PREDICTION OF FLOW IN NON PRISMATIC COMPOUND OPEN CHANNEL USING ARTIFICIAL NEURAL NETWORK

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

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In

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Submitted by

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CERTIFICATE

This is to certify that the thesis entitled, "**Prediction of Flow in Non prismatic Compound Open Channel using Artificial Neural Network**" submitted by **Kamel Miri** 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 him 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
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ABSTRACT

Each river in the world is unique. Some are gently curved, others are meander, and some others are relatively straight and skewed. The size of river geometry also changes from section to section longitudinally due to different hydraulic and surface conditions called non-prismatic channel. Much of the research work are found to be done on prismatic compound channels. There has also been a progress of work found for meandering channels. But an era which has been neglected is that of the work for non-prismatic compound channels. An effort has been made to scrutinize the research work related to non-prismatic channels in different types of flow conditions. An experimental observation has been made to investigate the velocity distribution, boundary shear stress distribution and energy loss of a compound channel with converging flood plain. The calculation of Depth average velocity, energy loss, boundary shear stress in non-prismatic compound channel flow is more complex. The prediction of the flow characteristics in compound channels with prismatic and non-prismatic floodplains is a challenging task for hydraulics engineers due to the three dimensional nature of the flow. Simple conventional approaches cannot predict the above mentioned flow characteristics with sufficient accuracy, hence in this area an easily implementable technique the Artificial Neural Network can be used for prediction, validation and analysis of the flow parameters mentioned. The model performed quite satisfactory when compared with the other conventional methods.

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Wij	Weight factor which represents interconnection of i^{th} node of the first layer to the j^{th} node of the second layer
f	Sigmoidal transfer function
W_{kj}	Weight factor which represents interconnection of k^{th} node of the first layer to the j^{th} node of the second layer
Ep	Mean squared error for a pattern
$\Delta W_{(t)}$	Weight changes at any time t
n	Learning rate
α	Momentum coefficient
α	Width ratio
σ	Aspect ratio
θ	Angle of convergence of divergence
S	Slope of the channel
B	Channel cross section width
b	Width of the main channel
h	Main channel width
s	Main channel side slopes
D_r	Relative Depth
β	Depth ratio
Xr	The distance of the point velocity in the width wise of the cross section / total width of the cross section taken into consideration.
Yr	Distance of point velocity depth wise of the cross section / total depth of the cross section taken into account.
Z_r	Point velocity in the length wise direction of the channel)/total length of the non-prismatic channel.
z_1 & z_2	Bottom elevation above a given datum at section 1 and 2 respectively.

y_1 & y_2	the flow depths at section 1 and 2
v_1 & v_2	Mean velocities at section 1 and 2 respectively
h_1	Local energy loss due to channel contraction
α_1 & α_2	Velocity head correction factors at section 1 and 2
E_1 & E_2	Energy at section 1 and section 2
ΔP	Pressure difference
τ_o	Boundary shear stress
d	Outer diameter of the tube
ρ	Density of the flow
v	Kinematic viscosity of the fluid
Δh	Difference between the two readings of pitot tube, static and dynamic heads
MSE	Mean squared error
RMSE	Root Mean squared error
MAE	Mean absolute error
MAPE	Mean absolute percentage error
ANN	Artificial Neural Network

CHAPTER 1

INTRODUCTION

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 rivers provide peace and Serenity to human kind. People have lived near 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.

Compound channels have been employed in river engineering for many years because of their importance in environmental, ecological, and design issues related to flood defence schemes. One advantage of two stage channels in the natural river, generally a main river channel and its floodplain, is to increase the channel conveyance during floods. It is important to understand the flow characteristics of rivers in both their inbank and overbank flow conditions. When the flow is out-of-bank, typically during a flood, there is a significant increase in the complexity of flow behavior, even for relatively straight reaches. The difference in velocity between the main channel and the floodplain flows may produce strong lateral shear layers, which lead to the generation of large scale turbulent structures, typically large platform vortices, as shown by Sellin (1964), Ikeda et al. (1994 and 2001), Ikeda (1999) and Bousmar (2002). In overbank flow the main channel flow is affected by the floodplains and the conveyance capacity is usually reduced. Open channel flow can be said to be as the flow of fluid (water) over the deep hollow surface with the cover of atmosphere at the top. Open channels are classified as the following.

1. Prismatic Open Channels

2. Non prismatic Open Channels

The open channel in which shape, size of cross section and slope of the bed remain constant are said to be as the prismatic channels otherwise it is non prismatic channel. Natural channels are an example of the non-prismatic channels and manmade open channels are the example of prismatic channels. Some examples of non-prismatic channels are flow through culverts , flow through bridge piers and obstructions, channel junction and etc. Study of non-prismatic 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.

The complexity of the problem rises more when dealing with a compound channel with non-prismatic floodplains. In non prismatic compound channels with converging floodplains, due to change in floodplain geometry water flowing on the floodplain now crosses over water flowing in the main channel, resulting in increased interaction and momentum exchanges. This extra momentum exchange should also be taken into account in the flow modelling. It is well known that when the flow is out-of-bank the discharge capacity of a compound channel is affected by the momentum exchange between the main channel and its associated floodplains. The momentum transfer across the main channel/floodplain interface reduces the conveyance capacity of the main channel and increases the discharge capacity of the floodplain, particularly at low relative depths, and consequently reduces the total conveyance capacity of the entire channel cross section.

Experimental facilities, instrumentation and computer models have been gradually improved in the world. In fact, for the last 2 or 3 decades, development of new velocity measuring devices, data collection systems and numerical models has made possible considerable advances in knowledge relating to water engineering problems.

The main objective of the depth average velocity measurements was to investigate the proportion of flow in main channel and on the floodplains at different positions along the flume. The velocity distributions were also used to investigate the force and energy balances in compound channels with non-prismatic floodplains.

Using a pointer gauge, which was located on an instrument carriage, the longitudinal water profiles have been recorded. The total energy head was estimated by adding the kinetic energy head to the water surface profile level. The boundary shear stress distribution is another important parameter in river modelling. It is required when studying force balances, or when calibrating a mathematical model, which commonly requires knowledge of the variation of local resistance coefficients. To evaluate the boundary shear stress distribution around the wetted perimeter, and the shear forces for each relative depth, boundary shear stress measurements were performed at selected cross-sections.

1.2 ARTIFICAL NEURAL NETWORK

ANN is a new and rapidly growing computational technique. In recent years it has been broadly used in hydraulic engineering and water resources. It is a highly self-organised, self-adapted and self-trainable approximator with high associative memory and nonlinear mapping. ANNs can be seen to be a simplified model of human nervous system, it can simulate complex and nonlinear problems by employing a different number of nonlinear processing elements i.e. The nodes or neurons. The nodes are connected by links or weights. ANNs may consists of multiple layers of nodes interconnected with other nodes in the same or different layers. Various layers are referred to as the input layer, the hidden layer and the output layer. The inputs and the inter connected weights are processed by a weight summation function to produce a sum that is passed to a transfer function The output of the transfer function is the output of the node.

In this research work multi-layer perception network is used. Input layer receives information from the external source and passes this information to the network for processing. Hidden layer receives information from the input layer and does all the information processing, and output layer receives processed information from the network and sends the results out to an external receptor. The input signals are modified by interconnection weight, known as weight factor wij which represents the interconnection of ith node of the first layer to the jth node of the second layer. The sum of modified signals (total activation) is then modified by a sigmoidal transfer function *(f).* Similarly output signals of hidden layer are modified by interconnection weight (Wij) of kth node of output layer to the jth node of the hidden layer. The sum modified k signal is then modified by a pure linear transfer function *(f)* and output is collected at output layer.

Let Ip = (I_{p1}, I_{p2},…,I_{pl}), p=1,2,…,N be the pth pattern among N input patterns.W_{ji} and W_{kj} are connection weights between ith input neuron to jth hidden neuron and jth hidden neuron to kth output neuron respectively.

Output from a neuron in the input layer is

Opi=Ipi, i=1,2,…,l (1)

Output from a neuron in the hidden layer is

Opj = f (NETpj) = f($\sum_{i=0}^{l} Wji\ Opi$), j = 1,2,…,m (2)

Output from a neuron in the hidden layer is

Opk = f (NET pk) = f ($\sum_{i=0}^{l} Wkj\ Opj$), k=1,2,…,n (3)

1.2.1 Sigmoidal Function

A bounded, monotonic, non-decreasing, S Shaped function provides a graded nonlinear response. It includes the logistic sigmoid function

$$F(x) = \frac{1}{1+e^{-x}} \tag{4}$$

Where x = input parameters taken

1.2.2 Learning or training in back propagation neural networks

Batch mode type of supervised learning has been used in the present case in which interconnection weights are adjusted using delta rule algorithm after sending the entire training sample to the network. During training the predicted output is compared with the desired output and the mean square error is calculated.

If the mean square error is more, then a prescribed limiting value, It is back propagated from output to input and weights are further modified till the error or number of iteration is within a prescribed limit.

Mean Squared Error, Ep for pattern is defined as

$$Ep = \sum_{i=2}^{n} \frac{1}{2} (Dpi - Opi)^2 \tag{5}$$

Where Dpi is the target output, Opi is the computed output for the ith pattern.

Weight changes at any time t, is given by

$$\Delta W(t) = -nEp(t) + \alpha \times \Delta W(t-1) \tag{6}$$

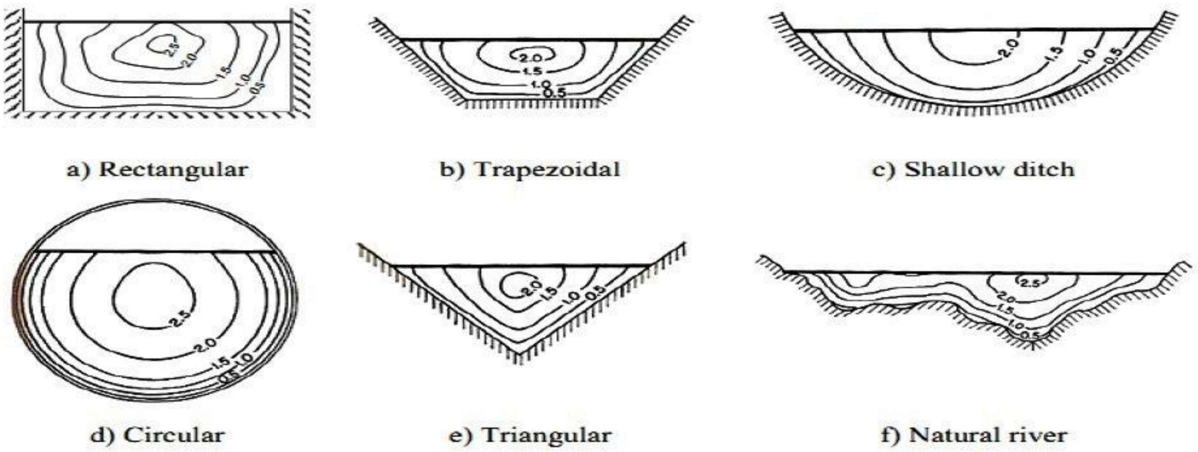
n = learning rate i.e. $0 < n < 1$

α = momentum coefficient i.e. $0 < \alpha < 1$

1.3 DEPTH AVERAGE VELOCITY DISTRIBUTION:

It is quite difficult to model flows in non prismatic converging compound channel as the width varies from section to section through out the channel. Depth-averaged velocity means the average velocity for a depth ‘h’ and is assumed to occur at a height of 0.4h from the bed level. The knowledge of velocity distribution helps to know the velocity magnitude at each point across the flow cross-section. It is also essential in many hydraulic engineering studies involving bank protection, sediment transport, conveyance, water intakes and geomorphologic investigation Compound channels are all the way different and velocity distribution is a combination of flood plain and main channel (Prismatic or Non prismatic).

