and surface roughness in term of the Darcy-Weisbach friction factor for several frequently flooded equatorial natural rivers. The resulted friction factor was found to increase rapidly for low flow depth.

Paarlberg *et. al*. (2008) presented the experimental work to determine the channel roughness of rivers by predicting dune dimensions during a flood wave by using an idealized mathematical model. It was a new physically-based method and the result of model predicts the shape of a flood wave which influences dune dynamics and thus roughness coefficient development in hydraulic models which can serve as starting point for future model calibrations.

Pinaki (2010**)** also analysed a series of laboratory tests for smooth and rigid meandering channels and developed mathematical equation using dimension analysis to evaluate roughness coefficients of smooth meandering channels of less width ratio and sinuosity.

Khatua and Patra (2012) conducted a series of laboratory tests for smooth and rigid meandering channels and developed mathematical equation using dimension analysis to evaluate roughness coefficients.The important variables considered in affecting the stage-discharge relationship were velocity, hydraulic radius, viscosity, gravitational acceleration, bed slope, sinuosity, and aspect ratio.

Moharana (2012**)** also presented the effect of geometry and sinuosity on the roughness of a meandering channel. Using a large data set applied a soft computing technique (ANFIS) to predict the roughness of a meandering channel.

CHAPTER 3

EXPERIMENTAL AND METHODOLOGY

CHAPTER 3

3.1 OVERVIEW

Normally, experimental work based on river is somewhat difficult to present in a laboratory in practical point of view. For this cause a designed model of a river in a laboratory is required. Rivers are generally meandering in nature but maintaining different sinuosity related to flow of water is difficult. To predict Stage-Discharge relationships in straight channel is easier than meandering channel. For a meandering channel a generalised model is required to be formulated to estimate the stage discharge relationships in meandering rivers. Many researchers have developed a number of models which partially satisfied the condition of meandering channels. So no proper model has been developed so far to predict stage-discharge relationship of a meandering channel taking all important parameters into account. Our present study is related to development of a model which predicts a suitable model which gives more accurate stage discharge prediction for meandering channel than previous. In our National Institute of Technology Rourkela, by the help of DST, there was a R&D project titled “Sinuosity dependency in stage-discharge and boundary shear distribution modeling for meandering compound channels”, here different meandering channels for different sinuosity river based model have been created for study of flow variables due to change in sinuosity and flow conditions. According to the requirement of the project the construction of the channel is maintained as follows.

3.2 DESIGN AND CONSTRUCTION OF CHANNEL

For carrying out study in meandering channels, experimental setup was built in Fluid mechanics and Hydraulics Laboratory of NIT, Rourkela. Here the main channel is constructed with Perspex sheet of 6mm/10mm thickness. The main channel is formed in trapezoidal shape having bottom width 0.33m, depth 0.065m and side slope 1:1 was built inside a steel tilting flume. The total length of the flume is 15m and the flumes can be tilted by hydraulic jack arrangement. (Fig shows the overall view of the channel.) The main channel is a sine generated curve of one and half wave length (wavelength, λ=2.162m) and is preceded and followed by a straight portion jointed with a transitional curved portion in order to have proper flow field developed in the test reach which is at the second bend apex of the central curve (Fig 3.1 shows Meandering channel of cross over angle 400, Fig.3.2 shows the schematic diagram of experimental setup and fig 3.3 represents the dimensions of channel with test section respectively). By the help of centrifugal pump (15Hp) the required amount of water is supplied to the flume from an underground sump via an overhead tank. This water is re circulated through the downstream volumetric tank fitted with closure valves for calibration purpose. Water entered the channel through bell mouth section via an upstream rectangular notch specifically built to measure discharge in such a wide laboratory channel. An adjustable vertical gate along with flow straighteners was constructed in upstream section. It is provided to reduce turbulence and velocity of approach in the flow near the notch section. At the downstream end another adjustable tail gate was also provided to control the flow depth and maintain a uniform flow in the channel. A movable bridge (approx. 1.2m width and 4m long) was provided across the flume in both axes over the channel area so that each location on the plan of meandering channel could be accessed for taking measurements. The broad parameters of this channel such as aspect ratio of main channel (δ), width ratio (α) were kept constant for all different sinuous channels. In all the experimental channels, the flow has been maintained uniform i.e. the water surface is parallel to bed of channel. This simplified approach has been tried to achieve which is also in line with the experimental work of Shino Al-Romaih and Knight (1999). This stage of flow is considered at normal depth, which can carry a particular flow only under steady and uniform conditions.

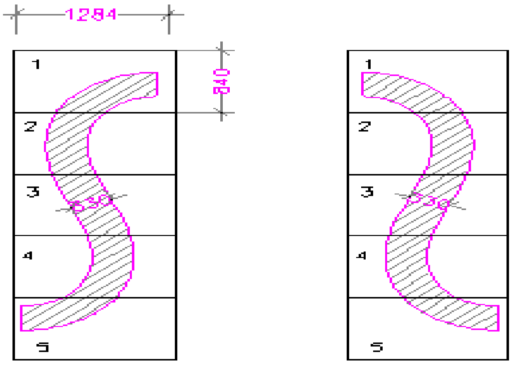


Fig.3.1. Designed plan of the experimental meandering channel (Sr=4.11)

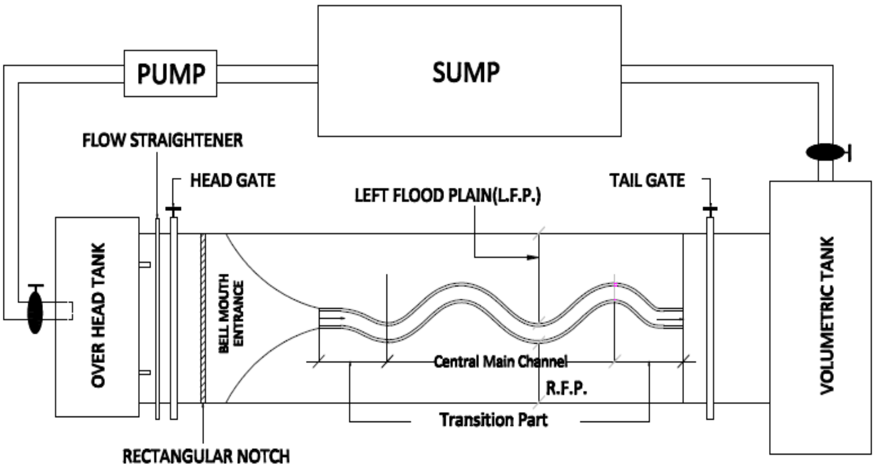


Fig.3.2. Schematic diagram of Experimental meandering channels with setup

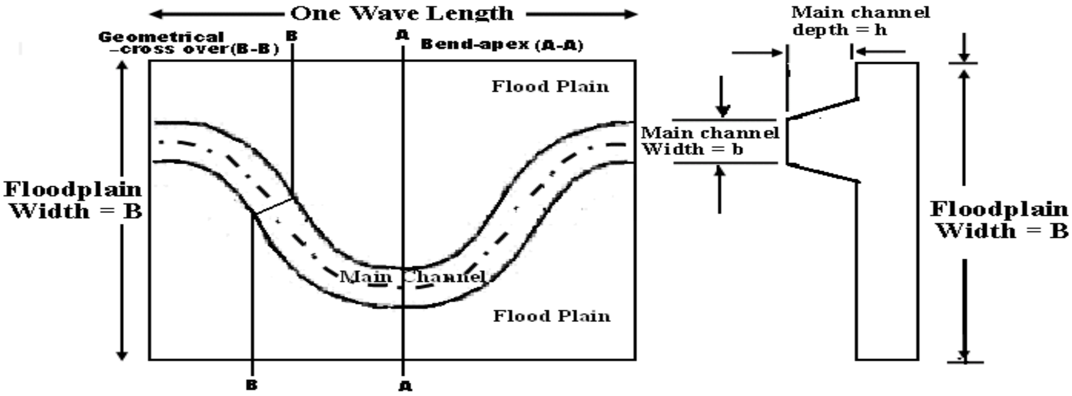


Fig.3.3 Longitudinal & Cross sectional dimension of the meandering channel

3.3 APPARATUS & EQUIPMENTS USED:-

In this present study Measuring devices like a pointer gauge having least count of 0.1 mm, rectangular notch, five micro-Pitot tubes each of them having 4.6 mm external diameter and five manometers were used in the experiments. These are used to measure velocity and its direction of flow in the channels. In the experiments structures like baffle walls, stilling chamber, head gate, travelling bridge, sump, tail gate, volumetric tank, overhead tank arrangement, water supply devices, two parallel pumps etc. are used. The measuring equipment and the devices were arranged properly to carry out experiments in the channels.

i. Pointer Gauge

ii. Rectangular Notch

iii. Micro Pitot tubes

iv. Series of Manometers

Fig.3.4 (i to iv) Apparatus used in experimentation in the meandering channel

3.4 EXPERIMENTAL PROCEDURE

All the observations are recorded at the central bend apex of the meandering channel. Point velocities were measured along verticals spread across the main channel so as to cover the width of entire cross section. Also at a number of horizontal layers in each vertical, point velocities were measured. Measurements were thus taken from left edge point to the right edge of the main channel bed and side slope. The lateral spacing of grid points over which measurements were taken was kept 4cm inside the main channel and also Pitot tube is moved from the bottom of the channel to upwards by 0.4H, 0.6H, 0.8H (H=total depth of flow of water)(Fig.3.5 shows the grid diagram used for experiments). Velocity measurements are taken by Pitot static tube (outside diameter 4.77mm) and two piezometers fitted inside a transparent fiber block fixed to a wooden board and hung vertically at the edge of flume. The ends of which were open to atmosphere at one end and the other end connected to total pressure hole and static hole of Pitot tube by long transparent PVC tubes. Before taking the readings the Pitot tube along with the long tubes measuring about 5m were to be properly immersed in water and caution was exercised for complete expulsion of any air bubble present inside the Pitot tube or the PVC tube. Even the presence of a small air bubble inside the static limb or total pressure limb could give erroneous readings in piezometers used for recording the pressure. Steady uniform discharge was maintained in each run of the experiment and altogether five runs were conducted.

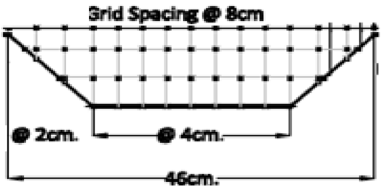


Fig.3.5 Typical grid showing the arrangement of velocity measurement points along horizontal and vertical direction at the test section for meandering channel.

3.5 EXPERIMENTAL CHANNELS:

The meandering channel is constructed of 330 mm wide at bottom, 460 mm at top having full depth of 65 mm, and side slopes of 1:1. The channel has wavelength L = 2162 mm and double amplitude 2A' = 1555 mm. Sinuosity of the channel is maintained 4.11.For better information the details of geometrical parameters for both the experimental channels are tabulated below and also fig.3.6 shows details overview of meandering channels.

