Prediction of Flow in Compound Open Channel Flows Using Artificial Neural Network

A Project Submitted
In Partial Fulfillment of the Requirements
For the Degree of

Bachelor of Technology
In
Civil Engineering

By

PARAMESWAR PANDA
Roll NO:10601023

DEPARTMENT OF CIVIL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

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Prof. K.K Khatua

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NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA
CERTIFICATE

This is to certify that the project entitled "**Prediction of Flow in Compound Open Channel Flows Using Artificial Neural Network"** submitted by Parameswar Panda [Roll no. 10601023] in partial fulfillment of the requirements for the award of Bachelor of Technology degree in Civil engineering at the National Institute of Technology Rourkela is an authentic work carried out by them under my supervision and guidance.

To the best of my knowledge the matter embodied in the project has not been submitted to any other university/institute for the award of any degree or diploma.

Date: 12.05.10

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Date: **Parameswar Panda**

Abstract

Accurate prediction of discharge in compound open channel is extremely essential for river engineering point of view. As this provide essential information regarding flood mitigation, construction of hydraulic structures and for prediction of sediment load. Most natural Rivers and streams consist of two stage channel i.e. main channel and flood plains. Earlier discharge determination model are studied to develop the models. Methods like COHM,SCM, DCM, and other models which is widely used. Here an effort has been made to predict the total discharge in compound channel with the comparison of above models with ANN based FFBP model. The model provides slightly better results then COHM, DCM but provides more accepted results then SCM.

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CHAPTER 1

INTRODUCTION

1. Introduction

Floods occurs when main channel inundates and severe discharge follow the flood plains which invades main channel, such channels are Compound channels which consist of different compartments: typically a main channel surrounded by floodplains two-stage channel, see Fig. 1.

Many practical problems in river engineering require accurate flow predictions in compound channels. For example, the hydraulic response to flood prevention measures, such as dredging the main channel and lowering or smoothing floodplains, depends on the flow velocities in these compartments. Likewise, local flow conditions determine the erosion and deposition rates of sediment in the main channel and floodplains.

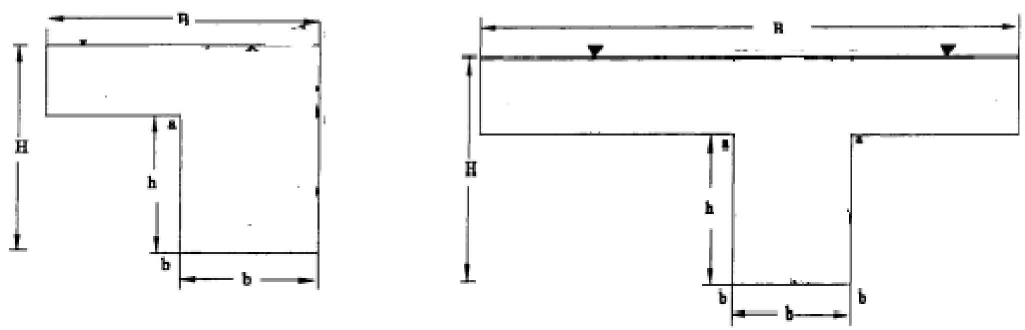


Fig.1: Cross section of a two-stage channel: (a) asymmetric with two identical floodplains N_{fp}=1 ;(b) symmetric with one floodplain N_{fp}=2.

H=Total Flow Depth

h=height of main channel

b=width of main channel

B=With of floodplains

1.1Objective and Scope of the Present Study:

A comparative study of flow in compound straight channel is done by comparing different approaches carried out by various researchers across the globe with experimental setup done in Fluid Mechanics lab of NIT Rourkela by (Khatua.K.K ,2008) and data obtained from FCF-Berhimngham data series, Experimental work done by (Soong W.T. and DePue II M.P.,1996) at UIUC, Tang's rigid and mobile channel data(Tang, 2001), Atabay's data(Atabay,2001) and with ANN based prediction .