In laminar flow max stream wise velocity occurs at water level; for turbulent flows, it occurs at about 5-25% of water depth below the water surface (Chow, 1959). Typical stream wise velocity contour lines (isovels) for flow in various cross sections are shown in Fig. 1.1.



a) Rectangular b) Trapezoidal c) Shallow ditch

d) Circular e) Triangular f) Natural river

Figure 1.1 Typical stream wise velocity contour lines (isovels) for flow in various cross sections

1.3.1 Logarithmic law

The “logarithmic law” formulation for the velocity profile in turbulent open channel flow is based on Prandtl’s (1926) theory of the “law of the wall” and the “boundary layer” concept. The boundary layer is a thin region of fluid near a solid surface (bed or wall) where the boundary resistance and the viscous interactions affect the fluid motion and subsequently, the velocity distribution. In the fully developed flow region, this layer includes two main sublayers.Near the solid boundary, a viscous sub-layer (laminar layer) forms where the viscous force is predominant. In contrast, further away from the boundary, the turbulent shear stresses play a major role in the defect layer (turbulent layer).The “law of the wall” states that the in the stream wise direction, the average fluid velocity in the boundary layer varies logarithmically with distance from the wall surface.

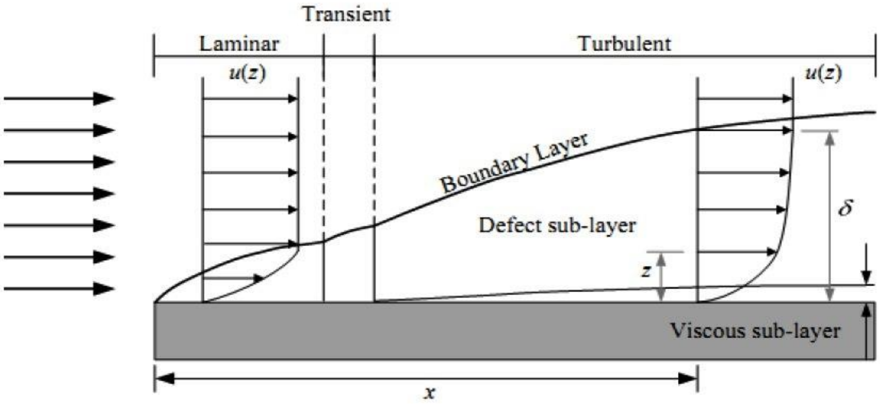


Figure 1.2 External Fluid flow across a flat plate

1.4 ENERGY AND ENERGY LOSS IN NON-PRISMATIC COMPOUND CHANNEL:

Distribution of energy in a compound channel is an important aspect. So it needs to be addressed properly. It is seen that, the river generally exhibit a two stage geometry (deeper main channel and shallow floodplain called compound section) having either prismatic or non-prismatic geometry (geometry changes longitudinally). Due to flow interaction between the main channel and flood plain the flow in a compound section consumes more energy than a channel with simple section carrying the same flow and having the same type of channel surface. Again in converging channel some more parameters are influenced such as width contractions. Due to the rapidly growing population, and to the consequent demand for food and accommodation, more and more land near to river areas has been used for agriculture and settlement making the channel cross section converging. An improper estimation of floods, will lead to an increase in the loss of life, and properties. The modelling of such flows is of primary importance when seeking to identify flooded areas and for flood risk management studies etc.

Again conventional approaches which are based on empirical methods lack in providing high accuracy for the prediction of the energy losses. That’s why a new and accurate techniques are highly demanded. This study introduces an efficient approach to estimate the energy losses with the help of artificial neural network which is a promising computational tool in civil engineering.

1.5 BOUNDARY SHEAR STRESS IN NON-PRISMATIC COMPOUND CHANNEL:

Precise estimation of boundary shear force distribution is essential to deal with various hydraulic problems such as channel design, channel migration and interaction losses. Bed shear forces are useful for the study of bed load transfer where as wall shear forces presents a general view of channel migration pattern.

the analysis of non-prismatic compound channels under different geometric and hydraulic condition are necessary to understand one of the flow properties such as distribution of boundary shear which is a better indicator of secondary flows than velocity, on different parameters like aspect ratio, sinuosity, ratio of minimum radius of curvature to width and hydraulic parameter such as relative depth. With the purpose of obtaining shear stress distribution at the walls and on the bed of compound non-prismatic channel, experimental data collected from laboratory under different discharge and relative depths maintaining the geometry, slope and sinuosity of the channel constant, are analyzed and confronted. Preston-tube technique is used to collect velocity heads at various intervals along the wetted perimeter and within the flow that helps to calculate shear stress values using calibration curves proposed by Patel (1965).

When water flows in a channel the force developed in the flow direction is resisted by reaction from channel bed and side walls. This resistive force is manifested in the form of boundary shear force. Otherwise stated, tractive force, or boundary shear stress, is the tangential component of the hydrodynamic forces acting along the channel bed. Distribution of boundary shear force along the wetted perimeter directly affects the flow structure in an open channel. Knowledge on boundary shear stress distribution is necessary to define velocity profile and fluid field. Also computation of bed form resistance, sediment transport, side wall correction, cavitations, channel migration, conveyance estimation, and dispersion are among the hydraulic problems which can be solved by bearing the idea of boundary shear stress distribution. Other factors that affect the distribution of shear stress in straight non-primatic compound channel are shape of the cross-section, number and structure of secondary flow cells, depth of flow, sediment concentration and the lateral-longitudinal distribution of wall roughness. During flood when rivers are at high stage, the flow from the main channel spills and spreads to the adjacent floodplain. The reduced hydraulic radius and higher roughness of floodplain result in lower velocities in floodplain as compared to the main channel. The interaction between the faster moving fluid in main channel and slower fluid in floodplain result in a bank of vortices as shown by Knight and Hamed (1984), referred to as "turbulence phenomenon". Consequently there is a lateral transfer of momentum that results in an apparent shear stress at the interface of main channel and floodplain which significantly distort flow and boundary shear stress patterns. The intricate mechanism of momentum transfer in a straight two stage channel is demonstrated in Fig.1.2.

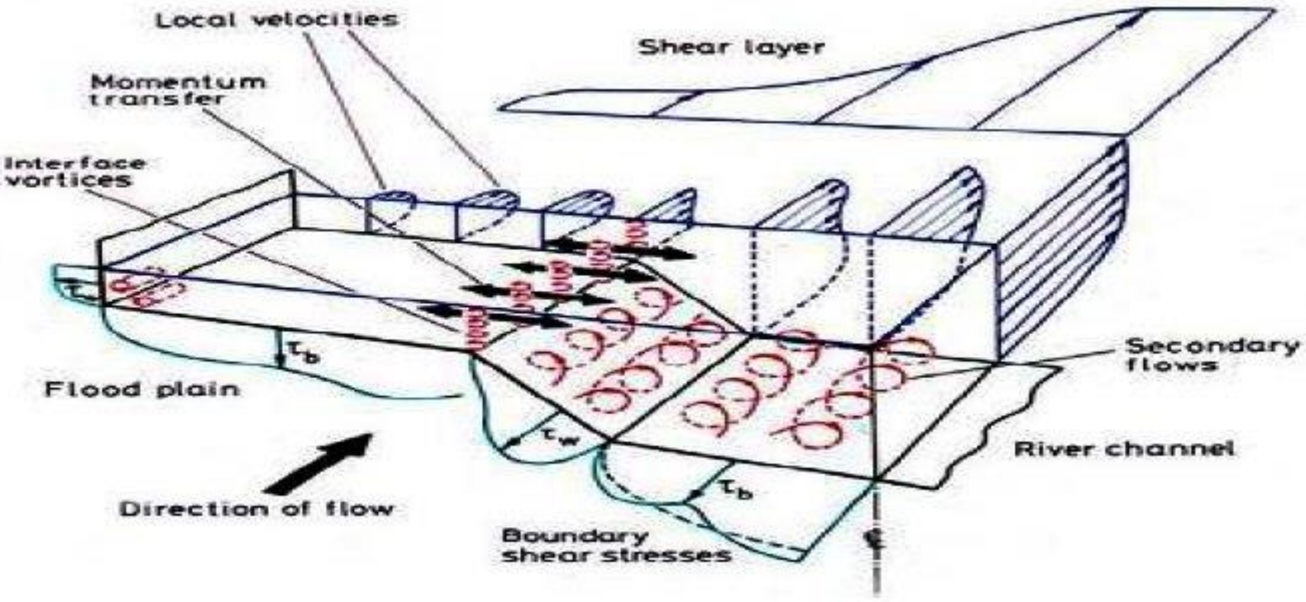


Fig.1.3 3D flow structures in open channel

1.6 OBJECTIVE OF PRESENT RESEARCH WORK:

The general aim of this research is to improve the floodplain hydraulics in compound channels with non-prismatic floodplains. In this research an attempt will be made to to study the prediction of Depth average velocity, the amount of energy stored in an experimental section and the amount of energy lost throughout the sections of a non-prismatic compound channel and the Boundary Shear stress generated throughout the sections of a non-prismatic compound channel using an Adaptive Artificial Neural Network method.

Comparison will be made between the old conventional methods and the new and advised Adaptive method of Artificial Neral Networks to see which method is more precise and accurate and gives faster and brighter results.

The following specific aspects of river flood hydraulics will be investigated for non-prismatic straight compound channels with overbank flow:

I. To study the distribution of stream wise depth-averaged velocity for a single flow depth, also to study its variation at different flow depths for overbank flow conditions.

II. Determination of the amount of energy stored throughout the sections of a non-prismatic compound channel and also the amount of energy lost throughout the experimental sections of a non-prismatic compound channel.

III. To carry out an investigation concerning the distribution of local shear stress in the main channel and flood plain of non-prismatic compound channel.

IV. Determination of boundary shear stress distribution along the wetted perimeter in non-prismatic compound channels.

V. To conduct experiment and analyze experimental data for the investigation of longitudinal wall and bed shear stress for different flow depths for compound non-prismatic open channels.

VI. To devise an adaptive method specifically Artificial Nerual Network method to predict, validate and compare the results of the study subjects with the old conventional methods.

VII. Comparison of the results obtained with the conventional techniques and analysis of the precision and accuracy of the overall research work.

1.7 ORGANIZATION OF THESIS:

In this thesis an attempt has been made to predict flow parameters of a non-prismatic compound channel using an adaptive system specifically the Artificial Neural Network. A prediction of Depth average velocity, Energy stored and lost throughout the experimental channels and the Boundary Shear Stress created throughout the experimental sections of the channel has been done using the ANN technique. A comparison has been done between the actual results obtained and the predicted results obtained and the accuracy of the ANN technique has been confirmed.

In this thesis the organization is as below

- Chapter one is all about Introductions. First of all the Artificial Neural Network has been introduced and the advances and the importance has been discussed. A slight understanding on what actually the Depth average velocity, Energy loss and Boundary shear stress study importance is and how they impact the phenomena. In this chapter the Objective of the whole research study and the current thesis has also been mentioned.

- Chapter two is all about the Literature review and the past studies that have been performed on the Artificial Neural Networks. Studies conducted on non-prismatic compound channels and the attempts to find out the velocity distributions, Energy and energy loss studies and the Boundary shear stress studies have been discussed with the name of the researchers and the year of study completion has been mentioned briefly and chronologically.

- Chapter three discusses the Experimentation and Methodology of the current research work with the detailed description of the experimentation process and the structure of the experiment channel and all the apparatus and equipments used throughout the research work. Measurements of the depth average velocity, the source of data selection, selection of hydraulic geometry and surface parameters have been mentioned. The analysis of energy loss and influencing parameters have been discussed and which factors are taken into consideration in the selection of hydraulic parameters for the study are mentioned. The measurements of Boundary shear stress have also been discussed in this chapter. The measurement of the bed slope of the channel is also of the concerns in this chapter.

- Chapter four is all about the Experimental Results that have been found after performing the experimentations and analysis. All the graphs of the correlations and the residual analysis are shown in the chapter in its respective study portions. The statistical results of the error calculations are present to show the accuracy of the present research work

- Chapter five an accumulation of the conclusions found from the results of the current research work.

CHAPTER 2

LITERATURE REVIEW

2.1 OVERVIEW

An attempt has been made in this chapter to bring together various aspects of past research in hydraulic engineering concerning the behavior of rivers and channels during overbank flow. Until the early Sixties, little was known of the complex flow patterns which exist between a channel and its flood plains, but 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.