Fig. 3.6 meandering channel inside the flume with measuring equipment

Table 3.1: Details of Geometrical parameters of the experimental runs

Sl No	Item description	Present Experimental Channels
1	Channel Type	Meandering 1
2	Flume size	4.0m×15m×0.5m long
3	Geometry of Main channel section	Trapezoidal (side slope 1:1)
4	Nature of surface of bed	smooth and rigid bed
5	Channel width	33cm at bottom and 46 cm at top
6	Bank full depth of channel	6.5cm
7	Bed Slope of the channel	0.00165
8	Sinuosity	4.11
9	Amplitude	1555 mm
10	Wave length	2162 mm

3.6 MEASUREMENT OF BED SLOPE

Measuring the bed slope of the flume, there are several methods exists which are used according to the practical conditions and researcher's interest. Here in our present study we measured the bed slope through water level piezometric tube. So first of all we took the water level with reference to the bed of the channel at the upstream side and then downstream side of the meandering channel which is 15m apart. Here the level is taken from the bottom of the bed excluding the Perspex sheet thickness. After taking the level at the two points, the difference in the corresponding level was measured. The bed slope of the channel is calculated by dividing this with the length of the channel (15m). For more accuracy this procedure was continuing for three times and the average was taken as the bed slope of 0.00165.

3.7 CALIBRATION OF NOTCH

For getting accurate and continuous discharge estimations of the channels, a rectangular notch is fitted at the upstream side of the flume. For calculating discharge more accurately notch calibration is required. For this, area of volumetric tank located at the downstream of the channel was measured properly. The height of water in the volumetric tank was recorded from the corresponding measuring scale connected to it. A constant time or a constant height of the water was maintained to record the increase the level of the water in the measuring scale or the time elapsed. Time variation depends on the rate of flow from the channel. Finally change in the mean water level in the tank over the time interval was recorded. By getting the volume of the water discharged and the corresponding time elapsed, the actual discharge was calculated for each run of the channel. The height of water flowing above the rectangular notch is measured by point gauge attached to the notch. Then form calibration the coefficient of discharge 'C_d' for each run is calculated as for the equation given below.

$$V_w = A \times h \tag{3.1}$$

$$Q_a = \frac{V_w}{t} \tag{3.2}$$

$$Q_{th} = \frac{2}{3} L \sqrt{2g} H_n^{3/2} \tag{3.3}$$

$$C_d = \frac{Q_a}{Q_{th}} \tag{3.4}$$

Where, Q_a is the actual discharge, Q_{th} is theoretical discharge, A is the area of volumetric tank, V_w volume of water, t time in sec, C_d is the coefficient of discharge calculated from notch calibration, h is the height of water in the volumetric tank, L is the length of the notch, H_n is the height of water above the notch and g is the acceleration due to gravity.

From the notch calibration, coefficient of discharge 'C_d' of rectangular notch was found to be 0.66.

3.8 MEASUREMENT OF DEPTH OF FLOW AND DISCHARGE

Depth of flow for all the series of experimental are measured by pointer gauge above the bed of the channel. The point gauge with least count of 0.1 mm was fitted to the movable bridge and operated manually. The construction of rectangular notch is provided at the upstream side for measuring the discharge in the channel. A volumetric tank located at the downstream side of channel to receive the incoming water flow through the channels. The discharge 'Q_{actual}' for each run is calculated as for the equation given below.

$$Q_{actual} = C_d \frac{2}{3} L \sqrt{2g} H_n^{\ 2/3} \tag{3.5}$$

Where, Q_{actual} is the actual discharge, C_d is the coefficient of discharge calculated from notch calibration, L is the length of the notch, H_n is the height of water above the notch and g is the acceleration due to gravity

3.9 MEASUREMENT OF LONGITUDINAL VELOCITY

Generally in a meandering channel high energy loss occurs at the bend apex. So it is required to measure the Velocity at this place due to minimum curvature effect and to study the flow parameters covering half of the meander wave length. In the present study, by using Pitot tube and manometer pressure head readings were taken. From these data corresponding velocities were calculated. Normally Pitot tube was placed at the apex bend in the direction of flow and then allowed to move along a plane parallel to the bed and until unless a relatively maximum head difference obtained in manometer. The total head h reading by the Pitot tube at the predefined points of the flow-grid in the channel is used to measure the magnitude of point velocity vector as $v=2gh$, where g is the acceleration due to gravity. Here the tube coefficient is taken as unit and the error due to turbulence considered negligible while measuring velocity. Each experimental runs of the channel are carried out by maintaining the water surface slope parallel to the valley slope to achieve the steady and uniform flow conditions.

CHAPTER 4

EXPERIMENTAL RESULTS

CHAPTER 4

4.1 OVERVIEW

In chapter 3 the experimental procedures has been described with the outlines are given for the experimental procedure carried out on the series of the tests. This chapter will now present the results of these tests in terms of the local velocity distributions and stage-discharge relationships and also the laboratory measurements are presented concerning the channel geometry, the stage discharge data, and the calibration of bed roughness, velocity and flow measurements.

It can be appreciated that before the effects of the meandering channel can be quantified, an understanding regarding the hydraulic behavior, of the flow must be obtained when the flow is confined to the channel alone. Therefore it is necessary to establish a proper equation to evaluate the friction factors for the channels. A series of such tests were carried out and their description and results are already presented in the previous chapters. Further analysis and discussion of the results, new model development and comparisons with the work of other researchers in the field are left until the following observations and comments on them are presented in this chapter. The stage-discharge curves of the meandering channel, as well as velocity contours for different flow depths are presented and discussed.

4.2 STAGE-DISCHARGE RESULTS:-

One of the most important relationships for a River Engineer is the stage-discharge relationship, which is essential for design and flood management purposes. From examining the stage-discharge data, shown in figure 4.1, it is possible to compare the efficiency of the meandering channel. In order to investigate the influence of the momentum transport mechanism on the discharges of meandering channel flow for different Froude numbers, stage-discharge relationships were found. The first procedure is to obtain uniform flow for a particular discharge. In order to achieve uniform flow, the tailgate/s was/were adjusted to give several MI and M2 profiles. The mean water surface slopes and related depths were then plotted versus tailgate position in a computer program and the tailgate setting which gave a mean water surface slope equal to the floodplain bed slope of 1.650x 10-3 was interpolated from the graphs .The depth related to this tailgate setting was then accepted as the normal depth. This procedure was repeated for every single experiment in order to obtain accurate stage-discharge relationships for the meandering channels.

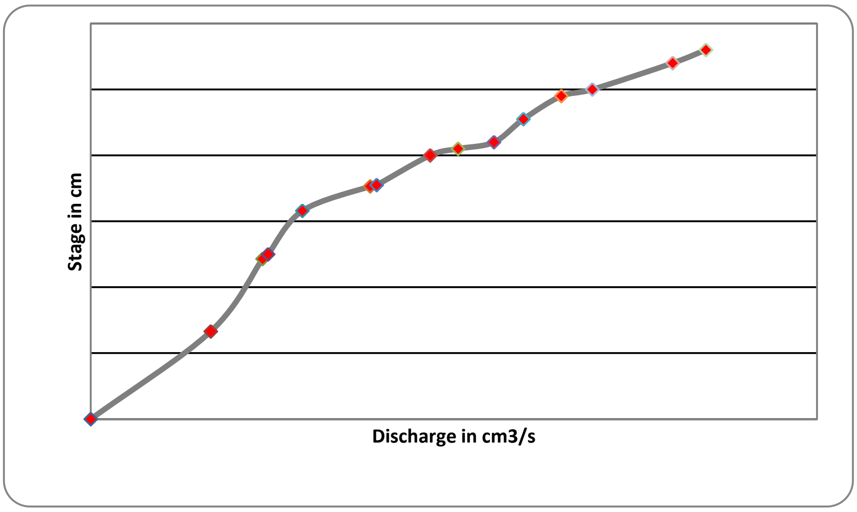


Fig 4.1 Stage-discharge curve for meandering Channel

In the present work it was difficult to succeed the steady and uniform flow condition in meandering channels due to the many effect such as curvature and the influence of a number of geometrical and hydraulic parameters. However, it is tried to achieve the water surface slope parallel to the valley slope so as to get an overall steady and uniform flow in the experimental channels. In all the experimental runs this easy methodology has been tried to achieve which is also in line with the experimental work of Shino, Al-Romaih and Knight (1999), Khatua (2008). This stage of flow is considered as normal depth, which can carry a particular flow only steady and uniform condition. The stage discharge curves plotted for meandering channels of sinuosity

4.11 are shown in Fig. 4.1. From the figures it is seen that the discharge increases with an increase in stage in meandering channels.

4.3 DISTRIBUTION OF LONGITUDINAL VELOCITY RESULTS :-

In order to determine point velocities and to obtain the discharge, a device commonly used is the Pitot static tube. A Pitot tube is a device which when used in conjunction with a manometer, determines the difference between the total and static pressures, (i.e. the dynamic pressure), at any point in a moving fluid. The dynamic pressure is related to the velocity via:

$$V = C\sqrt{2gH} \tag{4.1}$$

Where, V is the flow velocity

ΔP is the dynamic pressure,

g is gravitational acceleration

C is a non-dimensional constant

The coefficient C is dependent upon the degree of imperfection in the Pitot tube, and on its method of use. The exact dependency of such factors is outlined in BS1042, part 2A(1983), and as a consequence is not reiterated.The Pitot tube can also be used to evaluate the discharge in the channel provided sufficient velocity measurements have been made. The number of measurements of local velocity depends upon the nature of velocity distribution across the channel, i.e. more measurements are needed for complex flow patterns. Averaging each velocity over a small area of the channel, allows the evaluation of discharge to be obtained via numerical integration. In order to check the discharges, the cross-section was divided into a grid. The mean velocity of a sub area formed by the grid was assumed to be equal to the average of the four point velocities at the corresponding nodes. Due to the curvature of the wall near the channel boundaries, it was necessary to approximate some of the sub areas formed by the grid.

The Pitot tube used throughout this series of experiments had an outside diameter of 4.6mm, and was connected to water manometer which was adjustable to the horizontal. In order to precisely position the Pitot tube in the flow, it was placed in a transverse carriage, which allowed vertical, horizontal and rotational motion.

Longitudinal velocity is noted by Pitot-tube in the experimentation. In these channels the subsequent observations are carried out at the bend apex which is normal to flow direction. The detailed velocity distribution is carried out for meandering channels of sinuosity 4.11 respectively. The radial distribution of longitudinal velocity in contour form for the runs of the meandering channels is shown below. It gives the point form velocity measurement at different points is shown below. The contours of velocity distribution are shown in Fig. 4.3(i to v).