CHAPTER 2

LITERATURE REVIEW

2. LITERATURE REVIEW

Sellin (1964) and Van Prooijen (2004) investigated mixing patterns and secondary currents in compound open channel due to the difference in flow velocity between the main channel and the floodplain.These processes, observed in experimental studies are responsible for the lateral momentum transfer that generally slows down the flow in the main channel, while accelerating the flow in the floodplain. The lateral momentum transfer has been ignored when estimating the flow velocities in compound channels. Chow (1959) investigated Divided channel method DCM, by A force balance between gravity and bed friction leads to a cross sectional averaged flow velocity for each of main channel & floodplains (U_{mc} in the main channel and U_{fp} in the floodplains as stated by Chow (1959)). Such a compartment-averaged approach has the advantages of requiring little input like geometry, surface slope, bed roughness and their being straightforward to calculate, while recognizing the different properties of the compartments .Weber and Menéndez(2004) developed a model which overestimates U_{mc} and underestimates U_{fp}, due to neglect of lateral momentum transfer, that led to three different alternative approaches .Stephenson and Kolovopoulos (1990), Lambert and Myers (1998), Patra and Kar (2000) didn't consider the lateral momentum transfer, in particular to the interfaces. velocity difference between main channel and floodplain (U_{mc}–U_{fp}) and the channel dimensions introduced an interface stress interface between adjacent compartments as studied by Wormleaton et al. (1982), Prinos and Townsend (1984); Christodoulou (1992). The resulting averaged flow velocities are determined from a rather complicated set of analytical equations Bousmar and Zech (1999).Atabay & knight (2002) proposed some stage discharge relationship for symmetric compound channel section using their experimental work in FCF .According to their experimentation and analysis derived a simple empirical relation between stage and total discharge and stage in zonal discharge for uniform roughness and varying floodplains and width ratios .They also examined broad effect on stage discharge relationship due to floodplains width ratio.Ozbek et. al.(2003) used experimental result from FCF for computing apparent shear stress and discharge in symmetrical compound channels varying floodplain widths.They used VDM,DCM,HDM methods to compute apparent shear stress across the interfaces.They evaluated discharge value for each subsection and whole cross section .According to their results DCM and HDM provides better result than VDM.

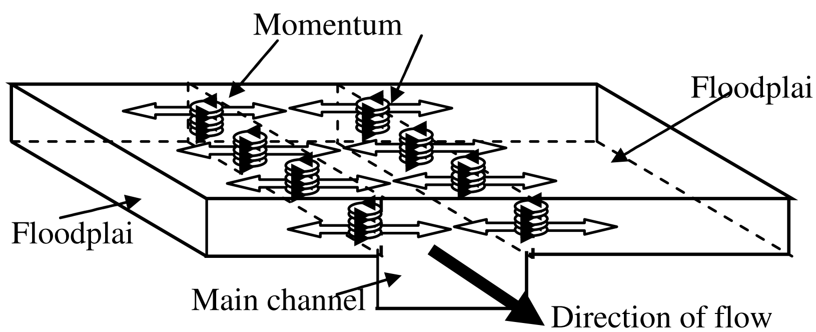


Fig.2 Schematic view of momentum transfer between main channel and floodplain for a two stage compound channel section

2.1METHODS FOR DETERMINATION OF DISCHARGE

2.1 SINGLE CHANNEL METHOD:-

Unfortunately the discharge calculation for compound channel is based mainly on refined one dimensional methods of analysis. If a compound channel is considered as single entity (Chow, 1958), the carrying capacity is underestimated because the single channel method suffers from a sudden reduction in hydraulic radius at just above bank full, that produces spurious discharge assessment when using the conventional Mannings, Chezy's or Darcy-Weischbach equation. While the more usual method of dividing the channel into deep section and floodplain is used, the resulting discharge is the overestimation of the actual capacity. The conventional Mannings, Chezy's or Darcy-Weischbach are well known examples of this approach, usually expressed as:

$$Q= \frac{1}{N} AR^{2/3} S^{1/2} \qquad (1)$$

$$Q = CA\sqrt{RS} \qquad (2)$$

$$Q = \left(\frac{8g}{f}\right)^{\frac{1}{2}} A\sqrt{RS} \qquad (3)$$

2.2 DIVIDED CHANNEL METHOD:-

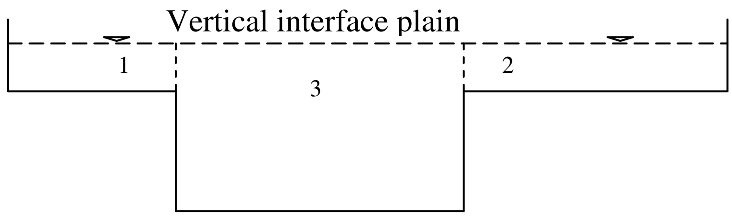
The usual practice of calculating discharge in a compound channel is the use of 'divided sections' method. Assumed vertical, horizontal or diagonal interface planes running from the main channel-floodplain junctions are used to divide the compound section into subsections, the discharge for each subsection is calculated using Manning's or Chezy's equation and added up to give the total discharge carried by the compound section. Generally Manning's formula are used for discharge calculation in compound channels and written as.

$$Q = \sqrt{S}\left(\frac{1}{n_{mc}} A_{mc}^{53} P_{mc}^{-23} + \frac{1}{n_{fp}} A_{fp}^{53} P_{fp}^{-23}\right) \qquad (4)$$

The methods fall into 5 categories and are briefly described as follows:-

2.3 Vertical division methods(VD):-

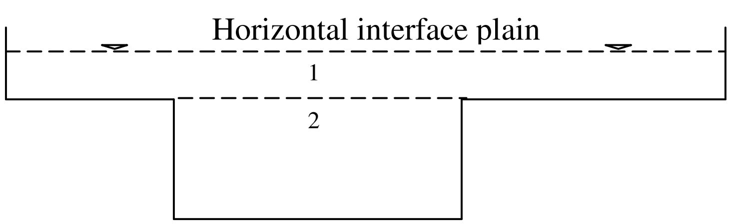
There are several vertical division methods which are based on altering the wetted perimeter of the sub area to account for the effect of interaction. Typically the vertical division lines between the main channel and the flood plain is included in the wetted perimeter for the discharge calculation in the main channel flow, but is excluded in the wetted perimeter for the discharge calculation of flood plain flow .This is intended to have the effect of retarding the flow in main channel and enhancing it in the flood plain. How ever simply altering the wetted perimeter by the vertical line does not completely reflects the interaction effect is not a simple function (Knight & Demetriou,1983;Knight & Schino,1990).It is found that this approach generally over predicts



flow rate(Wormleaton &Merrett,1990) and conceptually it is flawed since it applies an imbalance of shear forces at the interface. In general vertical interface methods overestimate discharge in main channel.

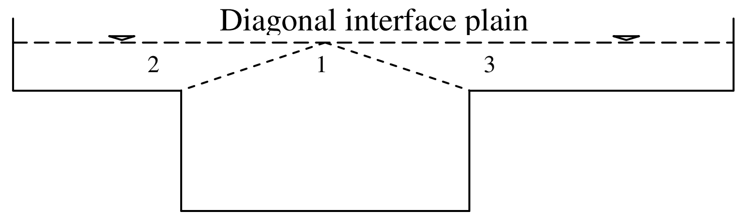
2.4 Horizontal Division methods(HD):-

Toebes and Sooky (1967) carried out laboratory experiments on two composite channel sections and showed that a nearly horizontal fluid boundary located at the junction between the main channel and floodplain would be more realistic than a vertical fluid boundary along the banks of the meandering channel in dividing the compound channel for discharge calculation



2.5 Diagonal Division methods(DD):-

In this method it is assumed that there is zero –shear stress line, which commences from the junction of main channel and flood plain and is inclined towards center of the main channel water surface, separating the main channel from its flood plains (Fig.). The total discharge is than obtained through summing up the discharges in each of the three individual zones .The idea of drawing division line having zero shear stress is logically acceptable , but the main difficulty is in finding the position of the division lines for all shapes of channels and flow depths, due to the three dimensional nature of the velocity fields .



Experimental results demonstrates that the shear stress s on the diagonal division lines are negligible, except for small relative flood plain depths (Wormleaton et al.1982;Knight &Hamed,1984) which are commonly experienced when a river just goes overbank.