There are limited studies available in literature concerning the flow in non-prismatic compound channel and the parameters affecting the flow specifically the Depth average velocity, the Energy Loss throughout the channel and the Boundary shear stress developed.

Studies are required to be conducted on these aspects as these are the heart and soul of the water characteristics in a non-prismatic compound channel and are very much essential for water engineers.

The literature review contains a large body of research on the subjects of Depth average velocity, Energy and Energy Loss, Boundary Shear stress and mainly on the previous research works that have used Artificial neural network as their primary and adaptive method for analysis and predictions carried out in open channel flows. This review intends to present some of the selected significant contribution to the study of the mentioned aspects from earlier times to the most recent ones available.

2.2 LITERATURE REVIEW RELATED TO THE RESEARCH WORK

PRESTON (1954) developed a simple technique for measurement of boundary shear stress. This technique was originally developed for smooth boundaries in a turbulent boundary layer using simple equations. He presented a non-dimensional relationship between the differential pressures, (Δp) and the boundary shear stress, (t_w), as follows

$$\frac{\Delta p}{\rho}\frac{d^2}{v^2} = F\ \left[\frac{d^2 tw}{\rho\, v^2}\right] \tag{7}$$

where *d* is the outside diameter of the tube, ρ is the density of the flow in $kg/m^{3'}$, *v* is the kinematic viscosity of the fluid in m2/s and F is an empirical function.

BRADSHAW AND GREGORY (1959) AND HEAD AND RECHENBERG (1962) pointed out their reservations about the applicability and accuracy of Preston's method.

ZHELEZNYAKOV (1965) was probably the first to investigate the interaction between the main channel and the adjoining floodplain. He demonstrated under laboratory conditions the effect of momentum transfer mechanism, which was responsible for decreasing the overall rateof discharge for floodplain depths just above the bank full level. As the floodplain depth increased, the importance of the phenomena diminished.

PATEL(1965) calibrated a new technique given in terms of two non-dimensional parameters X· and Y·, Where

$$y = 0.5x + 0.037 \qquad \text{for} \quad 0 < y < 1.5 \tag{8}$$

$$y = 0.8287 - 0.1381x + 0.1437x^2 - 0.0060x^3 \qquad \text{for} \quad 1.5 < y < 3.5 \tag{9}$$

$$x = y + 2\log_{10}(1.95y + 4.1) \qquad \text{for} \quad 3.5 < y < 5.3 \tag{10}$$

Following Patel's calibration, many investigators have studied boundary shear stress distributions in different channel geometries using the Preston tube.

GHOSH AND JENA (1973) AND GHOSH AND MEHATA (1974) reported studies on boundary shear distribution in straight two stage channels for both smooth and rough boundaries. They found the distribution of shear is non-uniform and the location of maximum bed and side shear to be some distance from the centreline and free surface. They related the sharing of the total drag force by different segments of the channel section to the depth of flow and roughness concentration.

MYERS AND ELSWY (1975) studied the effect of interaction mechanism and shear stress distribution in channels of complex sections. In comparison to the values under isolated condition, the results showed a decrease up to 22 percent in channel shear and increase up to 260 percent in floodplain shear. This indicated the possible regions of erosion and scour of the channel and flow distribution in alluvial compound sections.

MYERS (1978) studied the momentum transfer mechanism and found the apparent shear stresses were significantly greater than those exerted on a solid boundary or floodplain wall at the interface.

RAJARATNAM AND AHMADI (1979) studied the flow interaction between straight main channel and symmetrical floodplain with smooth boundaries. The results demonstrated the transport of longitudinal momentum from main channel to flood plain. Due to flow interaction, the bed shear in floodplain near the junction with main channel increased considerably and that in the main channel decreased. The effect of interaction reduced as the flow depth in the floodplain increased.

RAJARATNAM AND AHMADI (1981) showed that the boundary shear stress reduces from the centre of the main channel toward the edge of the floodplain and then sharply increases at the interface between the main channel and the floodplain. They also stated that, due to interaction between subsections in compound channels, the boundary shear stress in the main channel reduces

WORMLEATON, ALEN, AND HADJIPANOS (1982) undertook a series of laboratory tests in straight channels with symmetrical floodplains and used "divide channel" method for the assessment of discharge. From the measurement of boundary shear, apparent shear stress at the vertical, horizontal, and diagonal interface plains originating from the main channel floodplain junction could be evaluated. An apparent shear stress ratio was proposed which was found to be a useful yardstick in selecting the best method of dividing the channel for calculating discharge. It was found that under general circumstances, the horizontal and diagonal interface method of channel separation gave better discharge results than the vertical interface plain of division at low depths of flow in the floodplains.

KNIGHT AND DEMETRIOU (1983) conducted experiments in straight symmetrical compound channels to understand the discharge characteristics, boundary shear stress and boundary shear force distributions in the section. They presented equations for calculating the percentage of shear force carried by floodplain and also the proportions of total flow in various sub-areas of compound section in terms of two dimensionless channel parameters. For vertical interface between main channel and floodplain the apparent shear force was found to be more at low depths of flow and also for high floodplain widths. On account of interaction of flow between floodplain and main channel, it was found that the division of flow between the sub-areas of the compound channel did not follow the simple linear proportion to their respective areas.

KNIGHT AND HAMED (1984) extended the work of Knight and Demetriou (1983) to rough floodplains. The floodplains were roughened progressively in six steps to study the influence of different roughness between floodplain and main channel to the process of lateral momentum transfer. Using four dimensionless channel parameters, they presented equations for the shear force percentages carried by floodplains and the apparent shear force in vertical, horizontal, diagonal, and bisector interface plains. The apparent shear force results and discharge data provided the strength and weakness of these four commonly adopted design methods used to predict the discharge capacity of the compound channel.

MCKEE ET AL. (1985) confirmed Myers momentum balance approach using the Laser Doppler Anemometry (LDA) technique.

TOMINAGA ET AL. (1989) the boundary shear stress is highly affected by the secondary flow, and it increases where the secondary currents flow toward the wall and decreases when they flow away from the wall.

RHODES AND KNIGHT (1994) suggested that the bank slope had a significant effect on the boundary shear stress distributions at the interface between the main channel and floodplain.

BOUSMAR (2002) AND BOUSMARET AL. (2004A) Analysed the experiments on converging compound channels with symmetrically narrowing floodplains. They highlighted the geometrical momentum transfer and the associated additional head loss due to symmetrically narrowing floodplains force flow from the floodplains to the main channel. They estimated the additional head loss due to the mass transfer. Its value was found in several cases as large as the friction loss.

(BOUSMAR ET AL., 2004B) Performed additional investigations using digital imaging to record surface velocities and horizontal turbulent structures that generally develop in prismatic channels.

PROUST (2005) AND PROUSTET AL.(2006) Investigated the flow analysis of a compound channel with asymmetric geometry with a more abrupt convergence. They found that a larger mass transfer and total head loss is resulting from the higher convergence angle. The total head within the main channel decreased faster than that in flood plain.

SARAT KUMAR DARS, PRABIR KUMAR BASUDHAR (2006) The paper described the application of the artificial neural network model to predict the lateral load capacity of piles in clay. Three criteria were selected to compare the ANN model with the available empirical models. model equation is presented based on neural network parameters.

BOUSMARET AL. (2006) Investigated diverging compound channels, with symmetrically enlarging floodplains. He found the water profile rise in downstream direction. Due to deceleration the mean velocity decreased in downstream direction. Head losses increased in non prismatic section.

BAHRAM REZAEI (2006) Presented the experimental results of non-prismatic compound channels with converging floodplains, due to change in floodplain geometry. They found that, water flowing on the floodplain is crossing over water flowing in the main channel, resulting in increased interactions and momentum exchanges.

SARAT KUMAR DAS, PRABIR KUMAR BASUDHAR (2008) This paper presents a neural network model to predict the residual friction angle based on clay fraction and Atterberg's limits. Emphasis is placed on theconstruction of neural interpretation diagram, based on the weights of the developed neural network model, to find out direct or inverse effect of soil properties on the residual shear angle. A prediction model equation is established with the weights of the neural network as the model parameters.

A. BILGIL, H. ALTUN (2008) Investigated the flow resistance in smooth open channels using Artificial Neural Networks. The estimated values of friction coefficient is used in Manning’s Equation to predict the open channel flows in order to carry out a comparison between the proposed neural networks based approach and the conventional ones.

S.PROUST ET'AL (2008) Evaluated the relative weights of three sources of energy loss for non-uniform flows in compound channel: (1) the bed friction; (2) the momentum transfer due to turbulent exchange between the main channel and the floodplains; and (3) the momentum transfer due to mass exchange between the subsections. They also found that in compound channels with non-prismatic floodplains, the apparent shear forces in vertical interface are negative.

PARAMESWAR PANDA (2010) Predicted the flow in compound open channel using Artificial Neural Network. An ANN Algorithm has been developed to predict discharge capacity of compound channels observed at 190 comprehensive laboratory data of various experiments across the ingenious laboratory experiments done in NIT Rourkela.

REZAEI AND KNIGHT (2010) gave a modified SKM method to investigate the various converging angles and relative depths.

MRUTYUNJAYA SAHU, K.K.KHATUA, S.S.MAHAPATRA (2011) used a neural network approach for prediction of discharge in straight compound open channel flow. Discharge determination models such as the single channel method (SCM), the divided channel method (DCM), the coherence method (COHM) and the exchange discharge method (EDM) are widely used; however they are insufficient to predict discharge accurately therefor and attempt has been made to predict the total discharge in compound open channels with and Artificial neural network and compare it with the above models.

MRUTYUNJAYA SAHU (2011) predicted the flow and its resistance in compound open channel using adaptive approaches such as Artificial neural networks and adaptive fuzzy interference system for different hydraulic conditions.

MRUTYUNJAY SAHU, SRIJITA JANA, SONU AGARWAL, K.K. KHATUA (2011) point form velocity in the downstream of flow is predicted at different sections of the meandering channel. Back propagation learning rule in ANN network is considered for further analysis, as this network is well adept with pattern recognition and forecasting. In this further analysis, position of the point and depth of flow are taken as input and point form velocity is the output.

REZAEI AND KNIGHT (2011) found that for the lower water depths, the discharge evolution seems linear; whereas for higher water depths, it is nonlinear. The mass transfer in the second half of the converging reach is higher than that in the first half. They further found that in compound channels with non-prismatic floodplains, the apparent shear forces in vertical interface are negative.

RAY SINGH MEENA (2012) introduced about the parameterization of hydrologic and hydraulic modeling for simulation of runoff and flood inundated area mapping. Results indicated that for Kosi catchment, the empirical runoff prediction approach (ANN technique), in spite of requiring much less data, predicted daily runoff values more accurately than semi-distributed conceptual runoff prediction approach (SCS-CN method).

MRUTYUNJAYA SAHU, PRASHANT SINGH, S.S.MAHAPATRA, K.K.KHATUA (2012) proposed an adaptive network fuzzy interference system for the prediction of entrance length in pipe for low Reynolds number flow.

CHAPTER 3

EXPERIMENTATION AND METHODOLOGY

3.1 OVERVIEW

Normally experimental work should be conducted on natural streams for non-prismatic compound channels, but because of the time consuming process and the fact that natural streams are difficult to have access to in our recent locational condition, we have restrained our work to only laboratory work and laboratory modeling for the non-prismatic compound channel in which we have performed our experiments and have recorded the readings for the analysis of different flow parameters, so all our research work has been restricted to laboratory modeling and the artificial channel built inside the laboratory indicating the real aspect of non-prismatic compound channels.

Experiments have been conducted on the non-prismatic compound channel located in the Hydraulics laboratory of National Institute of Rourkela for analysis and study of different parameters influencing flow in non-prismatic compound channel specifically Depth average velocity, Energy stored and Energy lost throughout the experimental sections of the channel and finally the Boundary Shear Stress developed in each experimental section of the channel taken into consideration.