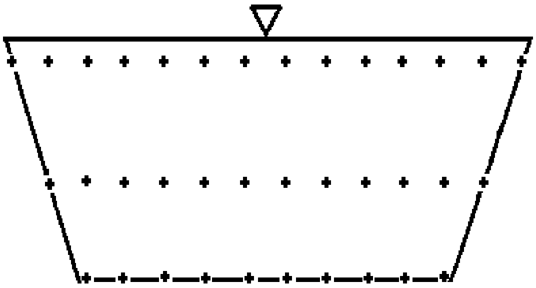
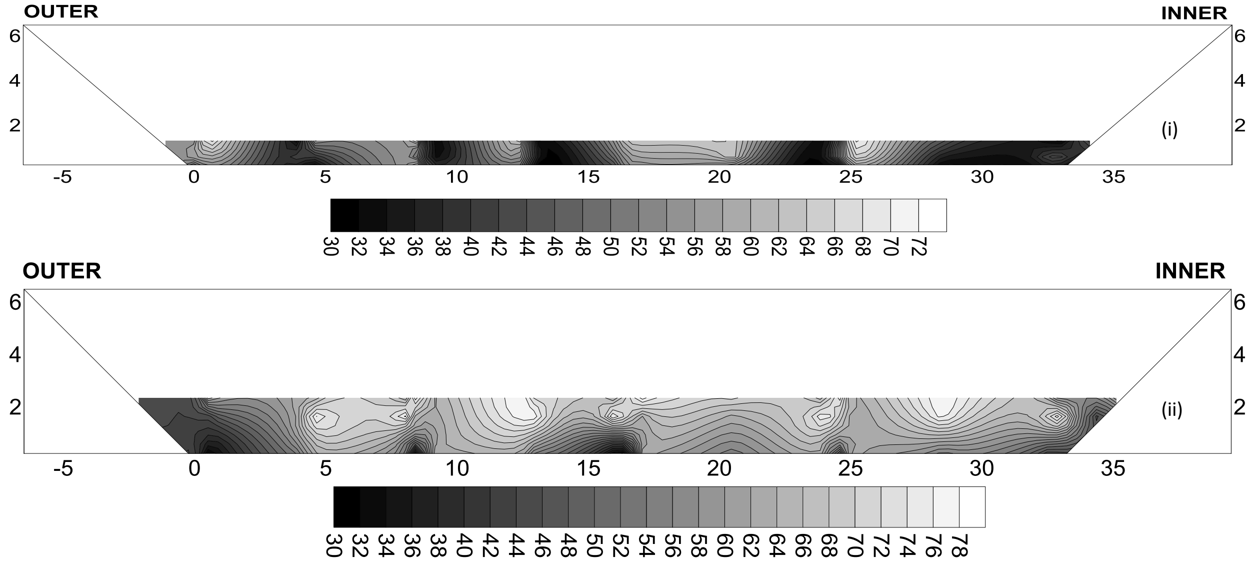


Fig.4.2 Grid Points of longitudinal velocity measurement



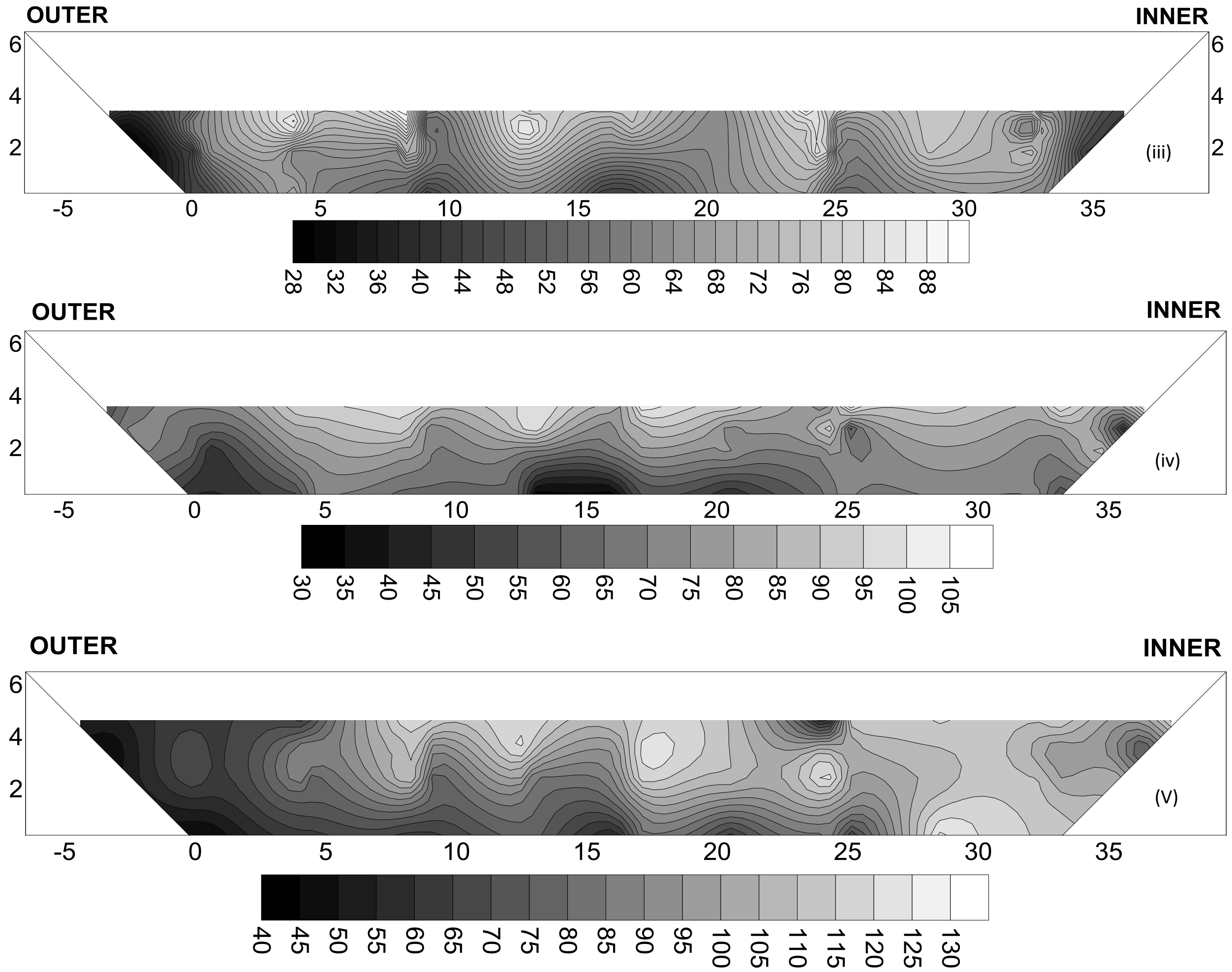


Fig.4.3 (i to v) -Longitudinal velocity contours for simple meandering channels

There were some points noted down from the counters of longitudinal velocity distribution in meandering channel cross-sections at location of bend apex. These are given below

A. Longitudinal velocity distribution in the form of contours points that are skewed with curvature. Contours with more velocity are getting gradually increasingly at the inner bank to outer bank at the bend apex of meandering channel.

B. It is observed that in all cases of depth, the maximum velocity occurs at the inner wall in the bend entrance where the radius of curvature is the minimum and negative pressure gradient occurs from outer bank.

C. It was clearly proved that distribution of longitudinal velocity affected significantly by sinuosity of meandering channel. The results of meandering channel with sinuosity 4.11 shows irregular longitudinal velocity distribution. Similar reports are also seen for deep channels of Das (1984) and Khatua (2008) the distribution of longitudinal velocity as erratic.

4.4 VARIATION OF ROUGHNESS COEFFICIENTS IN MEANDERING CHANNELS

A major area of uncertainty in river channel analysis is the accuracy in predicting the discharge carrying capability of river. The discharge calculation for channel is based mainly on refined one dimensional analysis using the conventional Manning's, Chezy's or Darcy-Weischbach equation already given in upper.

Sellin et al. (1993), Pang (1998), and Willetts and Hardwick (1993) reported that the Manning's roughness coefficient not only denotes the characteristics of channel roughness but also influences the energy loss of the flow. For sinuous channels the values of n become large indicating that the energy loss is more for such channels. The experimental results for Manning's n with depth of flow for simple meander channels are plotted. The plot indicates that the value of n increases as the flow depth increases. An increase in the value of n can be mainly due to the increase in resistance to flow for wider channel with shallow depth consuming more energy than narrower and deep channel. It can also be seen from figure is that steeper channels consume more energy than the flatter channels. The detailed calculation of roughness coefficients are tabulated in Table.4.1.

Table.4.1 Details of Hydraulic parameters of the experimental runs.

Depth of flow (cm)	Length (cm)	Discharge (cm^3)	Area (cm^2)	Perimeter (cm)	Slope	Manning`s Roughness n	Chezy`s C	Darcy Weisbach Friction Factor f	Reynolds no R_e	Froude's no F_r
1.33	339	1486.9777	64.57143	34.8809	0.00165	0.014081	41.7941	0.04492	5483.18	0.5235
2.43	339	2128.8676	121.7565	36.4365	0.00165	0.014317	23.6187	0.1406	6251.53	0.5172
2.5	339	2197.1703	125.5114	36.5355	0.00165	0.014406	23.3224	0.1442	8054.92	0.4981
3.53	339	3462.3575	182.3641	37.9921	0.00165	0.014511	21.3987	0.1713	8230.69	0.4845
3.55	339	3542.5646	183.4977	38.0204	0.00165	0.014624	21.6999	0.1666	9490.98	0.4775
4	339	4205.8081	209.3036	38.6568	0.00165	0.014706	21.3243	0.1725	10205.6	0.4718
4.55	339	5361.4314	241.6219	39.4346	0.00165	0.014707	22.1357	0.1601	11688.4	0.4634
4.9	339	5830.2022	262.6336	39.9296	0.00165	0.014708	21.3739	0.1717	12441.9	0.4591
5	339	6214.5362	268.7005	40.0710	0.00165	0.01471	22.0546	0.1613	13182.5	0.4546
5.4	339	7210.4218	293.2513	40.6367	0.00165	0.014728	22.6015	0.1536	14936.6	0.4456
5.6	339	7622.3854	305.6964	40.9195	0.00165	0.014713	22.5267	0.1546	15607.1	0.4310

a.Variation of Manning's *n* with Depth of Flow

The experimental results for Manning's n with depth of flow for the present highly meandering channels investigated and plotted in Fig 5.1. Manning's *n* is found to decrease with increase of aspect ratio (ratio of width of the channel to the depth of flow) indicating that highly meander channel consumes more energy as the depth of flow increases. So, with increase in aspect ratio Manning's n decreases. Manning's *n* also varies with aspect ratio for different depth.

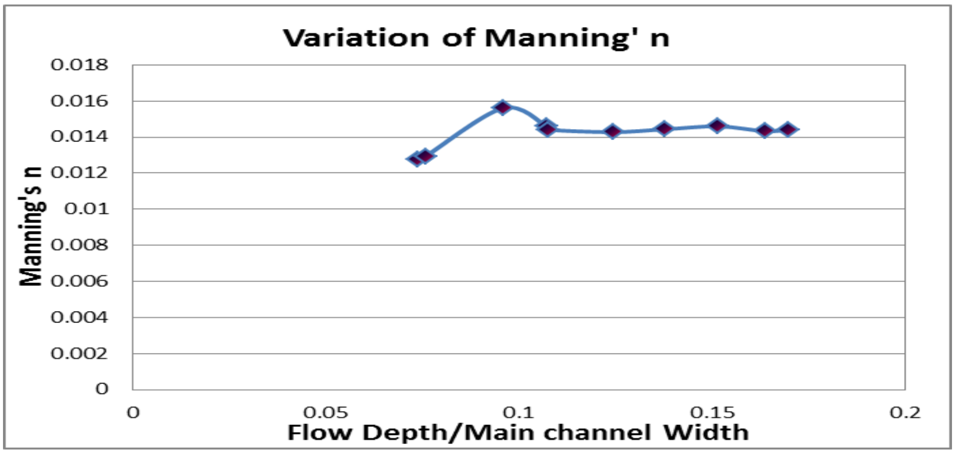


Fig.4.4 Variation of Manning’s n with Depth of Flow

b.Variation of Chezy`s *C* with Depth of Flow

The variation of Chezy’s *C* with depth of flow for the highly meandering channels investigated for different depth of flows is shown in Fig 5.2. It can be seen from the figure that the meandering channels, exhibits a steady decrease in the value of *C* with depth of flow. Chezy’s *C* is found to be constant at higher depth of flow. So it can be suggested that the Chezy’s formula can be applicable to predict stage-discharge relationship more correctly as compared to other formulas mainly for highly meandering channels at higher depths of flow only.