2.6 The Coherence method (COHM):

The coherence method (COHM) of Ackers (1991, 1992b & 1993a&b) is now well established as one of the best 1-D approaches for dealing with overbank flow and the related problems of heterogeneous roughness and shape effects. The 'coherence', **COH,** is defined as the ratio of the basic conveyance, calculated by treating the channel as a single unit with perimeter weighting of the friction factor, to that calculated by summing the basic conveyances of the separate zones. Thus

$$COH = \frac{\sum Ai\sqrt{\sum Ai / \sum (fiPi)}}{\sum \left[Ai\sqrt{Ai/(fiPi)} \right]} \qquad (5)$$

where *i* identifies each of the *n* flow zones, and A is the sub-area, P the wetted perimeter and f the Darcy-Weisbach friction factor. The closer to unity the COH approaches, the more appropriate it is to treat the channel as a single unit, using the overall geometry. The extreme cases COH may be as low as 0.5. Where the coherence is much less than unity then discharge adjustment factors are required in order to correct the individual discharges in each sub-area. Experimental studies of overbank flow in the FCF (Ackers, 1993a) suggest that different discharge adjustment factors (DISADF) are required in at least four distinct regions of depth, The experimental evidence shows (Ackers, 1993b) that

COH<DISADE<1.0 i.e. $\frac{Q_{\sin gle}}{Q_{zones}} \leq \frac{Q_{actual}}{Q_{zones}} \leq 1$ (6)

This implies that when overbank flow occurs, for a given stage or depth the actual discharge is always less than the basic value calculated on the basis of summing the discharge in different zones, but greater than the value based on treating the channel as a single unit, i.e.

$$Q_{single} \leq Q_{actual} \leq Q_{zones} \quad (7)$$

It also means that for a given discharge the actual stage is higher than that predicted by zonal summation but lower than that predicted on the basis of treating the channel as single unit.The conveyance or discharge capacity of a channel, Q, is related to the energy slope by the geometric and roughness parameters defined the conveyance, K, as

$$Q = KSf^{1/2} \quad (8)$$

Ackers (1993a) introduced a modified conveyance parameter, K_D, in order to make it more suitable for use in overbank flow analysis, defined K_D as

$$K_D = Q\Big/\sqrt{8gS_f} = A\sqrt{\{A/(fP\}} \quad (9)$$

Thus for a typical compound channel that is divided into three sub-areas, the main river channel and two symmetric floodplains, then the basic conveyance, *K*DB, (before allowing for any interaction effects) is given by the sum of the individual conveyances for each sub-area as

$$K_{DB} = A_c\sqrt{\{A_c/(f_c P_c\}} + 2A_f\sqrt{\{A_F/(f_F P_F\}} \quad (10)$$

where the subscripts 'C' and 'F' refer to main channel and floodplain respectively. The actual discharge is then obtained from Eq. (11), by multiplying the basic conveyance by a 'discharge adjustment factor', DISADF, to give the correct discharge, allowing for any interaction effects. Thus

$$K_D = DISADFK_{DB} \quad (11)$$

As numerical values of COH are generally less than one, and typically the discharge calculated by assuming a single channel is less than the discharge calculated by summing the zonal values. The actual discharge is usually somewhere between these two values, as shown elsewhere by Knight (1997). Vertical division lines should be used between zones, or sub-areas, and not used in the wetted perimeters for any of the zones. The 'basic' zonal discharges are calculated from standard resistance equations, i.e. Eqs (6) & (7) and added together to obtain the 'basic' discharge, which is then adjusted to account for the effects of the interaction between the main channel and the floodplain flows. The adjustment required depends on the characteristics of the channel and also varies with stage. Ackers (1992b) provided a different adjustment function for each of the four regions of depth, and a logical procedure for selecting the correct value from those calculated assuming each adjustment factor in turn. He also provided additional corrections to account for the effect of deviations of up to 10^0 between alignment of the main channel and the floodplains, and a procedure for dividing the computed total discharge at any stage into main channel and floodplain components, based on experiments by Elliot & Sellin (1990). Ackers (1992a) also suggested that the square of the discharge adjustment factor could be used to give the mean boundary shear stress in each sub-area.