Besides the fact that National Institute of Technology Rourkela had limited resources and limited experimental facilities, still the study was carried out quite satisfactory and was completed with the guidance of experienced and hardworking professors of water resources specifically Dr. K. K. Khatua and other hardworking staff of Water Resources specialization

3.2 DESIGN AND CONSTRUCTION OF CHANNEL

Experiments have been conducted in two sets of non-prismatic compound channels with varying cross section built inside a concrete flume measuring 15m long ×.90m width × 0.55m depth and flume with perpexsheet of same dimensions. The width ratio of the channel is α=1.8 and the aspect ratio is σ=5 where width ratio is the ratio between width of floodplain to width of main channel and aspect ratio is the ratio between width of channel to depth of flow. The converging angle of the channels are taken as 12.38° and 5^0 (Naik 2014).Converging length of the channel is found to be

0.84m and 2.28m.We had also gathered data from the compound channels with non-prismatic floodplains converging from 400mm to 0mm along 2m and 6m lengths, and narrowing from 400mm to 200mm along a 6m length (Rezai 2006) (corresponding convergence angles of 8=11.31, 8=3.81, and 8=1.91 degrees respectively),

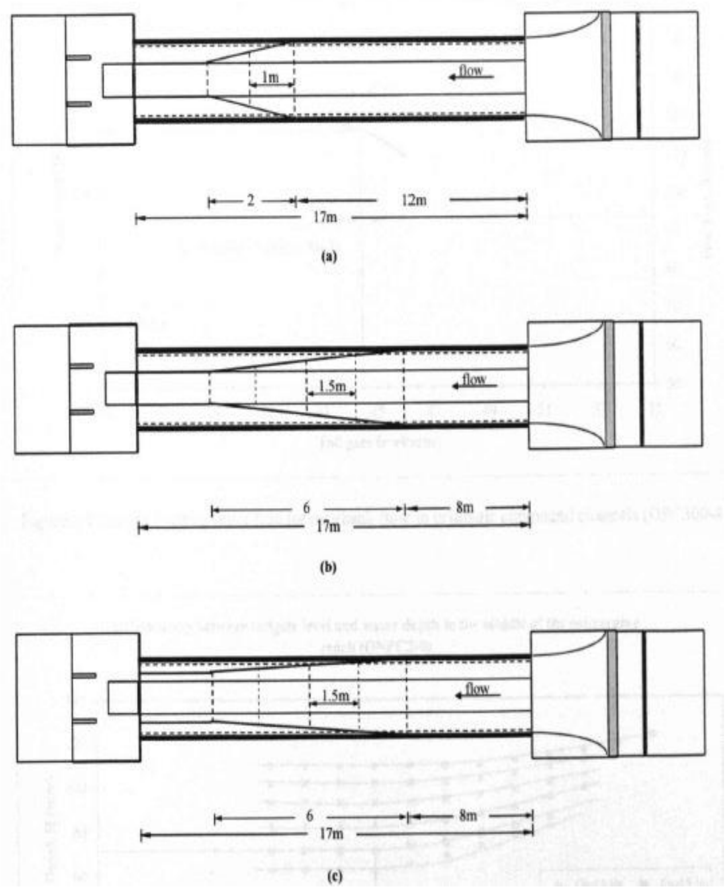


Fig.3.1 Plan view of compound channels with non-prismatic floodplains; (a) converging from 400 to 0mm along a 2m length (ONPC2-0); (b) narrowing from 400mm to 0 mm along a 6m length (ONPC6-0) and; c)converging from 400mm to 200mm along a 6m length (ONPC6-200)

Water was supplied through a Centrifugal pumps (a 15 hp) discharging into a RCC overhead tank. In the downstream end there lies a measuring tank followed by a sump which feed the water to the overhead tank through pumping. This arrangements completes the recirculation system of water for the experimental channels. (Fig.2a,) shows the diagram of dimensions of channel with test section respectively.2 (b) shows the typical grid showing the arrangement of velocity measurement points along horizontal and vertical direction at the test section. Water was supplied to the flume from an underground sump via an overhead tank by centrifugal pump (15 hp) and recirculated to the sump after flowing through the compound channel and a downstream volumetric tank fitted with closure valves for calibration purpose. Water entered the channel bell mouth section via an upstream rectangular notch specifically built to measure discharge in the laboratory channel. An adjustable vertical gate along with flow straighteners was provided in upstream section sufficiently ahead of rectangular notch to reduce turbulence and velocity of approach in the flow near the notch section. At the downstream end another adjustable tail gate was provided to control the flow depth and maintain a uniform flow in the channel. A movable bridge was provided across the flume for both span wise and stream wise movements over the channel area so that each location on the plan of compound converging channel could be accessed for taking measurements.

Fig.3.2 Top views of the experimental channel located in the hydraulics laboratory of NIT Rourkela

Table 3.1 Hydraulic parameters for the experimental channel data set collected from literature & experiments

Verified test channel	Types of channel	Angle of convergent/Divergent	Longitudinal slope (S)	Cross sectional geometry	Total channel width (B) in m	Main channel width (b) in m	Main channel depth (h) in m	Main channel side slope (s)	Width ratio B/b (α)
1	2	3	4	5	7	8	9	10	11
Rezai(2006)	Convergent (CV2)	(Θ=11.31°,2m)	0.002	Rectangular	1.2	0.398	0.05	0	3
Rezai(2006))	Convergent (CV6)	(Θ=3.81°,6m)	0.002	Rectangular	1.2	0.398	0.05	0	3
Rezai(2006)	Convergent (CV6)	(Θ=1.91°,6m)	0.002	Rectangular	1.2	0.398	0.05	0	3
N.I.T.Rkl data	Convergent	(Θ=5°,2.28m)	0.0011	Rectangular	0.9	0.5	0.1	0	1.8
N.I.T.Rkl data	Convergent	(Θ=12.38°,0.84 m	0.0017	Rectangular	0.9	0.5	0.1	0	1.8

3.3 APPARATUS & EQUIPMENTS USED:

Water surface measurements were measured directly with point gauge located on an instrument carriage, which could be moved along the flume. A vertical manometer was used to measure the static and dynamic pressure. Preston tube was utilized for the measurement of point velocity in each and every recording taken into consideration which performed quite satisfactory for the current research work.

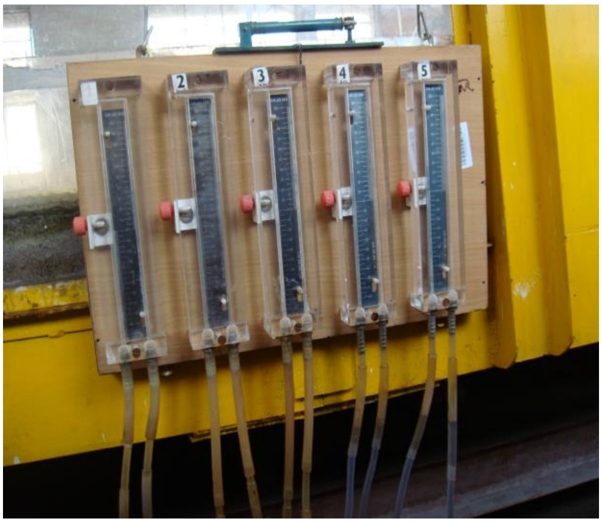


Fig.3.3 Series of Manometers

Fig.3.4 Taill Gate

Fig.3.5 Non prismatic section of the channel

Fig.3.6 Arrangements of the channel

3.4 EXPERIMENTAL PROCEDURE

The measurements were made each 5mm and 10mm in converging flume of .840 m and 2.28m length. Point velocities were measured along verticals spread across the main channel and flood plain so as to cover the width of entire cross section. Also at a no. of horizontal layers in each vertical, point velocities were measured. Measurements were thus taken from mid-point of main channel to the left edge of floodplain. The lateral spacing of grid points over which measurements were taken was kept 5cm inside the main channel and the flood plain. Velocity measurements were taken by Pitot static tube (outside diameter 4.77mm) and two piezometers fitted inside a transparent fibre 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 connected to total pressure hole and static hole of Pitot tube by long transparent PVC tubes at other ends. 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. The angle of limb of Pitot tube with longitudinal direction of the channel was noted by circular scale and pointer arrangement attached to the flow direction meter. Pitot tube was physically rotated with respect to the main stream direction till it recorded the maximum deflection of the manometer reading. A flow direction finder was used to get the direction of maximum velocity with respect to the longitudinal flow direction. Steady uniform discharge was maintained the run of the experiment and several runs were conducted for overbank flow with relative depth varying between 0.15-0.51.

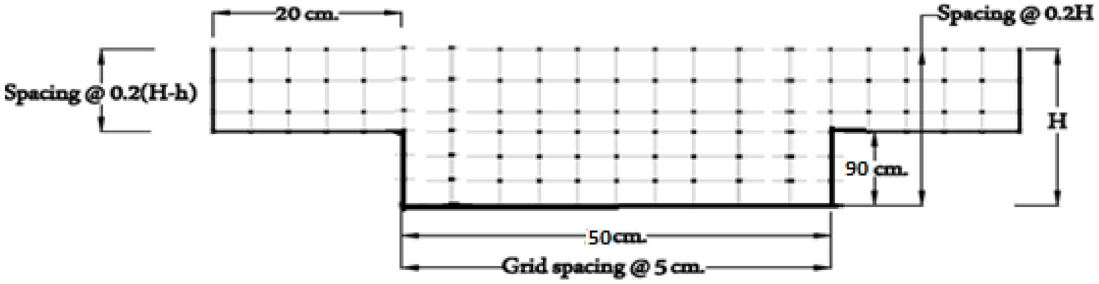


Fig.3.7 Typical grid showing the arrangement of velocity measurement points along horizontal and vertical direction at the test section.

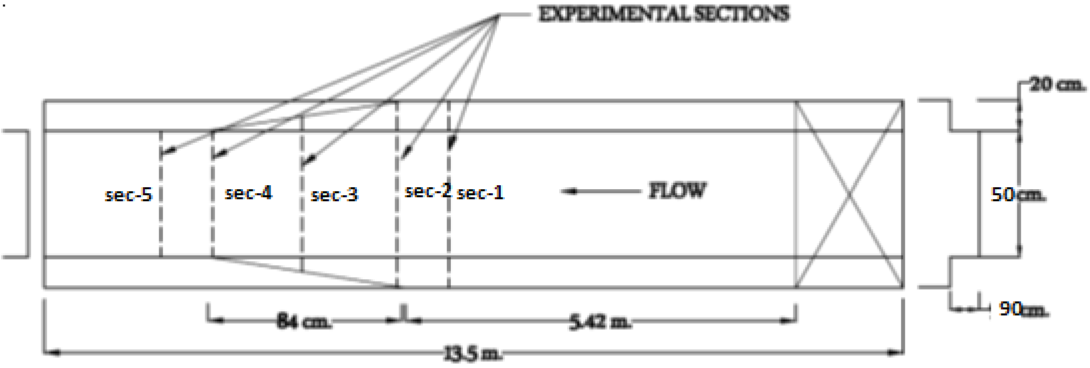


Fig.3.8 Longitudinal & Cross sectional dimension of the compound channel of non-prismatic section (all dimensions are in cm).

3.4.1 MEASUREMENT OF DEPTH AVERAGE VELOCITY

In the present work velocity readings are taken using Pitot tubes. These are placed in the direction of flow and then allowed to rotate along a plane parallel to the bed and till a relatively maximum head difference appeared in manometers attached to the respective Pitot tubes. The deviation angle between the reference axis and the total velocity vector is assumed to be positive, when the velocity vector is directed away from the outer bank. 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 $U = (2gh)^{1/2}$, where g is the acceleration due to gravity. Resolving U into the tangential and radial directions, the local velocity components is obtained. Here the tube coefficient is taken as unit and the error due to turbulence considered negligible while measuring velocity. Point velocities were measured along verticals spread across the main channel and flood plain so as to cover the width of entire cross section. Also at a no. of horizontal layers in each vertical, point velocities were taken. Particularly the point velocities at a depth of 0.4H (where H is the depth of flow at that lateral section across the channel) from channel bed in main channel region and 0.4(H-h) on floodplains (h is depth of main channel) were measured throughout the lateral section of the compound cross section to experimentally determine the depth averaged velocity distribution under each discharge condition. Measurements were thus taken from left edge point of flood plain to the right edge of floodplain including the main channel bed

3.4.2 SOURCE OF DATA AND SELECTION OF HYDRAULIC PARAMETERS

Along with the presently carried out experimental data set, an extensive literature related to analysis of converging compound channels are also reviewed. The standard data set were collected from several are prepared in Table 1

3.4.2.1 Selection Of Hydraulic, Geometric And Surface Parameters

Flow hydraulics and momentum exchange in converging compound channels are significantly influenced by both geometrical and hydraulic variables, the computation become more complex when the floodplain width contracted and become zero. The flow factors responsible for the estimation of boundary shear stress and depth average velocity are

i. Converging angle denoted as θ.
ii. Relative flow depth denoted as *Dr*.
iii. Width ratio (α) i.e .ratio of width of floodplain to width of main channel.
iv. Aspect ratio (σ) i.e. ratio of width of main channel to depth of main channel.
v. Relative distance (Xr) the distance of the point velocity in the width wise of the cross section / total width of the cross section taken into consideration.
vi. Relative depth (Yr) the distance of point velocity depth wise of the cross section / total depth of the cross section taken into account.
vii. Relative distance (Z_r) i.e of point velocity in the length wise direction of the channel)/total length of the non-prismatic channel. Total five flow variables were chosen as input parameters and energy as output parameter .