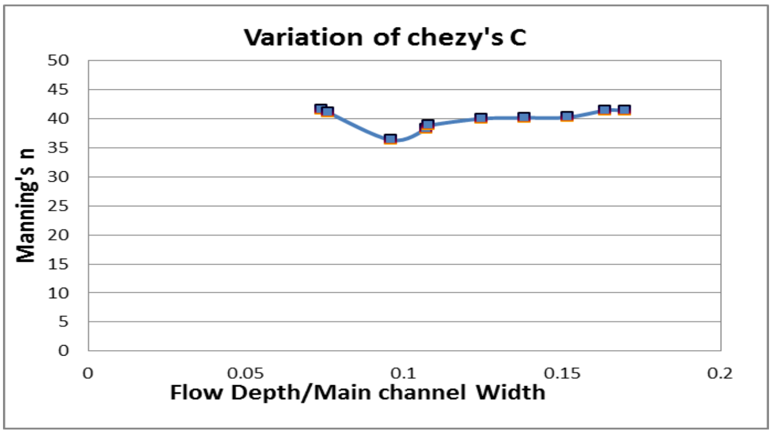


Fig.4.5 Variation of Chezy’s C with Depth of Flow

c.Variation of Darcy-Weisbach *f* with Depth of Flow

The variations of friction factor f with depth of flow for the present meandering channels are shown in Fig. 5.3. The behavioral trend of friction factor *f* is also increasing with flow depth. From the Figs. 5.1 it is seen that the roughness coefficients *n* and f are behaving in similar manner because, the relationship between the coefficients with hydraulic radius (R) can be expressed as $f = \frac{8g}{R^{1/3}} n^2$.

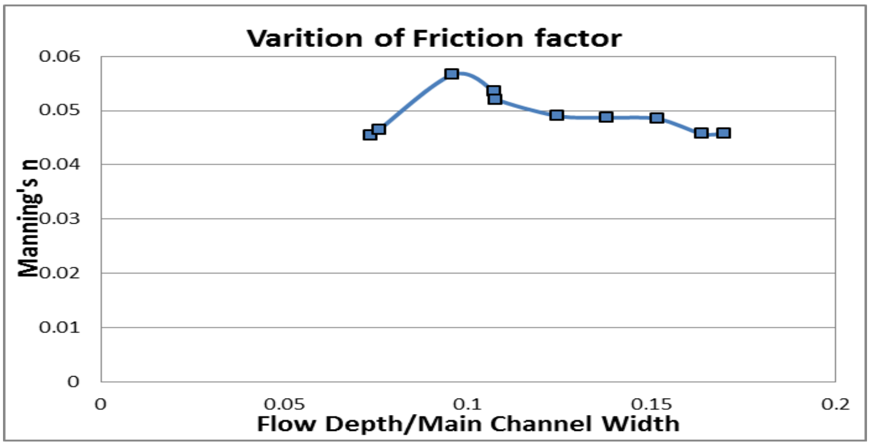


Fig 4.6 Variation of Friction factor f with Depth of Flow

Here it can be suggested that the Darcy-weisbach formula can also be applicable to predict stage-discharge relationship more correctly as compared to Manning's *n* formulas mainly for highly meandering channels at higher depths of flow only. The behavior may change for other slope conditions. Now it is required for further processing to see the behavioral trends of the roughness coefficients of a highly meandering channel due to higher and lower slopes.

d.Variation of Manning’s *n* with Aspect Ratio

The variation of roughness co-efficient in terms of Manning’s *n* are plotted with aspect ratio in Fig 5.4. It is seen that, when depth of flow increase the Manning’s *n* also increased, the flow resistance are found to be increased. Further it is seen that for aspect ratio value up to 8 to 10, increases sharply and Manning’s *n* also increases, after that Manning’s *n* value is found to remain constant (in between 8 to 6). It indicates that for higher depth of flow for Manning’s *n* value tends to be constant. For the higher depth of flow which is inter mingling of the flow with the fluid particles for this turbulence is more as compared to in lower depth of flow the turbulence in flow decreases

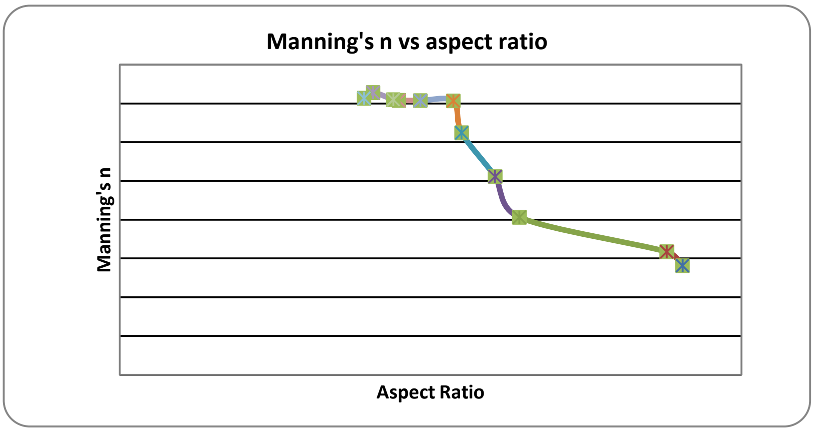


Fig 4.7 Variation of Manning’s *n* with Aspect Ratio

e.Variation of Manning’s *n* with Reynolds’s no

The variation of roughness co-efficient in terms of Manning’s *n* are plotted with the variation of Reynolds’s number in Fig 5.5. It is seen that, when Reynolds’s number is decreases Manning’s *n* also decreases; it means Manning’s *n* is directly proportional to Reynolds’s number. When Manning’s *n* increase Reynolds’s number is also increases. Because in higher sinuosity loss of energy is low for this when Manning’s *n* increase Reynolds’s number are also increases by Saine, *et.al*. (2013).

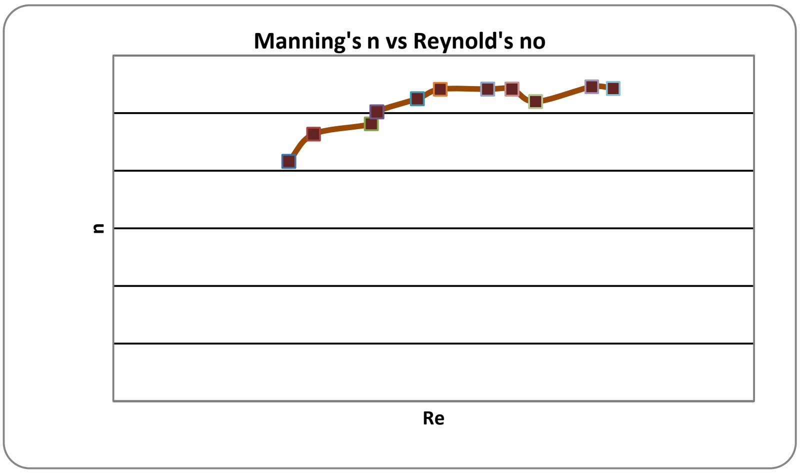


Fig 4.8 Variation of Manning's *n* with Reynolds's Number

f.Variation of Manning's *n* with Froude's no

The variation of roughness co-efficient in terms of Manning's *n* are plotted with the variation of Froude's number in Fig 5.6. In this case, we tried to find the effect of gravity on evaluation of resistance of a meandering channel. It is seen than Manning's *n* decreases with Froude's no. This may be due to that Froude's number is directly proportional to mean velocity and at the same time Manning's n is inversely proportional to mean velocity. Due to this reason Manning's *n* decreases with successive increment of Froude's number.

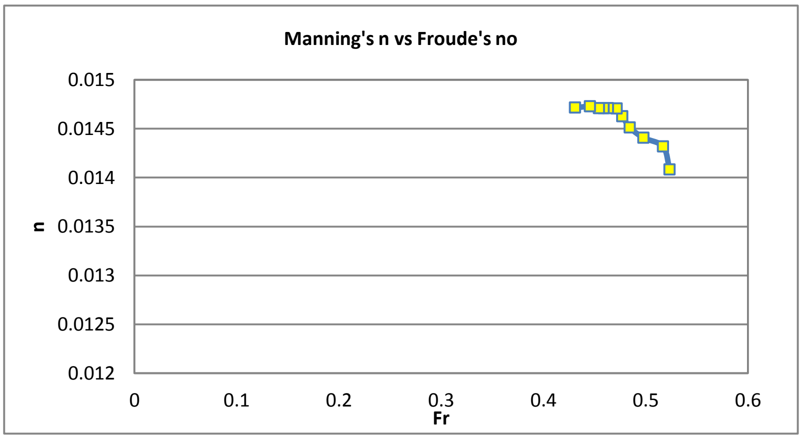


Fig 4.9 Variation of Manning's *n* with Froude's Number

Experiments are carried out to examine the effect of channel sinuosity, and cross section geometry and flow depths on the prediction of roughness coefficients in a highly meandering channel (Sr = 4.11). Based on analysis and discussions of the experimental investigations certain conclusions can be drawn.

- The flow resistance in terms of Manning's *n*, Chezy's *C* and Darcy-Weisbach friction factors *f* changes with flow depth for a meandering channel. The resistance coefficient not only denotes the roughness characteristics of a channel but also the energy loss of the flow. The assumption of an average value of flow resistance coefficient in terms of Manning's *n* for all depths of flow results in significant errors in discharge estimation.
- The Manning's *n*, Chezy's *C* and Darcy-Weisbach friction factors *f* are found to very significantly for low aspect ratio. The variation is less for higher depth of flow.
- The variation of Chezy's *C* and Darcy-Weisbach friction factors *f* are found to be less as compared to Manning's n for the present highly sinuous meandering channel.
- The variation of Manning's n is found to be mostly dependent upon the non-dimensional parameters such as (i) geometric parameters like aspect ratio, slope and sinuosity (ii) flow parameters like Reynolds no, Froude's no.
- Manning's n is found to increase with aspect ratio for the lower depth of flow but at higher depth of flow Manning's *n* tends to be constant.
- It increases with Reynolds no when Manning's *n* increases because in higher sinuosity loss of energy is low. Manning's *n* decreases with Froude's no. This may be due to that Froude's number is directly proportional to mean velocity and at the same time Manning's n is inversely proportional to mean velocity.

CHAPTER 6

CONCLUSION

I. THERORETICAL STUDY

5.1 SUMMARY

In the previous chapter the experimental results for meandering channel having stage discharge, velocity contour, and roughness variation are described. To formulate a generalized model to predict stage discharge relationships in a meandering channel, the data of series of meandering channels of same geometry but with different sinuosities are used for the present study. The other meandering channels which are now added for the study consist of a meandering channels with different sinuous are 1.00, 1.11, 1.41, 2.03 respectively and are similar to the present meandering channel of different sinuosity of 4.11 but same dimension of meandering channels i.e. width =330mm and depth =65mm. The details of the analysis of the other four channels can be found from Mohanty et.al 2012, 2013, Patnaik et.al 2012 and Mohanty et.al 2012. This chapter focuses on modeling the stage discharge distributions in meandering channels, since these features in many engineering studies involving conveyance, sediment transport, bank erosion, habitats and geomorphology.