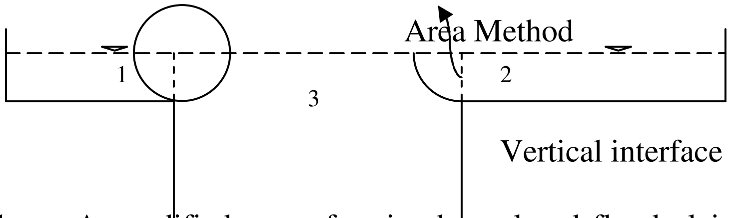
Although the coherence method was based originally on laboratory data from the FCF, it has been applied successfully to a number of natural rivers. Ackers (1993a) shows the stage discharge relationship for the River Severn at Montford Bridge, predicted with nc = 0.0307 and nf = 0.0338. The four regions of flow found to be present in the FCF laboratory data appear to be present also in natural rivers, although field measurements are scarce, particularly for floodplains with large depths of submergence. More field data and analysis are required. The COHM is more difficult to apply when the roughness of the main channel river bed varies with discharge, as is the case in sand bed rivers.

2.7 Z method (Zero shear methods):-

It has a theoretical basis. Holden(1986) developed a method of accounting for shear stress that assumed an arbitrary position in the interface as in figure .In this method a zero shear stress is assumed to act on an interface between main channel and flood plain with arbitrary position .The flow area for each part of channel are then adjusted (Stephenson &Kolovopoulos,1990)

$$A_{cc}=A_c-2(\Delta A) \quad (12)$$

$$A_{ff}=A_c+2(\Delta A) \quad (13)$$



Where A=modified area of main channel and flood plain respectively and the correction area ΔA can be obtained from the equilibrium of the forces acting on the flood plain , where a vertical interface divides the main channel from flood plain ,given by

$$\sum F_f - \tau_v d = \rho g A_f S \quad (14)$$

$\sum F_f$ is shear force on wetted perimeter of main channel per unit stream wise length and τ_v is the apparent shear stress on vertical interface. d=depth of flow over flood plain If the arbitrary interface with zero shear stress is used

$$\sum F_f = \rho g (A_f + \Delta A) S \quad (15)$$

From (1).and (2). $\Delta A = (\tau_v / \rho g S) d$ (16)

$\tau_v$is given by Prinos-Townsend empirical Formula(1984)

$$\tau_v = 0.874 (\Delta A)^{0.982} (d/H)^{-1.129} (W_f/W_c)^{-0.514} \quad (17)$$

W_f and W_c are the widths of flood plain and main channel respectively and ΔV is the difference of velocity between main channel from flood plain

It should be noted that this method is only valid with the range of empirical results employed and is not generally applicable.

2.8 Exchange discharge method (EDM):

Each subsection of a compound channel can be considered as a single channel submitted to a lateral flow per unit length ql. The conservation of mass may be written

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial X} = q_1 = q_{in} - q_{out} \qquad (18)$$

Where q_{in}, inflow discharge and q_{out}, outflow discharge.

The momentum equation for a unit length also accounts for the lateral flow.

$$\frac{\partial}{\partial t}(\rho AU) = -\frac{\partial}{\partial x}(\rho AU^{2)} + \rho q_{in}u_1 - \rho q_{out}U + \rho gA(S_0 - S_f) - \rho gA\frac{\partial H}{\partial x} \qquad (19)$$

where q, density of water; g, gravity constant; U ¼ Q=AU, depth averaged velocity; H, water depth; and ul, velocity of the lateral inflow in the direction of the main flow. It is noticeable that inflow and outflow convey different momentum since their initial velocities are not the same .

$$S_e = -\frac{\partial}{\partial x}(z + \frac{U}{2g}^{2}) = S_f + \frac{q_{in,r}(U - u_{t,r}) + q_{in,i}(U - u_{i,i})}{gA} = S_f + S_a$$