3.4.3 ANALYSIS OF ENERGY LOSSES AND INFLUENCING PARAMETERS

The resistance to flow of a channel can be significantly increased by the presence of contractions of floodplain. Various methods exists for accounting the additional resistance which are generally for simple channels or meandering channels in term of geometric and flow variables. It has been confirmed that ignoring contraction losses due to converging floodplain can introduce significant error in channel conveyance estimation.

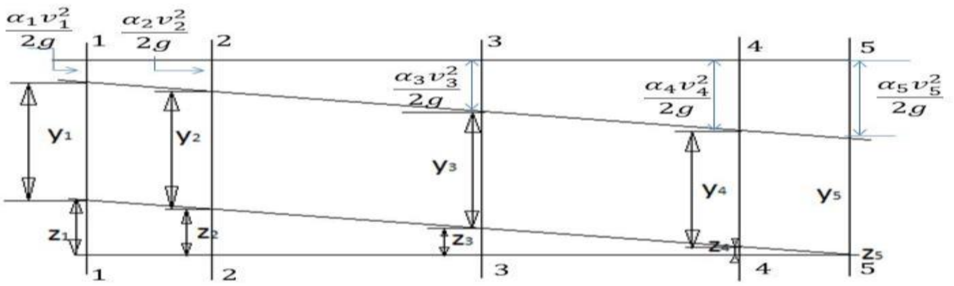


Fig.3.9 Sketch of Energy profile of different section

Consider a channel reach from section 1 to section 2 as shown in Figure1. The total energy head loss can be calculated from the equation of conservation of energy between sections 1-2.

$$E_1 = z_1 + y_1 + \frac{{v_1}^2\,\alpha_1}{2g} \qquad (11)$$

$$E_2 = z_2 + y_2 + \frac{{v_2}^2\,\alpha_2}{2g} \qquad (12)$$

Due to conservation of energy we know that

$E_1 = E_2$

$$z_1 + y_1 + \frac{{v_1}^2\,\alpha_1}{2g} = z_2 + y_2 + \frac{{v_2}^2\,\alpha_2}{2g} \qquad (13)$$

Where z_1&z_2 are the bottom elevation above a given datum at section 1 and 2 respectively.

y_1 is the flow depth at section 1.

y_2 is the flow depth at section 2.

$v_1$and v_2 are the mean velocities at section 1 -2 respectively.

h_1 is the local energy loss due to channel contraction.

$\alpha_1$and α_2 are the velocity head correction factor at section 1 and 2 respectively.

Similarly the value of h_2,h_3,h_4,h_5 are calculated for the section 2-3,3-4,4-5 respectively.

The local energy loss due to the convergence between section 1 and 2 can be expressed as

$$h_1 = E_1 - E_2 \qquad (14)$$

Similarly local energy loss coefficients of different angles of Rezai are calculated .

3.4.3.1 SELECTION OF HYDRAULIC PARAMETERS FOR ENERGY LOSS

Flow hydraulics and momentum exchange in converging compound channels are significantly influenced by both geometrical and hydraulic variables , the computation become more complex when the floodplain width contracted and become zero. The flow factor responsible for the estimation of energy losses are

i. Converging angle denoted as θ
ii. Width ratio(α)i.e.ratio of width of floodplain to width of main channel
iii. Aspect ratio(σ)i.e.ratio of width of main channel to depth of main channel
iv. Depth ratio Dr=(H-h)/H. H(height of water at a particular section),
h(height of water in main channel)
v. Relative distance (z_r)i.e position of point velocity in the length wise direction of the channel)/total length of the non-prismatic channel.

Hence in this study these five flow variables are chosen as input parameters and energy as output parameter.

3.4.4 SHEAR STRESS MEASUREMENTS

Shear studies in open channel flow has many implications such as bed load transport, channel migration, momentum transfer etc. Bed shear forces are useful for the study of bed load transfer where as wall shear forces presents a general view of channel migration pattern. There are several methods used to evaluate bed and wall shear stress in an open channel. The Preston-tube method is an indirect estimate for shear stress measurements and is widely used for experimental channel which is described below. In the following section, results regarding the distribution of boundary shear stress along with the contours of local shear stress is shown and discussed. Also the mean boundary shear stress results are discussed in details.

3.4.4.1 Methods for estimation of Boundary shear stress

Using Preston's technique (1954) together with calibration curves of Patel's (1965) local boundary shear stress measurements were made around wetted perimeter of the present converging channel. Preston developed a simple shear stress measurement technique for smooth boundaries in a fully developed turbulent flow using a Pitot tube. Based on the law of the wall assumption (Bradshaw and Huang, 1995), i.e. the velocity distribution near the wall can be empirically related to the differential pressure between the dynamic and static pressures, Preston presented a non-dimensional relationship between the differential pressures, ΔP and the boundary shear stress,τ_o

$$\frac{\Delta p}{\rho}\frac{d^2}{v^2} = F\left[\frac{d^2 tw}{\rho\, v^2}\right] \tag{15}$$

Where, d is the outside diameter of the tube, ρ is the density of the flow, ν is the kinematic viscosity of the fluid and F is an empirical function. Following this work, Patel (1965) presented definitive calibration curves for the Preston tube defined in terms of two non-dimensional parameters which are used to convert pressure readings to boundary shear stress:

$$x = \log_{10}\left(\frac{\Delta p\, d^2}{4\rho\, v^2}\right) \quad (16) \qquad\qquad y = \log_{10}\left(\frac{t_w\, d^2}{4\rho\, v^2}\right) \quad (17)$$

The calibration of x*and y* for different regions of the velocity distribution (i.e. viscous sub layer, buffer layer and logarithmic layer) is expressed by three different formulae

$$y = 0.5x + 0.037 \qquad \text{for} \quad 0 < y < 1.5 \tag{18}$$

$$y = 0.8287 - 0.1381x + 0.1437x^2 - 0.0060x^3 \qquad \text{for} \quad 1.5 < y < 3.5 \tag{19}$$

$$x = y + 2\log_{10}(1.95y + 4.1) \qquad \text{for} \quad 3.5 < y < 5.3 \tag{20}$$

In the present case, all shear stress measurements are taken at all the five sections of the converging angles. The pressure readings were taken using Pitot tube. These are placed at the predefined points of the flow-grid in the channel, facing the flow. The manometers attached to the respective Pitot tubes are used to measure head difference. The differential pressure was then calculated from the readings on the vertical manometer:

$$\Delta P = \rho g \Delta h \qquad (21)$$

Where Δh is the difference between the two readings from the dynamic and static, g is the acceleration due to gravity and ρ is the density of water. Here the tube coefficient is taken as unit and the error due to turbulence considered negligible while measuring velocity.

3.4.4.2 Selection of hydraulic parameters for Boundary Shear Stress

Selection of the currect hudraulic parameter for the Computation of the Boundary Shear Stress generated at the walls of the non-prismatic sections throughout the compound channel is essential. The flow factors responsible for the estimation of boundary shear stress and depth average velocity are:

i. Converging angle denoted as θ
ii. Width ratio (α) i.e .ratio of width of floodplain to width of main channel
iii. Aspect ratio (σ) i.e. ratio of width of main channel to depth of main channel
iv. Depth ratio (β) = (H-h)/H. where H=height of water at a particular section and, h= height of water in main channel
v. Relative distance (Z_r) i.e of point velocity in the length wise direction of the channel)/total length of the non-prismatic channel. Total five flow variables were chosen as input parameters and energy as output parameter

3.4.5 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 non-prismatic 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. For more accuracy this procedure was continuing for three times and the average was taken as the bed slope of 0.0011 for 5º converging compound channel and 0.0017 for 12.38º converging compound channel.

CHAPTER 4

RESULTS

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 Depth average velocity distributions, Energy stored throughout the experimental sections and the energy loss between the experimental sections of a non-prismatic compound channe and also the Boundary Shear stress generated in each section of the non-prismatic comoound channel. The laboratory measurements were taken, readings have been recorded for all the sections of the non-prismatic compound channel individually for all of the above mentioned studies taken into account for this research work. After obtaining the records and the readings from the experimental work, analytical work was performed of the data. Conventional methods have been used for each single aspect, tables have been arranged and overall conventional techniques have been used to find out the results.

After finding out the results in the old conventional methods for Depth average velocity, Energy and Energy loss calculations and the Boundary Shear distribution for the non-prismatic compound channel, an Adaptive method has been used for ease of work. Artificial Neural Network has been used to find out or to predict the results for the above mentioned aspects of flow and it has been seen that less amount of time has been taken and accurate results have also been found in comparison to that of the old conventional techniques. A comparison has also been made between the actual experimental data results or in simple words the target values and the predicted values obtained by ANN technique and have been compared. The error in calculations have also been compared and shown in this research work.

4.2 DEPTH AVERAGE VELOCITY RESULTS:

Depth-averaged velocity means the average velocity for a depth ‘h’ is assumed to occur at a height of 0.4h from the bed level. Distribution of flow velocity in longitudinal and lateral direction is one of the important aspects in open channel flows. It directly relates to numerous flow features like water profile estimation, shear stress distribution, secondary flow, channel conveyance and host to other flow entities.

The depth average velocity measurements have been taken at 5 consecutive sections for the two channels of 5 and 13.38 degrees of the non-prismatic compound channels constructed in the Hydraulics laboratory of the National Institute of Technology Rourkela.