5.2 Problem statement

Manning's roughness coefficient, Chezy's coefficients and Darcy;s coefficients are mainly depending upon different independent dimensionless geometric, hydraulic and surface parameters. Many previous researchers have presented models for evaluations of roughness calculation only taking some limited dimensionless parameters and found to fit mainly for straight channels. But for meandering channels the equations do not satisfy. If we consider all dimensionless parameters, then in previous formulation given by many researchers cannot be used in meandering channel for velocity and hence the discharge calculations. On behalf of this we need to modified or generate a new mathematical model for discharge calculation for meandering channel. In meandering channel there are many types of factors are present but in every cases it is impossible to take all dimensionless parameters for analysis. Mainly some dependent and also independent dimensionless parameters are present. Previous analysis for stage discharge many models are modeled but they did not considered every dependent and independent dimensionless parameters for analysis in meandering channels. In these cases crucial conditions occurs for this we need a mathematical model for calculating stage discharge in meandering channels. The stage-discharge relationship is of particular importance in flood alleviation schemes and is often extrapolated when dealing with extreme flood events. The stage discharge calculation for meandering channel is typically more difficult to model than the velocity. Due to this many authors decide to ignore it altogether or gave little attention to it, despite its vital role in river hydraulics. From the literature study and experimental analysis it is found that velocity varies with some influencing dimensionless parameters. Such as

- Sinuosity
- Aspect ratio
- Froude number
- Reynolds's number
- Slope

Sinuosity:-

Geoscientists use the sinuosity ratio to determine whether a channel is straight or meandering. The **sinuosity ratio** is the distance between two points on the stream measured along the channel divided by the straight line distance between the two points. If the sinuosity ratio is 1.05 or greater the channel is considered to be a meandering one.

Aspect ratio

The aspect ratio of a channel describes the proportional relation between its width and its height.

Froude number

It is a dimensionless number defined as the ratio of inertia force to gravity force.

$$Fr = \frac{V}{\sqrt{gD}} \quad (5.1)$$

Reynolds's number

It is a dimensionless number defined as the ratio of inertia force to viscous force.

$$\mathrm{Re} = \frac{\text{inertia force}}{\text{viscous force}} = \frac{\rho Vr}{\mu} \quad (5.2)$$

Slope

It is the Sin of the angel of longitudinal axis at the surface of the channel with horizontal.

5.3 Background

From the knowledge of literatures there are some mathematical formulations given by different investigators for evaluation of roughness coefficient in terms of n, friction factor f and Chezy's Care described below.

Cowan (1959) developed a procedure for estimating the effects of some factors to determine the value of n for a channel. This equation provides much more flexibility and accuracy than can be achieved using Chow (1959) in isolation. The value of n may be computed by

$$n = (n_b + n_1 + n_2 + n_3 + n_4)m \quad (5.3)$$

Where, n_b is the base value of *n* for a uniform, smooth and straight channel in natural materials, $n_1$is the correction factor for the effect of surface irregularities, n_2 is the value for variations in shape and size of the channel cross section, $n_3$is the value for obstructions, $n_4$is the value for vegetation and flow conditions, m is the a correction factor for meandering of the channel.

The original **Soil Conservation Service** (SCS) (1963) method is also used for selecting roughness coefficient values for meandering channels as shown below.

$$\frac{n'}{n} = (\frac{f'}{f})^{1/2} = 1.0 \text{ For s<1.2} \tag{5.4a}$$

$$\frac{n'}{n} = (\frac{f'}{f})^{1/2} = 1.15 \text{ For 1.2=< s< 1.5} \tag{5.4b}$$

$$\frac{n'}{n} = (\frac{f'}{f})^{1/2} = 1.3 \text{ For s >=1.5} \tag{5.4c}$$

Toebes and Sooky (1967) carried out extensive series of experiments in laboratory flumes from which the influence of channel roughness, slope and channel depth on the discharge capacity of a meandering channel was investigated. To determine the overall conveyance of meandering channels as a function of stage is given by

$$\frac{f'}{f} = 1.0 + 6.89R \text{ For s=1.1} \tag{5.5}$$

Where, R = Hydraulic radius in meters.

Limerions's (1970) proposed an equation which is meant for calculation of roughness coefficient in terms of Manning's in natural alluvial channels. This equation was developed for discharges from 6 – 430 m3/s, and n/$R^{0.17}$ ratios up to 300 although it is reported that little change occurs over R > 30.It is given by

$$n = \frac{0.0926R^{0.17}}{1.16 + 2\log(R/d_{84})} \tag{5.6}$$

Where, R is the hydraulic radius and d_{84} the size of the intermediate particles of diameter that equals or exceeds that of 84% of the streambed particles, with both variables in feet.

Jarrett (1984) developed a model to determine Manning's *n* for natural high gradient channels having stable bed flow without meandering coefficient. He proposed, value of Manning`s *n* as

$$n = \frac{0.32S^{0.38}}{R^{0.16}} \tag{5.7}$$

Where, *S* is the channel gradient, *R* is the hydraulic radius in meters.

The simplest and most widely used method is the **Soil Conservation Service** (SCS) method for selecting roughness coefficient values. The relationship was linearized, known as the Linearized SCS (LSCS) Method (James1992). He proposed the value of Manning's n using two cases of sinuosity (S_r), i.e. LSCS method for meandering channel flows is given by

$$\frac{n_s}{n} = 0.43s + 0.5 \qquad \text{For } s < 1.7 \tag{5.8a}$$

And $\frac{n_s}{n} = 1.3$ for s > 1.7

(5.8b)

Shino, Al-Romaih and Knight (1999) reported the effect of bed slope and sinuosity on discharge of meandering channel. Conveyance capacity of a meandering channel was derived using dimensional analysis is stated as

$$S = 10\left(\frac{f}{8}\right)^{1/2} \tag{5.9}$$

Where, S=Sinuosity of the Channel

Nayak (2010) developed mathematical equations by using dimension analysis to evaluate roughness coefficients in terms of Manning's *n*, friction factor *f* and Chezy's *C* .These mathematical formulations are given below.

$$C = k \times \frac{g^{0.95}R^{1.35}\alpha}{S^{0.02}\nu^{0.9}S_r} \tag{5.10a}$$

$$f = \frac{8\nu^{1.8}{S_r}^2S^{0.04}}{0.01^2\alpha^2R^{2.7}g^{0.9}} \tag{5.10b}$$

Where, R is the hydraulic radius,νis the viscosity, g is the gravitational acceleration, S is the bed slope, S_r is the sinuosity, αis the aspect ratio , k is a constant of value 0.001.

Khatua and Patra (2012) carried out a series of laboratory tests for smooth and rigid meandering channels and developed numerical equation using dimension analysis to evaluate Manning's n.

$$n = \frac{S_r \nu^{0.72} S^{0.07} m^{0.29}}{7k\alpha g^{0.86} R^{1.2}} \tag{5.11}$$

Where, R is the hydraulic radius, νis the viscosity, g is the gravitational acceleration, S is the bed slope, S_r is the sinuosity, αis the aspect ratio, k is a constant of value 0.001

5.4 DESCRIPTION

As previously describe that we want to produce a mathematical equation, by using which we can easily calculate the stage discharge for meandering channels. In this present work, an efficient technique is used for forming a mathematical equation. So mathematics like Statistics Data Editor System (SPSS) is proposed for prediction of roughness coefficients in terms of Manning's *n*, Darcy-Weisbach *f* and Chezy's *C*.

5.4.1 Regression Analysis

The term "regression" originates from the 14th century, where it had a biological mean in gas "the act of going back". It was first adapted to a more general statistical context by the well-known statisticians Udny Yule and Karl Pearson. However, its first statistical form was published by Legendre (1805) and by Gauss (1809) in the field of astronomy, where they applied the method of least squares to the problem of determining orbits of bodies about the Sun. Since then, regression analysis has been widely applied to the study of biology, behavioral and social sciences and more recently in finance, industry and many other practical aspects of real life. Regression is a generic term for all methods attempting to fit a model to observed data in order to quantify the relationship between two groups of variables. The fitted model may then be used either to merely describe the relationship between the two groups of variables, or to predict new values. The first widely studied form of regression analysis has been linear regression, due to the simplicity of the model and the statistical properties of the estimators. Linear regression is usually used for the purpose of hypothesis testing or for the purpose of prediction and forecasting. Many statistical methods and techniques have emerged from its study and one of them is the simultaneous confidence band. This chapter provides a general review of linear regression and presents some preliminary results necessary for the construction and comparison of simultaneous confidence bands throughout the thesis.

5.4.2 Linear Regression Analysis

A common problem in experimental science is to observe how some sets of variables affect others. Some relations are deterministic and easy to interpret, others are too complicated to understanding or describe in simple terms, that possibly having a random component. In the present study, by using relatively simple empirical methods we estimated these actual relationships by simple functions or random processes. Among all the methods used for calculating such complex relationships, linear regression possibly is the most useful. In this methodology, it is necessary to assume a functional, parametric relationship between the variables in question, and also unknown parameters which are to be estimated from the available data. Two sets of variables can be well-known at this stage such as Predictor variables and response variables. Predictors variables are those that can either be set to controlled or else take values that can be observed without any error. Our objective is to discover that how changes occurs in the predictor variables that affect the values of the response variables. Extra names frequently attached to these variables in different books by different authors are the following:

Predictor variables / Input variables/X-variables/Regressors/Independent variables and Response variable / Output variable/ Y-variable/Dependent variable.

Here some relation was give below,

Response variable = Linear model function in terms of input variables

+ Random error (5.12)

In the simplest case when we have data $(y_1; x_1), (y_2; x_2),..., (y_n; x_n)$, the linear function of the form

$$y_i = \beta_0 + \beta_1 x_i + \epsilon_i \; ; \; i = 1; 2; \ldots ; n \tag{5.13}$$

can be used to relate y to x. We will also write down this model in generic terms as

$$y = \beta_0 + \beta_1 x + \epsilon \tag{5.14}$$

Here, ϵ is a calculating error of any individual function.

Linear regression analysis means it is a statistical technique used to model data comprising of a dependent random variable and one or more independent variables, so as to evaluate the relationship between the dependent variable and the independent variables. In statistics, simple linear regression is the least squares estimator of a linear regression model with a single helpful variable. In other words, simple linear regression fits a straight line through the set of n points in such a way that makes the sum of squared residuals of the model (that is, vertical distances between the points of the data set and the fitted line) as small as possible. Specifically, the dependent variable y is expressed as a function of the independent variables $x_1, x_2, \ldots, x_m$, the corresponding parameters $\beta_0, \beta_1, \ldots, \beta_k$ and an error term e as in

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_m x_m + e. \tag{5.15}$$

The error term e is a random variable that represents the unexplained variation in the dependent variable y. If a sample of n observations are available with the i^{th} observation given by (y_i, x_{i1}, x_{i2}, . . . , x_{im}) for i = 1, . . . , n, the i^{th} observation is assumed to satisfy the relationship

$$y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + . . . + \beta_m x_{im} + e_i \qquad (5.16)$$

Where b_0, b_1, . . . , b_k are the same for all observations. The linear regression model can also be represented in the matrix form

$$Y = X\beta + e \qquad (5.17)$$

Where $$Y=\begin{pmatrix} y_0 \\ y_1 \\ . \\ . \\ . \\ y_n \end{pmatrix} \quad X = \begin{pmatrix} 1\ x_{11}\ x_{12}\ \ldots.\ x_{1m} \\ 1\ x_{21} x_{22}\ \ldots.\ x_{2m} \\ .\ \ .\ \ .\ \ \ldots.\ \ . \\ .\ \ .\ \ .\ \ \ldots.\ \ . \\ 1\ x_{n1} x_{n2}\ \ldots.x_{nm} \end{pmatrix} \quad \beta = \begin{pmatrix} \beta_0 \\ \beta_1 \\ . \\ . \\ . \\ \beta_m \end{pmatrix} \quad e = \begin{pmatrix} e_1 \\ e_2 \\ . \\ . \\ . \\ e_n \end{pmatrix}$$

The matrix X is called the design matrix as its components can be suitably chosen via design. Moreover, the linear regression model is subject to the following assumptions:

- The errors follow a normal distribution with the mean zero and constant variance $\sigma^2 > 0$ and they are independent.
- The independent variables x_1, . . . , x_m are error-free and the design matrix X has full column rank k + 1.