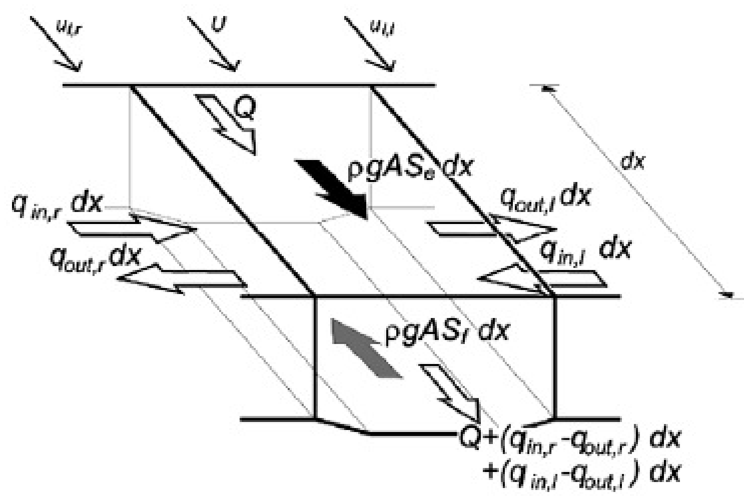


Fig4 :Momentum equilibrium for a compound channel subsection

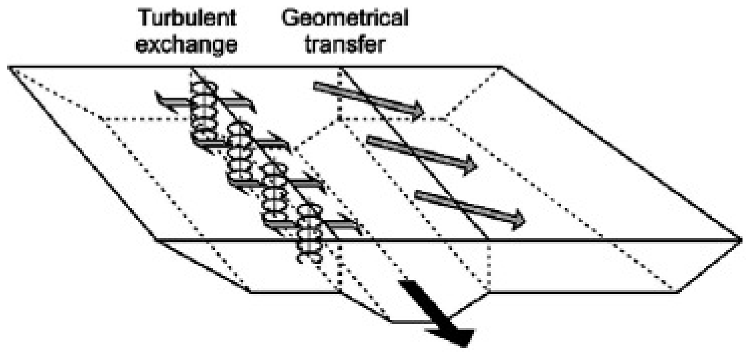


Fig5 : Flow exchange at interfaces between main channel and floodplains.

where the lateral flow has been divided into right-side r and leftside l inflow; Se, total head loss per unit length; and Sa, additional loss due to lateral inflow, i.e. momentum transfer effect. The lateral flows represent turbulent exchange and geometrical transfer. The turbulent exchange discharge, qt, is the mass of fluid which oscillates between main channel and floodplain, due to the large vortical structures that develop in the shear layer at the interface, and may be modelled using a mixing length.

It is proportional to the velocity difference between subsections (Uc - Uf) and to the interface area per unit length (H -hf), where c and f stands for main channel and floodplain, respectively; and hf is the bank level:

$$q_{cf}{}^{t} = q^{t}_{fc} = \psi^{t}\left|U_c - U_f\right|(H - h_f) \tag{20}$$

where Wt (=0.16) proportionality factor. Because turbulent exchange is an oscillating discharge, the lateral inflows, qt ,cf , from main channel to floodplain and the dual inflow, qt fc , are equal. Accordingly, the turbulent exchange does not affect the conservation of mass of the above equation but has a significant effect on the momentum balance.

The geometrical transfer, qg, corresponds to the floodplain conveyance variation due to a non-prismatic geometry or to a gradually varied flow in a prismatic geometry.

$$q^{g}_{fc} = \psi^{g} K_{fc} \frac{dK_f}{dx} S_{ff}^{1/2}; \tag{21}$$

$$q^{g}_{cf} = \psi^{g} K_{cf} \frac{dK_f}{dx} S_{ff}^{1/2} \tag{22}$$

Using the momentum equation of the above equation to correct the friction in the 1st equation and assuming that the head loss Se is the same in all subsections, the subsection discharge is given by

$$Q = \frac{A_i R_i^{2/3}}{n_i} S_f^{1/2} = K_i S_f^{1/2} = K\left(\frac{S_e}{1+\chi_i}\right)^{1/2} \tag{23}$$