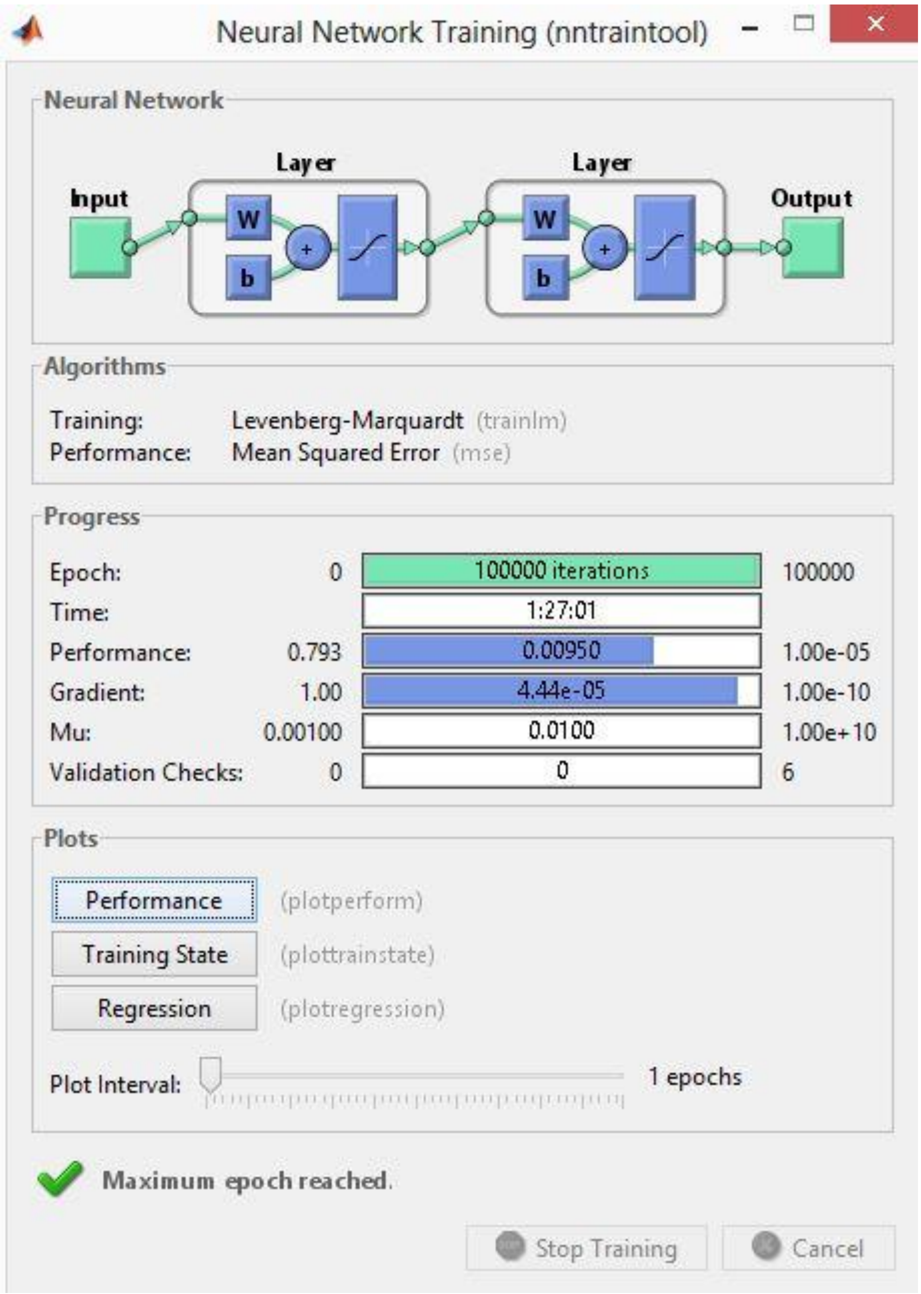
Data from the studies of Bahram Rezai(2006) conducted on the non-prismatic reach of a compound channel has also been taken into considerations. The depth-averaged velocity distribution within the cross-section was measured at three positions for the 2m converging case (x=12m, x=13m, and x=14m) and five positions for the 6m narrowing cases (x=8m, x=9.5m, x=llm, x=12.5m, and x=14m) for each relative depth.

In this part of the study, the adaptive technique of Artificial Neural Network has been used to predict he Depth average velocity distribution along the non-prismatic reach of a compound channel.

A total of 19648 data points were gathered including the input and target parameters of which 17192 data points were the Input parameters and 2456 data points were the Output of the Target points or values.

70% of the input and target values have been taken as the Training data set for the current network and the remaining 30 % of the input and target parameters has been taken as the Testing data set for the current Network, which means that 12035 data points from the input parameters have been assigned as the training data set and 5157 data points have been assigned as the training data set for the Input Parameters, also 1720 data were assigned as the training data set for the target values and the remaining 736 data points were assigned as the testing data set for the target values.

The analysis was performed in a Pentium 4 processor computer with the Matlab2010 software.



Training: Levenberg-Marquardt (trainlm)
Performance: Mean Squared Error (mse)

Epoch:	0	100000 iterations	100000
Time:		1:27:01	
Performance:	0.793	0.00950	1.00e-05
Gradient:	1.00	4.44e-05	1.00e-10
Mu:	0.00100	0.0100	1.00e+10
Validation Checks:	0	0	6

Plot Interval: 1 epochs

✓ Maximum epoch reached.

Fig.4.1 Details of the Neural Network tool in Matlab2010

A Regression coefficient of 0.977 has been obtained which shows that the results obtained are quite satisfactory as we can see the difference and deflection of the actual target values and the predicted values are quite less as is shown in the figure below

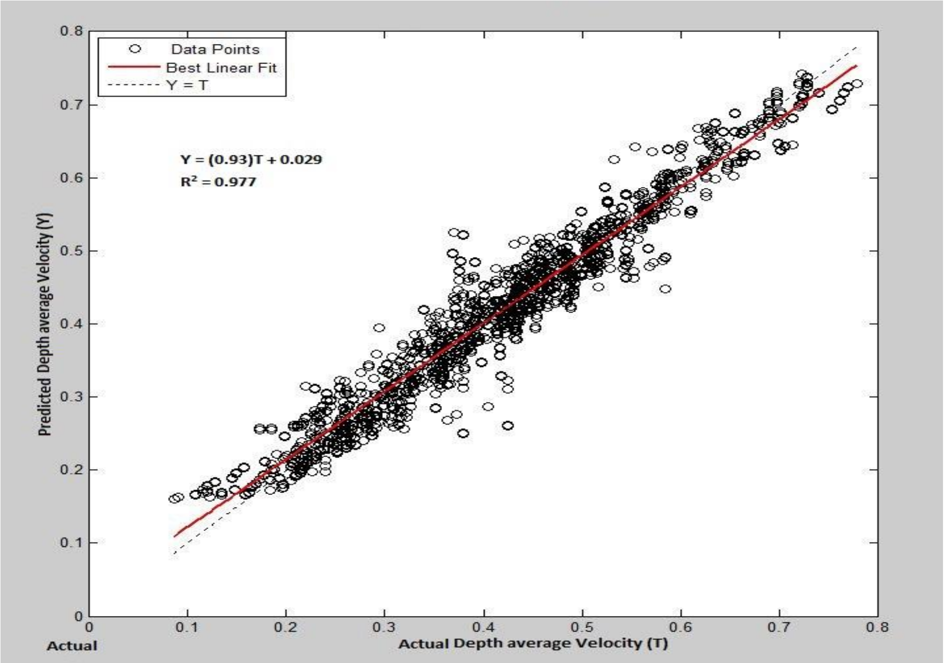


Fig.4.2 Correlation plot of actual depth average velocity and predicted depth average velocity

For better understanding of the accuracy of the results obtained from the Artificial Neural Network and the comparison of this adaptive technique to the conventional ones or the experimental results we take into account the residual distributions of the training and testing data sets as are shown in the figures below.

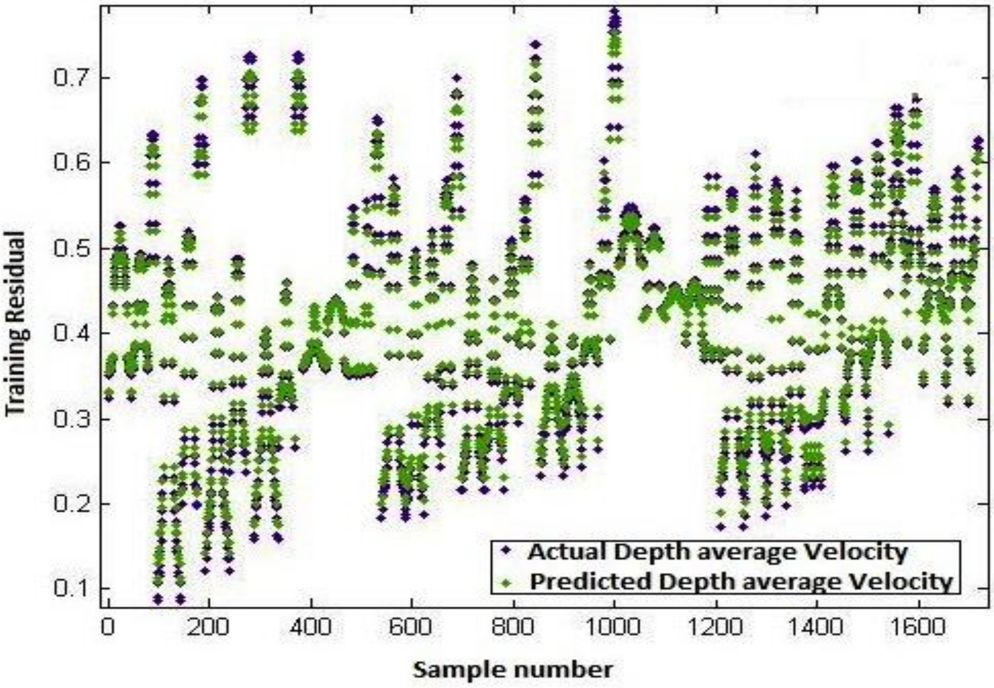


Fig.4.3 Comparison of actual and predicted depth average velocity (training data)

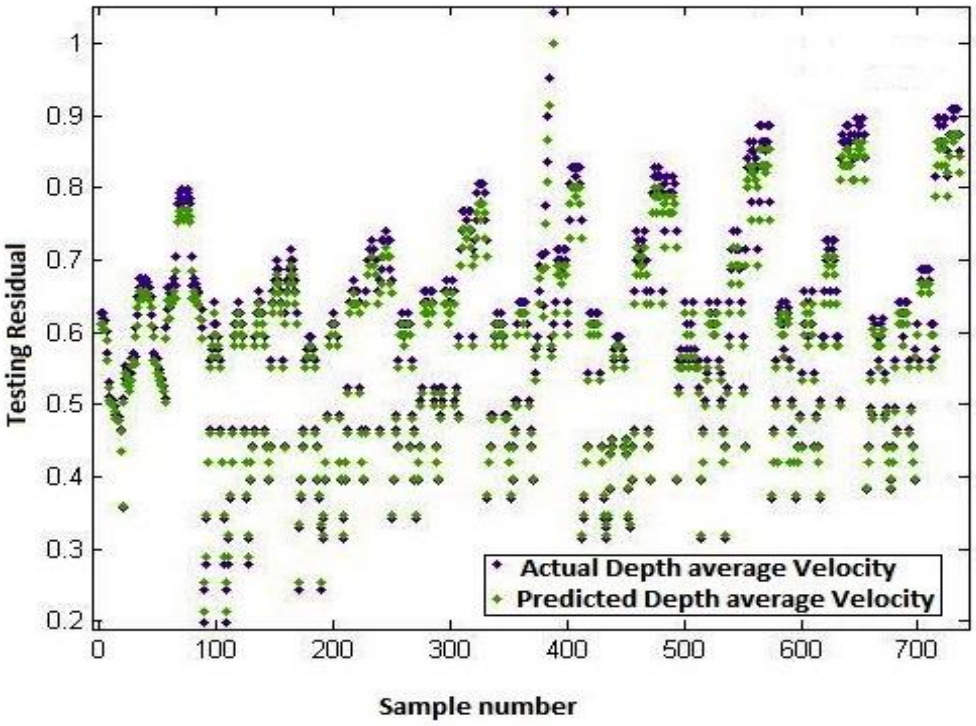


Fig.4.4 Comparison of actual and predicted depth average velocity (testing data)

As the predicted data pattern follows actual data with little or no exception ,it means the models predict the pattern of the data distribution with adequate accuracy.

Error Calculations have been performed and the effective factors specifically the Mean Squared Error (MSE), the Root Mean Squared Error (RMSE), Mean Absolute Error (MAE), and the Mean Absolute Percentage Error(MAPE) have been calculated and listed in the table below

Table 4.1 Statistical Results of Emperical Equations in Calculations

Error Calculations	**Depth average velocity**
MSE	0.000255
RMSE	0.015958
MAE	0.012193
MAPE	2.40

4.3 ENERGY AND ENERGY LOSS RESULTS

The total experimental data set is divided into training set and testing set. For Energy Calculations 679data are used among which 476 are training data and 203 are taken as testing data. And overall the total data set for Energy loss Analysis is taken as 532 data set among which 373 data are taken as training data and the remaining 159 are taken as testing data. The number of layers and neurons in the hidden layer are fixed through exhaustive experimentation when mean square error is minimised for training data set. It is observed that minimum error is obtained for 6-7-1 architecture.

So the back propagation neural network (BPNN) used in this work has three layered feed forward architecture.