5.4.3 Regression Calculations

➢ Least Squares

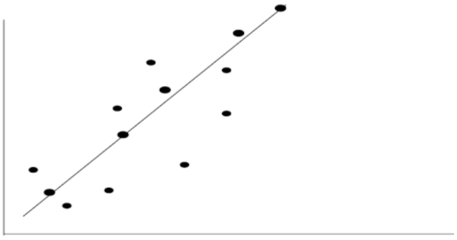
In this section we will deal with datasets which are correlated and in which one variable, x, is classed as an independent variable and the other variable, y, and is called a dependent variable as the value of y depends on x.

We saw that correlation implies a linear relationship. Well a line is described by the equation

$$y = a + bx \qquad (5.18)$$

Here b = the slope of the line and a = the intercept.

Here we use the principal of least square and we draw a line through the data set so that sum of square deviations of all points from the line is minimized.



Using some calculation, we can find the equation of this least square line:

$Y=\beta_0+\beta_1 x$ (5.19)

- The Simple Linear Regression Model

If there is a linear connection between x and y in the population the model will be as below. We find that for a particular value of x, when an observation of y is made we get:

$Y=\beta_0+\beta_1 x+\epsilon$ (5.20)

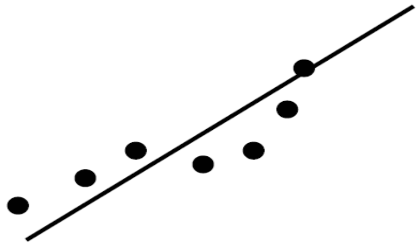
Where ϵ is a random error which measures how far above or below the true regression line that the actual observation of y lies. The mean of ϵ is zero. And this model is called probabilistic model. It contains 3 unknown parameters,

β_0 =the intercept of the line

β_1= the slope of the line

And σ^2 is the variance of ϵ

We need to estimate these parameters using data in our sample. In fact we have already seen the sample statistics that we will use to estimate parameters. Remember σ^2 measures how spread out the points are from the true regression line.



According to our Linear Regression Model most of the variation in y is caused by its relationship with x. Except in the case where all the points lie exactly on a straight line (i.e. where r = +1 or r = -1) the model does not explain all the variation in y. The amount that is left unexplained by the model is SSE. Suppose that the variation in y was not caused by a relationship between x and y, then the best estimate for y would be y the sample mean. And the Sum of Squared Deviations of the actual y's from this prediction ȳ would be

$$SS_{yy}=\sum(y-\bar{y})^2 \qquad (5.21)$$

If little or none of the variation in y is explained by the contribution of x then SS_{yy} will be almost equal to SSE (sum of squared errors). If all of the variation in y is explained by its relationship with x then SSE will be zero.

The coefficient of determination is

$$r^2=\frac{SS_{yy}-SSE}{SS_{yy}} \qquad (5.22)$$

This represents the proportion of the total sample variability in y i.e. explained by a linear relationship between x & y.

R-Squared measures how well the model fits the data. Values of R-Squared close to 1fit well. Values of R-Squared close to 0 fit badly.

- Assumptions behind linear regression

The assumptions that must be met for linear regression to be valid depend on the purposes for which it will be used. Any application of linear regression makes two assumptions:

(A) The data used in fitting the model are representative of the population.

(B) The true underlying relationship between X and Y is linear. All you need to assume to predict Y from X are (A) and (B). To estimate the standard error of the prediction S_y, you

Also must assume that:

(C) The variance of the residuals is constant (homoscedastic, not heteroscedastic).

For linear regression to provide the best linear unbiased estimator of the true Y, (A) through (C) must be true, and you must also assume that:

(D) The residuals must be independent.

To make probabilistic statements, such as hypothesis tests involving *b* or *r*, or to construct confidence intervals, (A) through (D) must be true, and you must also assume that:

(E) The residuals are normally distributed.

Contrary to common mythology, linear regression does not assume anything about the distributions of either X or Y; it only makes assumptions about the distribution of the residuals. As with many other statistical techniques, it is not necessary for the data themselves to be normally distributed, only for the errors (residuals) to be normally distributed. And this is only required for the statistical significance tests (and other probabilistic statements) to be valid; regression can be applied for many other purposes even if the errors are non-normally distributed.

5.5 Source of data and Selection of Parameters

5.5.1 Source of data

The currently carried out experimental data set and also along with an extensive literature related to analysis of meandering channels are studied. The regular data set was collected from numerous references such as: Channel of Willets and Hardwick (Willets and Hardwick(1993)); University of Bradford (Shino, Al-Romaih and Knight (1999)); University of Glasgow, (MacLeod AB. (1997)); United Kingdom (Sellin et. al (1964)) River Main (Myers (1957), N.I.T Rourkela(Khatua (2007)), N.I.T Rourkela Experiment (Mohanty (2012)) , N.I.T Rourkela (Patnaik & Mohanty(2013)); etc. are prepared in Table 5.1.

5.5.2 Selection of hydraulic, geometric and surface parameters

From the experimental results and extensive literature study for meandering channels, it is seen that the investigators such as Acrement and Schneider (1989), Shino, Al-Romaih and Knight (1999), Khatua et.al (2012) proposed models to predict roughness coefficients and justify the dependency of flow variable on different hydraulic, geometrical and surface parameters. In the present study we considered taking these parameters into our consideration that influencing non-dimensional parameters such as bed slope of the channel (S), sinuosity (S_r), aspect ratio (α), Reynolds Number (R_e), Froude's number (F_r), and side slope. These parameters are taken as input for the model and roughness coefficient is taken as the output. Sinuosity (S_r) is the ratio of channel length to valley length, refers to sinuous path of a channel. Aspect ratio (α) is the ratio of channel bottom width (b) to flow depth (h) in the channel. To include the effect of roughness of rough channels, the Manning’s *n* of a rough bed needs to be compared with a reference bed surface.

Table 5.1:-Details of Hydraulic parameter for all types of data collected from Globe

Verified test channels	Sl no	Longitudinal slope(s)	Main channel width (b) m	Main channel depth (h) m	Sinuosity (S_r)	Observed discharge (Q) range in m^3/sec	Flow Aspect Ratio	Manning's n	Reynolds no	Froude no
Present Very High MC NIT rkl data	1	0.00165	0.33	0.065	4.11	0.0021288 -0.007622	24.72-5.89	0.012-0.0147	5339-13805	0.42-0.52
High MC NIT rkl data	2	0.00165	0.33	0.065	2.03	0.001309-0.006508	19.41-6.6	0.011-0.0139	3465-17202	0.52-0.57
Mildly MC NIT rkl data	3	0.0011	0.33	0.065	1.3	0.002500-0.008780	14.04-5.29	0.0083-0.0123	6307-17202	0.44-0.64
Low MC NIT rkl data	4	0.0011	0.33	0.065	1.12	0.000512-0.012894	23.2-5.32	0.0082-0.017	1385-25515	0.2-0.73
Straight Channel NIT rkl data	5	0.0011	0.33	0.065	1	0.003386-0.015950	11-5.07	0.0072-0.0092	8162-31040	0.6-0.83
Glasgow MC	6	0.001	0.2	0.075	1.374	0.0005-0.0007	2.4-9.7	0.0107-0.0133	10793-38017	0.25-0.36
Abreeden MC	7	0.001	0.2	0.0525	1.374	0.0004-0.0023	3.82-8.6	0.0102-0.0134	2660-9691	0.35-0.5
Shino&Knight MC	8	0.0005-0.002	0.152	0.052	1.372	0.0006-0.03	12-2.6	0.005-0.021	2700-9710	0.17-0.9
Sellin MC	9	0.000996-0.001021	0.9	0.15	1.375-2.043	0.023-0.067	6.1-14.09	0.012-0.06	20261-54021	0.15-0.59
Willets & Hardwick MC	10	0.001	0.139	0.05	1.2-2.06	0.0004-0.0015	6.71-2.85	0.014-0.049	230-5509	0.1-0.34
Khatua	11	0.0019-0.0053	0.12	0.080-0.120	1-1.91	0.000192-0.007050	11-1.05	0-.008-0.018	1400-18000	0.4-0.82

:

5.6 MODEL DEVELOPMENT

5.6.1 Introduction

The stage-discharge curve is defined by a relationship between the discharge Q and the water depth H. According to Schmidt & Yen (2001), stage-discharge relationships for rivers are traditionally based on empirical power law equations fitted to measure the discharge and the corresponding stage. These measurements do not always form a unique relationship, either because of scatter in the measured data that depends on the site conditions and river geometry, or because of unsteady flow effects. For this data sets are collected and compared with each other by linear regression analysis. So in the present work for regression analysis (Linear Regression System) IBMSPSS software is used. In this analysis the variables are divided into two categories such as dependent and independent variables. By considering these variables a mathematical formulation is formulated. At the beginning all the variables are analysed through the experiments with keeping different sinuosity. But the variation of variables in comparison to Manning’s n and the relation between them are analysed through the IBMSPSS. From the analysis part a mathematical equation is formulated here.

To represent the stage-discharge relationship, a number of empirical equations are already formulated. But these empirical equations have some limitations about the range of data over which they were obtained. This can lead to inaccuracies if they are extrapolated, as is often required in flood prediction. Therefore a model is required for meandering channel which should consider the physical phenomena and the variable geometric and roughness parameters. Only then can a stage-discharge curve be 'safely' extrapolated. This chapter explores the application of the IBMSPSS to meandering channel, not only to test the calibration philosophy developed in Chapter 6, but also to test the general modeling approach to more complex channels shapes and where the roughness is more likely to be heterogeneous than homogeneous. Data from different channels such as, Channel of Willets and Hardwick (Willets and Hardwick(1993)); University of Bradford (Shino, Al-Romaih and Knight (1999)); University of Glasgow, (MacLeod AB. (1997)); United Kingdom (Sellin et. al (1964)) River Main (Myers (1957), N.I.T Rourkela(Khatua (2007)), N.I.T Rourkela Experiment (Mohanty (2012)) , N.I.T Rourkela (Patnaik & Mohanty (2013)) are used for these purposes.

5.6.2 Modelling of the meandering channel at NIT Rourkela

One of the major factors affecting the stage-discharge curve is the geometry; hence particular care needs to be taken in predicting the bankfull level in the simplified or analytical cross-section. These could have been made to be different without affecting the results by using Regression analysis of solution using the IBMSPSS.

From the literature study, it is seen that the roughness coefficient of a meandering channel varies from channel to channel and flow depth to flow depths. They are found to be function of geometric parameter, flow parameter and surface parameters. All are non-dimensionalised.

- Geometric parameter:
  - (a) Aspect ratio
  - (b) Slope
  - (c) Sinuosity,
- Flow parameters:
  - (a) Reynolds no
  - (b) Froude's no.

The dependency of roughness and the best functional relationships have been found out from different plots of the global data sets exit in the literatures. So it is in the following form

$$n = f\,(\delta, S0, Sr, Re, Fr) \qquad (5.23)$$

The variation of roughness co-efficient has been found out for five meandering channels of different sinuosity. The variation of roughness co-efficient in terms of Manning’s n are plotted for different aspect ratio in Fig (5.1). It is seen that, as sinuosity increased, Manning’s n also increased for the low sinuosity channel and straight channel (channels- 1 &2) the Manning’s n is found to be decreased with flow depth but for meandering channel of higher sinuosity but the flow resistance are found to be increase in aspect ratio. Further it is seen that for high sinuosity channel, Manning's n is found to remain constant. This may be due to the reason that at lower depth the meandering channel exhibits the higher energy loss due to bend affect but in higher depth of flow, the effect of bend loss diminishes. Next, the mean velocities of the meandering channels are calculated for each depth of flow.

Then the Reynolds no vs. Manning's n are plotted for all the channels and presented in Fig (5.2). From the Fig (5.2) it is seen that Manning's n decreases with Reynolds no for lower sinuosity channel but for higher sinuous channel Manning's increase with Reynolds number. Because for straight channel and low sinuous channel the loss of energy is less for higher depth of flow but higher sinuous channel, Manning's n increase with Reynolds number. The reason of the results may be considered as similar to the results of figure 1 i.e. Manning's vs. Aspect ratio.

In the third case, we tried to find the effect of gravity on evaluation of resistance of a meandering channel. Therefore, Manning's, n values are plotted with different Froude's no. Here in this fig Froude's no vs. Manning's n are plotted for all the flow channels. From Fig (5.3) it is seen than Manning's n decreases with Froude's no for both lower sinuous channel as well as higher sinuous channel. This may be due to that Froude's number is directly proportional to mean velocity and at the same time Manning's n is inversely proportional to mean velocity. Due to this reason Manning's n decreases with successive increment of Froude's number.

Similar to the previous cases, the variation of Manning's n is tested for channels of different sinuosity. Therefore in Fig (5.4) the relationships between Manning are n and sinuosity for different aspect ratios is plotted. In this case, it is clearly seen that when sinuosity increases, Manning's n substantially increases for a constant aspect ratio. The reason may be that velocity of the flow gradually decreased with increased sinuosity. It can be stated that, increase of sinuosity is found to have direct effects to de-crease the values of Manning's n, for a constant geometry of a meandering channel. Finally we have tested the variation of Manning's n with longitudinal slope in Fig (5.5). It is a well-known fact that the conveyance is mainly affected by longitudinal slope. Attempt has been made now to see the variation of roughness coefficient with respect to the longitudinal slope. Due to absence of different slope data, in the present work data of Shino (1999) has been analysed with our experimental data. From experimental data, it was clearly noticed that when slope increases the gravity component increase, so when force increase which subsequently reduces the roughness coefficient, therefore the Manning's n found to bed decrease. But in higher slope means greater than 0.001 from Fig (5.5), it is clearly show that roughness value in-creases. This reason may be that the higher value of slope, the formation of turbulence, eddies, starts producing more loss of energy, so increasing the value of Manning's n.

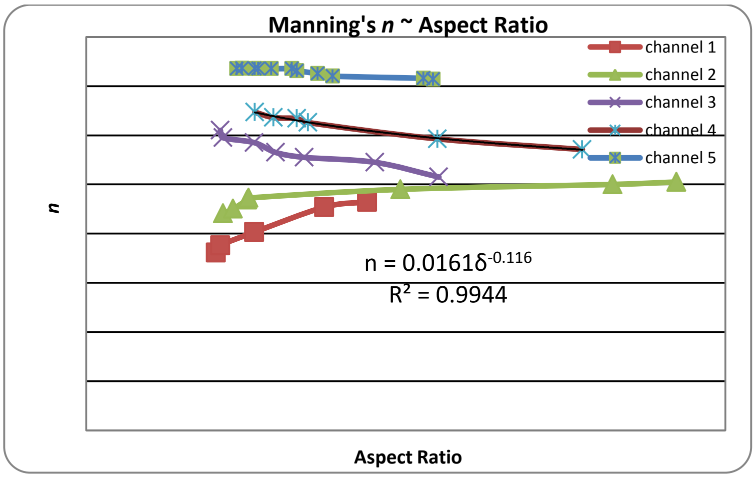


Fig 5.1 Manning's n vs. Aspect Ratio

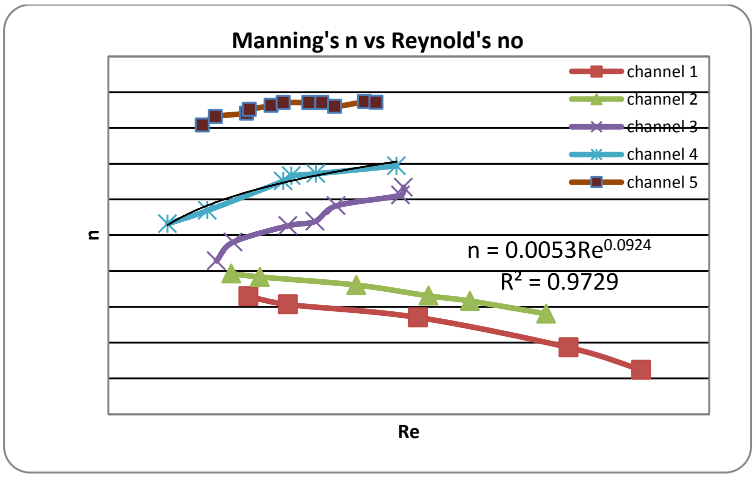


Fig 5.2 Manning's n vs. Reynolds's no

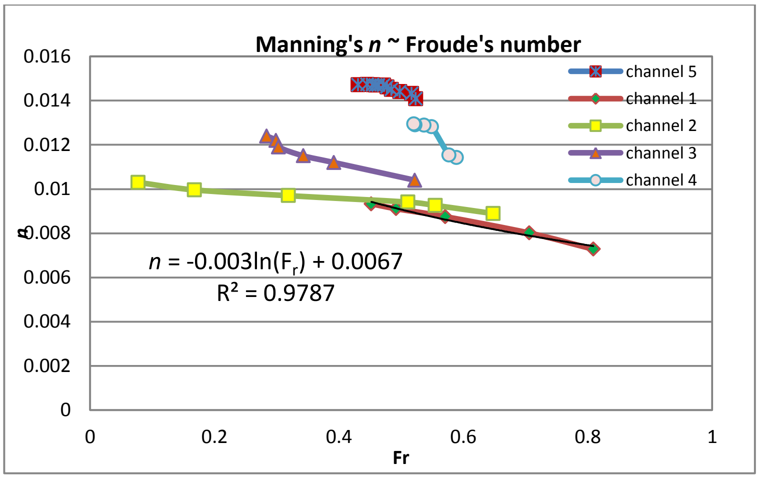


Fig 5.3 Manning's n vs. Froude's no

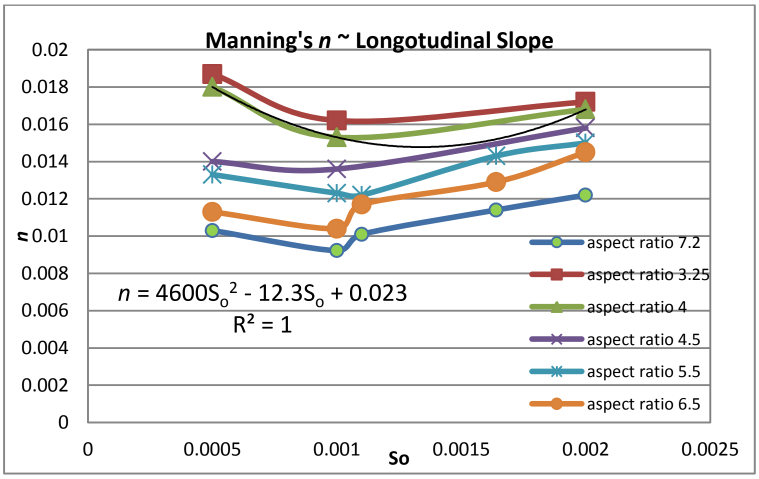


Fig 5.4 Manning's n vs. longitudinal Slope

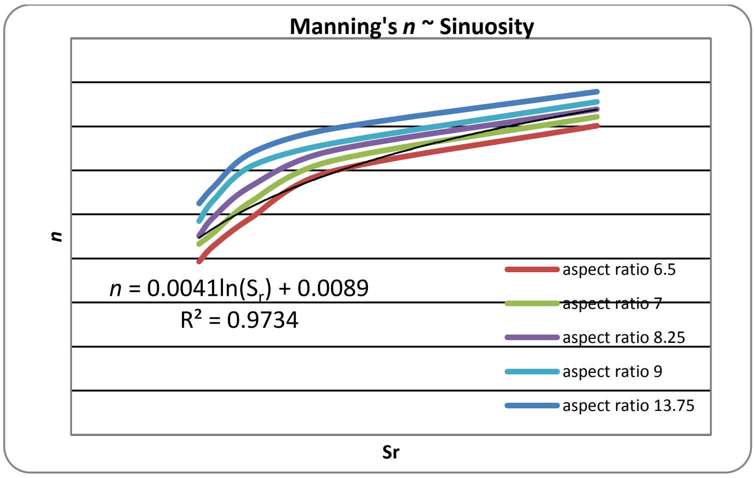


Fig 5.5 Manning’s n vs. Sinuosity

Fig 5-(1 to 5) Comparison of Manning’s n with different subsequent flow parameters.

By analysed the above plots, corresponding functional relationships of n with different non-dimensional geometric and hydraulic parameters are,

$$n = f(\delta)$$

$$n = A(\delta)^{-0.116} + c \tag{5.24a}$$

$$n = f(So)$$

$$n = A(So)^2 - BS_O + C \tag{5.24b}$$

$$n = f(Sr)$$

$$n = Aln(S_r) + c \tag{5.24c}$$

$$n = f(Re)$$

$$n = Aln(R_e) + c \tag{5.24d}$$

$$n = f(Fr)$$

$$n = A\ (Fr)^{-0.798} \tag{5.24e}$$

From the above graphs it’s shown that R2 value is very high and varies from 0.97 to 1. By using above relationships we compile to develop the *n* value by help of IBMSPSS software with analysis data sets. Dependent variables are taken in y axis and actual Manning’s n value considered as independent variable in x axis. By using IBMSPSS software, mathematical model is now formulated. From the regression analysis an empirical formulation is formulated. These equations shows the relation between Manning's n, with Aspect Ratio, Slope, Sinuosity, Reynolds number, Froude number.

Table 5.2: Unstandardized Coefficient by Linear Regression Analysis

Model		Unstandardized Coefficients	
		B	Std. Error
1	(Constant)	-.015	.052
	AR	-.156	.284
	So	.801	3.389
	Sr	.978	.130
	Re	.364	.307
	Fr	.124	.159

$$R^2=0.91$$

Table 5.2 data represent the result of linear regression analysis. From the above table the corresponding co-efficient are found and these values are used in the above equation 5.13. After formulation, a mathematical empirical relation is created and it shows in (5.25) the corresponding roughness co-efficient. After then by putting the different dependent variables from the above graph (5.1 to 5.15) then it will give a relation in a modified form which shows in (5.26) in accurate linear form.

$$n=-0.015-0.156\delta+0.801So+0.978Sr+0.364Re+0.124Fr \qquad (5.25)$$

After simplify this above equation,

$$n=-0.015-0.156*(0.0161\delta-0.116)+0.801*(4600\ So2-12.3So+0.023)+0.978*(0.0041\ln(Sr)+0.0089)+0.364*(0.0053\ Re0.0924)+0.124*(-0.003\ln(Fr)+0.0067)$$

$$n=0.013(1-0.015\,\delta^{-0.116}+0.3021\ln(S_r)+0.15Re^{0.0924}-0.3\ln(F_r)-9.852S_o(1-374\,S_o) \qquad (5.26)$$

$$\boxed{n=0.013(1-0.015\,\delta^{-0.116}+0.3021\ln(S_r)+0.15Re^{0.0924}-0.3\ln(F_r)-9.852\,S_o(1-374\,S_o)}$$

5.7 Validation

After formulation of the new mathematical model, an attempt has been taken to validate with the data of other investigators and present experimental channel data sets. So in the present study the necessary validation is carried out with previous known data sets. The results are as follows.