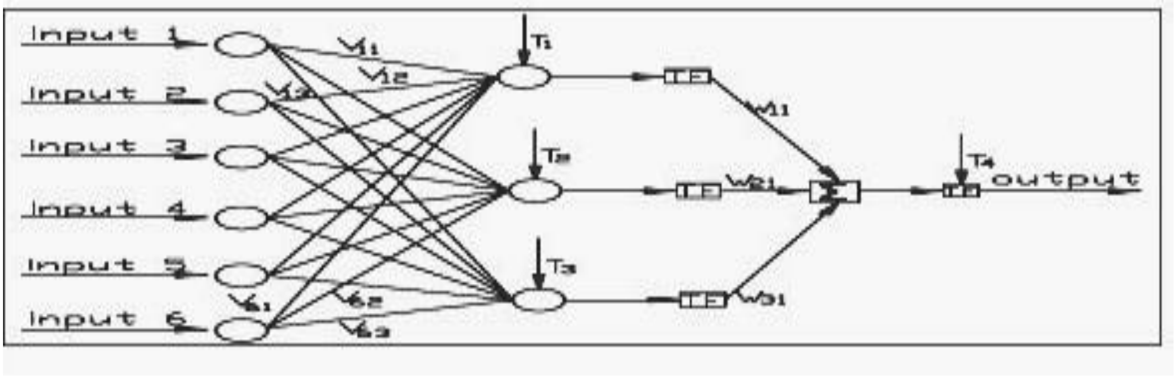


Fig. 4.5 Artificial Neural Network Structure

The model was run on MATLAB commercial software dealing with trial and error procedure.

A Correlation plot of actual energy and predicted energy stored throughout the experimental sections of the non-prismatic compound channel has been taken into account and also shown as below.

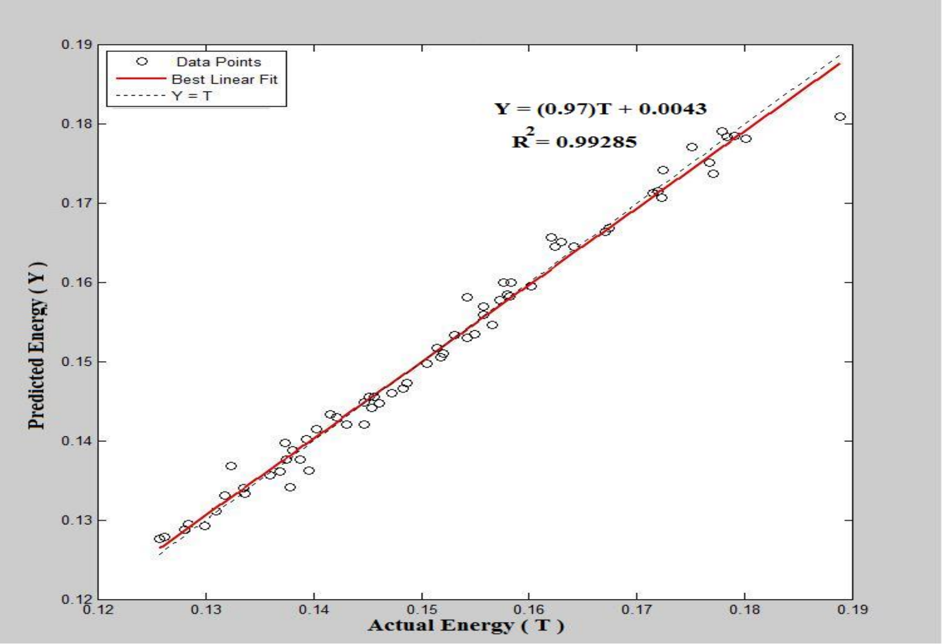


Fig.4.6 Correlation plot of actual energy and predicted energy

In a similar pattern, a correlation plot of actual Energy Loss and predicted Energy Loss throughout the experimental sections of the non-prismatic compound channel has been taken into account and also shown as below.

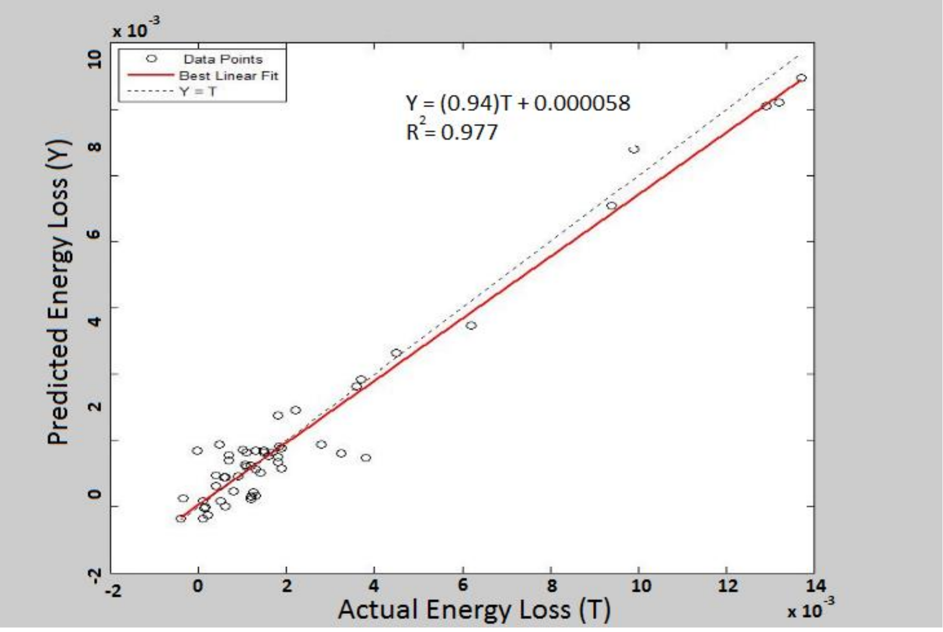


Fig.4.7 Correlation plot of actual energy loss and predicted energy loss

A regression curve is plotted between actual and predicted Energy and Energy Loss data which are shown in figures above. It can be observed that data for both cases are well fitted because a high degree of coefficient of determination R^2 of 0.993 is obtained for the Energy Calculations and R^2 of 0.977 is obtained for the Energy Loss Analysis between the sections.

The residual analysis are carried out by calculating the residuals from the actual energy loss and predicted energy loss data. The residual testing and training data are plotted against the sample number as shown in fig (4.8) and fig (4.9), which shows that the residuals are distributed evenly along the centerline of the plot. From this it can be said that the data are well trained.

As the predicted data pattern follows actual data with little or no exception ,it means the models predict the pattern of the data distribution with adequate accuracy.

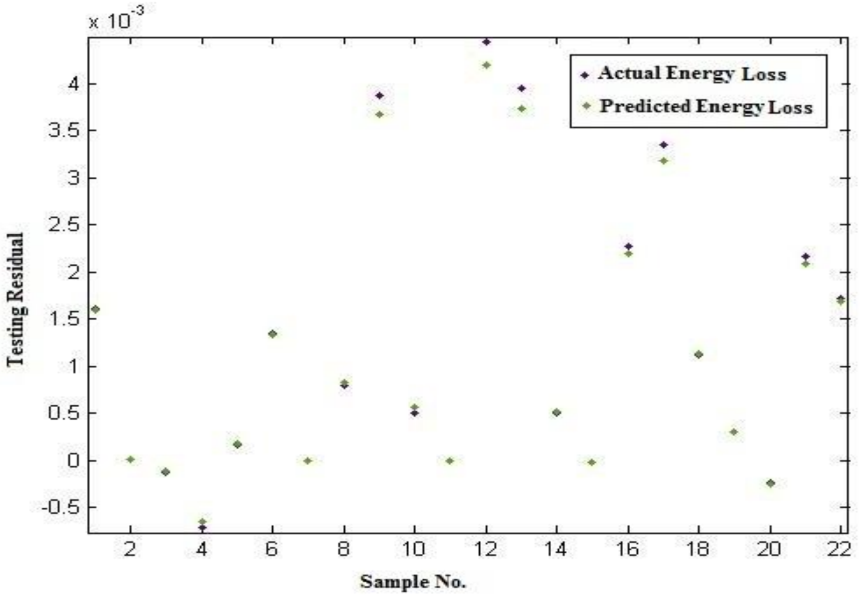


Fig.4.8 Residual distribution of training data of energy loss

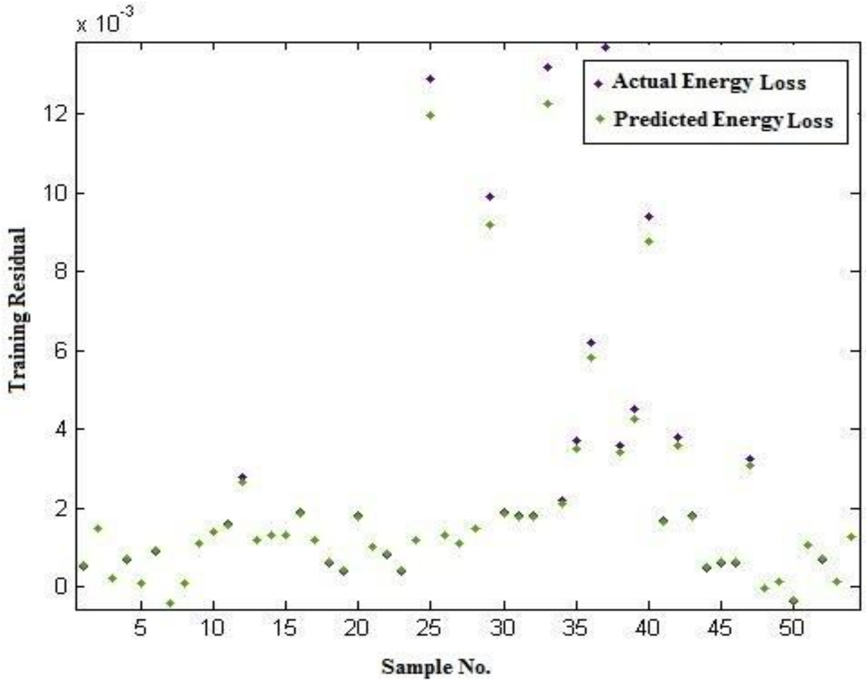


Fig.4.9 Residual distribution of testing data of energy loss

The table below shows the statistical results of the empirical equation in predicting energy and energy loss

Table.4.2 Statistical results of empirical equation in Error Calculations of Energy and Energy Loss

Error Calculations	**Energy**	**Energy loss**
MSE	0.00000045	0.00000006
RMSE	0.0006673	0.000238211
MAE	0.0004949	0.000107582
MAPE	0.3	4.49

4.4 Boundary Shear Stress Distribution Results

The total experimental data set is divided into training set and testing set. For Boundary Shear Stress Calculations 11998 data are used among which 10284 data are taken as the input data and 1714 data are taken as output data. A total of 7199 data are taken as the training data for input parameters and 3084 data are taken as the testing data for input parameters. Similarly 1120 data are taken as the training data set for the output paramters and the remaining 514 data are taken as the testing data set for the output parameters. The number of layers and neurons in the hidden layer are fixed through exhaustive experimentation when mean square error is minimized for training data set. It is observed that minimum error is obtained for 6-7-1 architecture. So the back propagation neural network (BPNN) used in this work has three layered feed forward architecture. The model was run on MATLAB commercial software dealing with trial and error procedure.