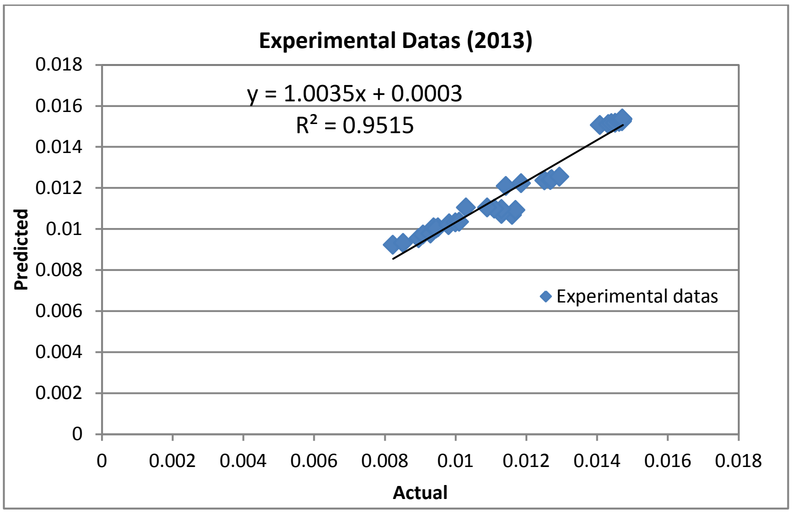


Fig 5.5 Actual vs. Predicted in Experimentation in Channel (2013)

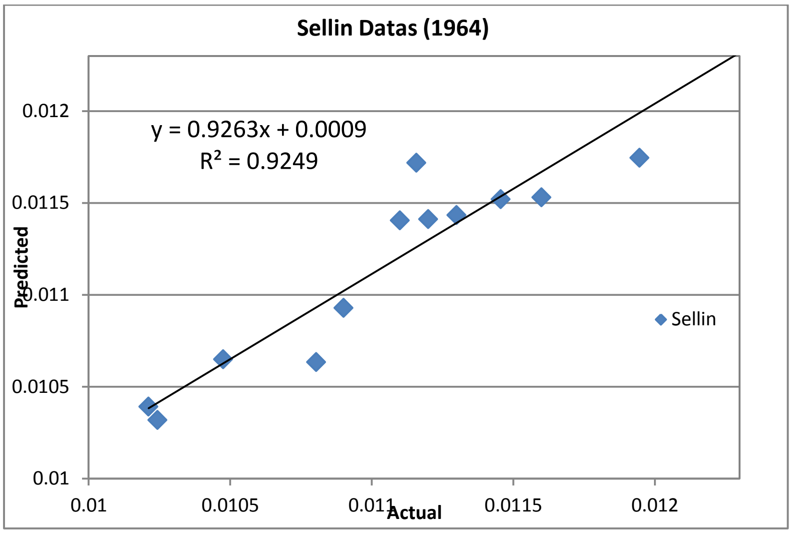


Fig 5.6 Actual vs. Predicted in Sellin (1964)

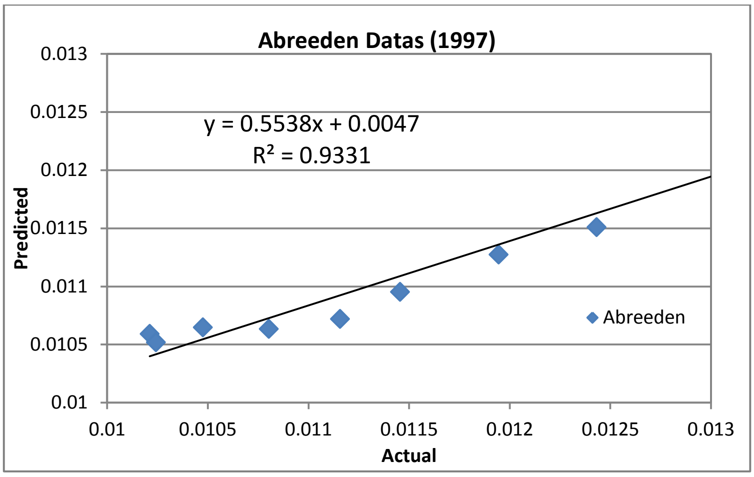
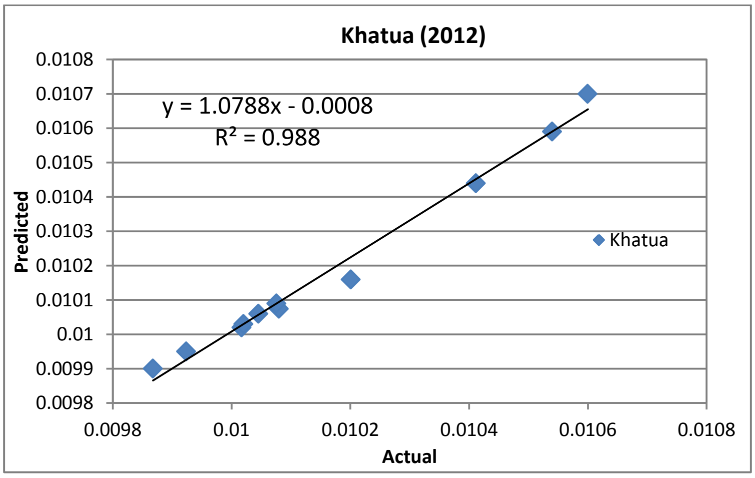


Fig 5.7 Actual vs. Predicted in Abreeden (1997)

Fig 5.8 Actual vs. Predicted in Khatua (2012)



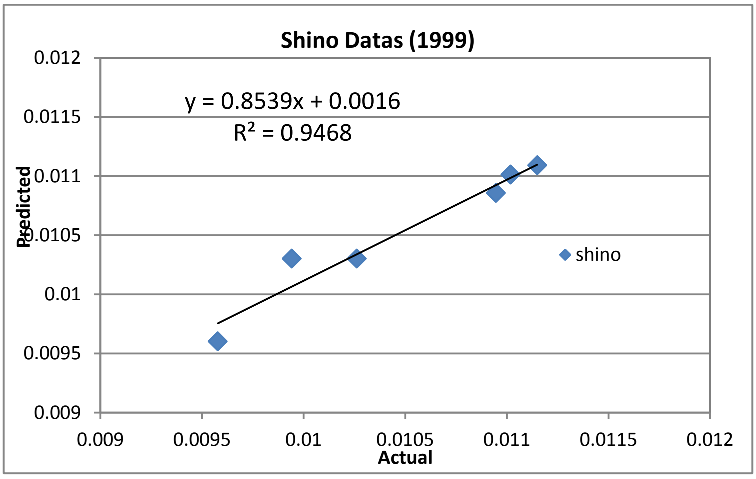


Fig 5.9 Actual vs. Predicted in Shino (1999)

Fig 5-(6 to 9) Validation occurs in between actual vs. predicted

It is clearly seen that from the graph, it’s plotted between the predicted Roughness coefficient verses actual Roughness coefficient for meandering channels. In this case, it is found that in Fig 5.5 both predicted vs. actual roughness coefficient agrees perfectly and also gives a satisfactory result along appropriately with determination/ Roughness coefficient is R^2=0.95.

Similarly, the comparison occurs in between the predicted vs. actual has been shown in Fig 5.6-5.8 for data sets of Sellin (1964), Abreeden (1997), Khatua et.al. (2012), Shino (1999) respectively the Regression coefficient R^2 for all these data sets are found to be 0.92, 0.93, 0.98, and 0.94.and these all are gives a satisfactory results. Therefore from the above figure it is clearly shown that the present model gives a better Stage-Discharge result which proves to adequacy of present developed model.

CHAPTER 5

CONCLUSIONS

CHAPTER 6

CONCLUSION

Intensive literature survey has been carried out to study the stage-discharge relation in meandering channels. From the literature, it is found that stage-discharge relation depends upon the properties prediction of roughness coefficient in terms of Manning's *n.* A method has been proposed method for predicting roughness coefficients of meandering channels. The results from the method are compared well with the other standard models. For the present experimental work, flow in meandering channels has been investigated. The following are the results from present experimentations.

- There were some points noted down from the counters of longitudinal velocity distribution in meandering channel cross-sections at location of bend apex and longitudinal velocity distribution in the form of contours points that are skewed with curvature. Contours with more velocity are getting gradually increasingly at the inner bank to outer bank at the bend apex of meandering channel. It is observed that in all cases of depth, the maximum velocity occurs at the inner wall in the bend entrance where the radius of curvature is the minimum and negative pressure gradient occurs from outer bank.
- Manning's *n* is found to be depending upon many non-dimensional hydraulic and geometric parameters. The experimental Investigation has been carried out to found the dependency of Manning's *n* with respect to geometric parameters like aspect ratio, slope and sinuosity and flow parameters like Reynolds no, Froude's no.
- The flow resistance in terms of Manning's *n*, Chezy's *C* and Darcy-Weisbach friction factors *f* also changes with flow depth for the meandering channels. The resistance coefficients not only denote the roughness characteristics of the channel but also the

energy loss of the flow. The assumption of an average value of flow resistance coefficient in terms of Manning's n for all depths of flow results in significant errors in discharge estimation.

- The Manning's *n*, Chezy's *C* and Darcy-Weisbach friction factors *f* are found to very significantly for low aspect ratio. The variation is less for higher depth of flow. Manning's n is found to increase with aspect ratio for the lower depth of flow but at higher depth of flow Manning's n tends to be constant. It increases with Reynolds no when Manning's *n* increases because in higher sinuosity loss of energy is low. Manning's n decreases with Froude's no. This may be due to that Froude's number is directly proportional to mean velocity and at the same time Manning's n is inversely proportional to mean velocity.
- Regression analysis has been carried out to formulate a mathematical model to predict Manning's *n* of a meandering channel. It is seen that, the model gives best result not only to the present experimental data sets but also the data sets of other investigation such as, Sellin (1964), Abreeden (1997), Khatua (2012) and Shiono (1999).
- The accuracy of models has also been studied and the R^2=0.91 are found for the presnt data sets. By using this model in our other experimental data sets also gives a satisfactory result along appropriately with determination/ Roughness coefficient is R^2=0.95.
- The method is also applied to the data of other investigators such as Sellin (1964), Abreeden (1997), Khatua (2007), Shino (1999) respectively and the R^2 value are found to be 0.92, 0.93, 0.98, and 0.94.respectively showing the satisfactory results of the present model. This proves the adequacy of present model.

6.2 SCOPE FOR FUTURE WORK

The present work leaves a wide scope for future investigators to explore many other aspects of a meandering channel analysis. The equations developed may be improved by incorporating more data from channels of different roughness conditions. Further investigation is required to study the flow properties and develop models to predict the boundary shear, zonal flow distribution, and energy loss aspects of having different geometry, sinuosity and roughness conditions. The channels here are rigid. Further investigation for the flow processes may also be carried out for mobile and of meandering channels of different geometry and sinuosity. Numerical analysis can also be applied to predict the flow variables of such channels for different geometry, flow and surface conditions.

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