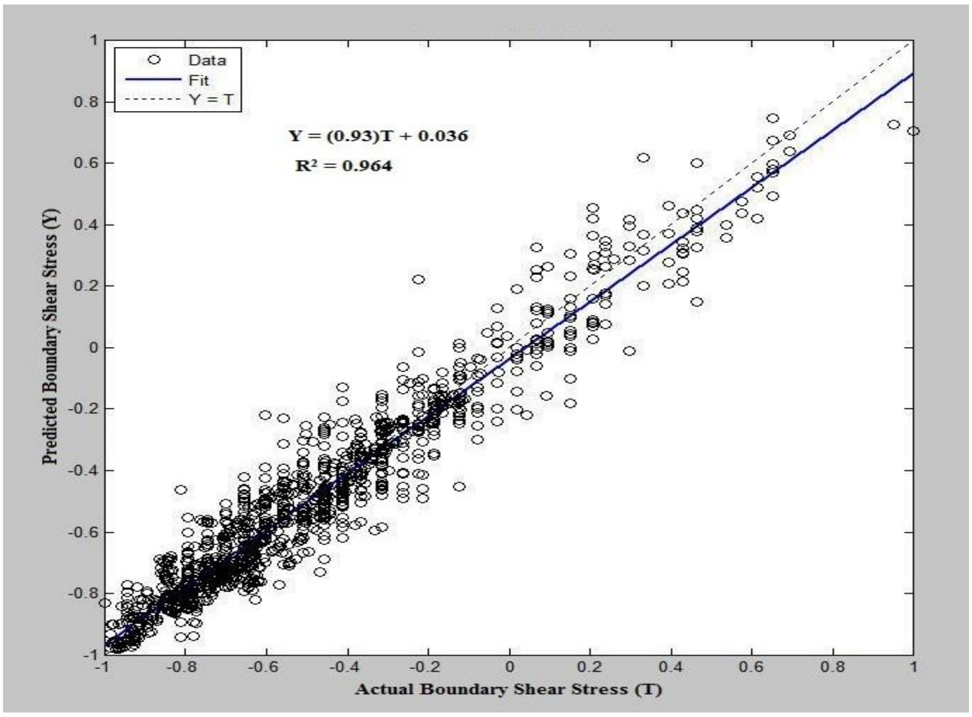


Fig.4.10 Correlation plot of actual boundary shear stress and predicted boundary shear stress Residual analysis are carried out throughout the experimental studies and the results are presented below

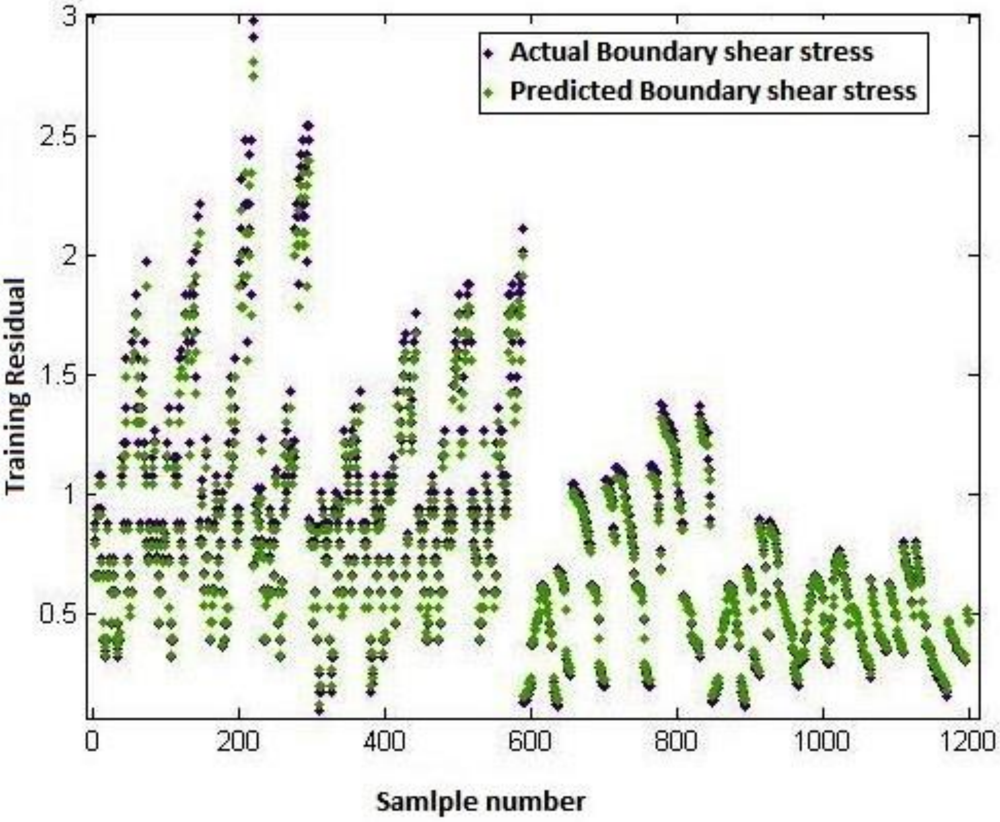


Fig 4.11 Comparison of actual and predicted boundary shear stress (training data)

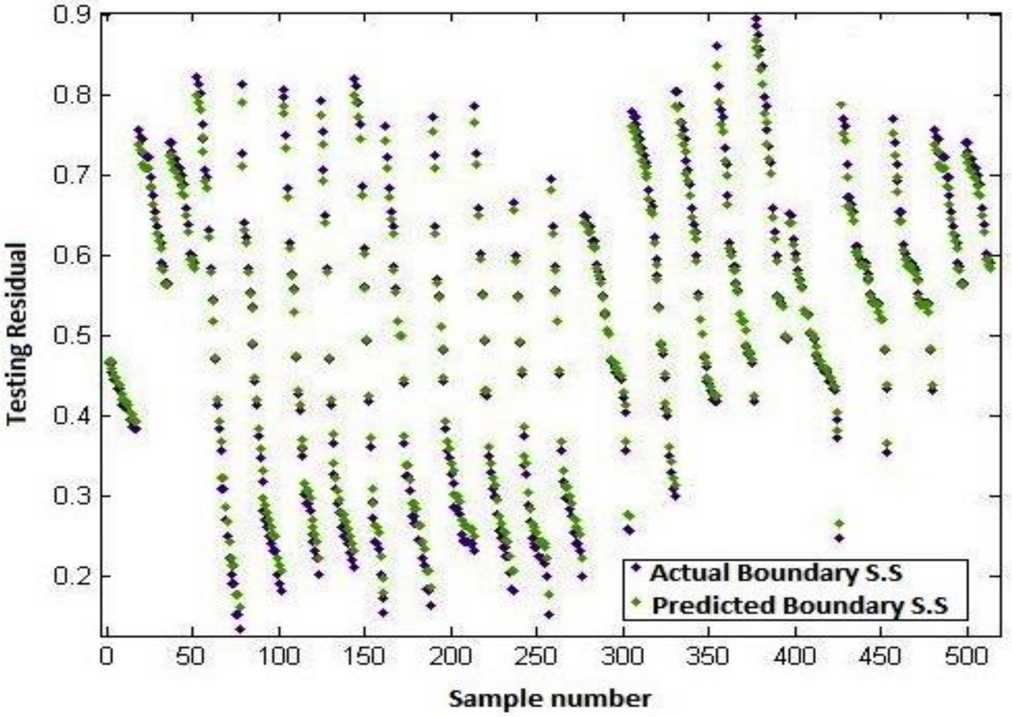


Fig.4.12 Comparison of actual and predicted boundary shear stress(testing data)

A regression curve is plotted between actual and predicted boundary shear stress which are shown in figure (4.9) and (4.10).It can be observed that data for both cases are well fitted because a high degree of coefficient of determination R^2 of 0.964 is obtained for the boundary shear stress Calculations. The residual analysis are carried out by calculating the residuals from the actual boundary shear stress and predicted boundary shear stress data. The residual testing and training data are plotted against the sample number as shown in fig (4.11) and fig (4.12), which shows that the residuals are distributed evenly along the centreline of the plot. From this it can be said that the data are well trained.

As the predicted data pattern follows actual data with little or no exception ,it means the models predict the pattern of the data distribution with adequate accuracy.

The amount of error in the present work has been calculated and analyized and presented as below

Table 4.3 Statistical Results of Empirical Equations in
Error Calculations of Boundary Shear Stress

Error Calculations	**Boundary shear stress**
MSE	0.001196
RMSE	0.034577
MAE	0.023199
MAPE	3.33

CHAPTER 5

CONCLUSIONS

SUMMARY:

The present theoretical investigation supported by experimental observation is made for Non-prismatic compound channels with floodplains having different flow aspect ratios. On thevbasis of the investigations concerning the non-prismatic reach of a compound channel to find out the Depth average velocity, Energy stored and Energy lost throughout the experimental sections and the Boundary shear stress developed throughout the experimental sections. flow, the following conclusions are drawn.

Five different types of straight compound channel configurations have been investigated Experimentally. Compound channels with non-prismatic floodplains, converging from 400mm to 0mm along 2m and 6m lengths and narrowing from 400mm to 200 mm along a 6m length.also two of the compound channels constructed in the hydraulics laboratory of National Institute of Technology Rourkela with the respective angles of 5 and 13.36 degrees. The specific objectives of the experimental research programme, have been completed successfully. In this Chapter the main conclusions of this research are presented

CONCLUSIONS:

1. Selection of depth average velocity of converging compound channels are found to depends upon a numbers of hydraulic and geometric parameters out of which aspect ratio, depth ratio, width ratio, relative distance, converging angle and relative depth are the most influencing parameters.

2. An ANN model is proposed for accurate estimation of depth average velocity of converging compound channels. The trend and pattern of experimental data matches with predicted energy loss. The basic reason of high degree of prediction accuracy lies in the fact of capability of nonlinear mapping of inputs and outputs in a Neural Network system. The nonlinear relation of geometrical and hydraulic input parameters with and depth average velocity data are difficult to establish with traditional depth average velocity data prediction methodology. In addition, the conventional techniques cannot be taken into account the real life factors operating in the system. It can be inferred that this model is more adaptive to the prediction of boundary shear stress and depth average velocity under different conditions.

3. ANN model holds for depth average velocity MSE as 0.00025, RMSE as0.015958, MAE as 0.012193 and MAPE 2.40. So the present ANN model is more convincing model.

4. From the experimental results on converging compound channels, it is seen that the energy loss between two sections at the binging is higher than that in later sections. This gradually decreases and reaches minimum just before the mid of converging section. After reaching minimum, there is a gradual increase trend is observed. This may be due to that at the entry section there is a huge loss of energy because of sudden contraction from prismatic part to

non-prismatic part. After that the flow gets a transition reducing the loss and it is believed that the transition is complete before mid-section.

5. In the lower width ratio converging experimental channels energy loss is higher at initial overbank flow depths then the loss decreases and reaches minimum at the end of non-prismatic section. This is because the present lower wide floodplain converging compound channels have a shorter reach as compared to other higher width ratio channels.

6. Selection of energy loss of converging compound channels are found to depends upon a numbers of hydraulic and geometric parameters out of which aspect ratio, depth ratio, width ratio, relative distance, converging angle and relative depth are the most influencing parameters.

7. An ANN model is proposed for accurate estimation of energy loss of converging compound channels. The trend and pattern of experimental data matches with predicted energy loss. The basic reason of high degree of prediction accuracy lies in the fact of capability of nonlinear mapping of inputs and outputs in a Neural Network system. The nonlinear relation of geometrical and hydraulic input parameters with energy loss is difficult to establish with traditional energy loss prediction methodology. In addition, the conventional techniques cannot be taken into account the real life factors operating in the system.it can be inferred that this model is more adaptive to the prediction of energy loss under different conditions.

8. ANN model holds the energy loss prediction with minimal error i.e.MSE as 0.00000006 RMSE as0.000238211 MAE as0.000107582 and MAPE 4.49 which less than 10%.. Similarly for energy MSE as 0.00000045 RMSE as0.0006673 MAE as 0.0004949 and

MAPE 0.3. So the present ANN model is more convincing model.

9. Selection of boundary shear stress of converging compound channels are found to depends upon a numbers of hydraulic and geometric parameters out of which aspect ratio, depth ratio, width ratio, relative distance, converging angle and relative depth are the most influencing parameters.

10. An ANN model is proposed for accurate estimation of boundary shear stress of converging compound channels. The trend and pattern of experimental data matches with predicted energy loss. The basic reason of high degree of prediction accuracy lies in the fact of capability of nonlinear mapping of inputs and outputs in a Neural Network system. The nonlinear relation of geometrical and hydraulic input parameters with boundary shear stress data are difficult to establish with traditional boundary shear stress data prediction methodology. In addition, the conventional techniques cannot be taken into account the real life factors operating in the system. It can be inferred that this model is more adaptive to the prediction of boundary shear stress under different conditions.

11. ANN model holds the boundary shear stress prediction with minimal error i.e.MSE as 0.001196 RMSE as0.034577 MAE as0.023199 and MAPE 3.33which less than 10%.

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