$$\chi_1 = \frac{1}{gA_1}\left[\psi^t (H-h_1)\left(\frac{R_2^{2/3}}{n_2}\left(\frac{1+\chi_1}{1+\chi_2}\right)^{1/2} - \frac{R_1^{2/3}}{n_1}\right) + \psi^g K_{21}\frac{dK_1}{dx}\right]$$
$$\times\left[\frac{R_1^{2/3}}{n_1} - \frac{R_2^{2/3}}{n_2}\left(\frac{1+\chi_1}{1+\chi_2}\right)^{1/2}\right] \tag{24}$$

$$\chi_2 = \frac{1}{gA_2}\left[\psi^t (H-h_1)\left(\frac{R_2^{2/3}}{n_2}\left(\frac{1+\chi_1}{1+\chi_2}\right)^{1/2} - \frac{R_1^{2/3}}{n_1}\right) + \psi^g K_{12}\frac{dK_1}{dx}\right] \times$$

$$\left[\frac{R_2^{2/3}}{n_2}\left(\frac{1+\chi_1}{1+\chi_2}\right)^{1/2} - \frac{R_1^{2/3}}{n_1}\right]\left(\frac{1+\chi_1}{1+\chi_2}\right) +$$
$$\left[\psi^t (H-h_3)\left(\frac{R_2^{2/3}}{n_2}\left(\frac{1+\chi_3}{1+\chi_2}\right)^{1/2} - \frac{R_3^{2/3}}{n_3}\right) + \psi^g K_{32}\frac{dK_3}{dx}\right]\times\left[\frac{R_2^{2/3}}{n_2}\left(\frac{1+\chi_3}{1+\chi_2}\right)^{1/2} - \frac{R_3^{2/3}}{n_3}\right]\left(\frac{1+\chi_3}{1+\chi_2}\right)$$

$$\chi_3 = \frac{1}{gA_3}\left[\psi^t (H-h_3)\left(\frac{R_2^{2/3}}{n_2}\left(\frac{1+\chi_1}{1+\chi_2}\right)^{1/2} - \frac{R_1^{2/3}}{n_3}\right) + \psi^g K_{23}\frac{dK_3}{dx}\right]\times$$

$$\left[\frac{R_3^{2/3}}{n_3} - \frac{R_2^{2/3}}{n_2}\left(\frac{1+\chi_3}{1+\chi_2}\right)^{1/2}\right] \tag{25}$$

where subscript 2 stands for the main channel; subscripts 1 and 3 stands for the floodplains; and h_1 and h_3, main-channel bank level on floodplain 1 and 3 side, respectively.

The system of equations defines the values of the ratios in an implicit form, and as a function only of water depth, geometry and roughness. An analytical solution of for straight symmetrical uniform flow is given by Bousmar (1999) and Zech(1999) proposed a numerical solution procedure for the general case. When developing these solutions, it was assumed that the main channel velocity was larger than the floodplain velocity. This hypothesis enabled the absolute values to be replaced by the difference in brackets without any sign change. Solving Equations implied the extraction of the roots of quadratic equations. The hypothesis on the velocity gradient enabled one again to select the appropriate root. The tests for selecting the appropriate roots when developing the solutions also change.

2.9Two-Dimensional Method:

2.9.1Shiono–Knight method (SKM):

Shiono and Knight presented an analytical solution to the Navier–Stokes equation to predict the lateral variation of depthaveraged velocity in compound channels. The Navier–Stokes equation may be written in the following form for a fluid element in steady uniform flow in which there are both bed generated shear and lateral shear:

$$\rho\left[\upsilon\frac{\partial u}{\partial x}+w\frac{\partial w}{\partial z}\right]=\rho g\sin\theta+\frac{\partial\tau_{yx}}{\partial y}+\frac{\partial\tau_{zx}}{\partial z} \tag{26}$$

(i.e., Secondary flows = weight force + Reynolds stresses (lateral + vertical), where u, v and w are the local velocities in the x (streamwise), y (lateral) and z (vertical) directions respectively; S_0 =sin h, is the bed slope; τ_{yx} and τ_{zx} are the Reynolds stresses on planes perpendicular to the y and z directions respectively; q is the water density; and g is the gravitational acceleration.) Shiono and Knight obtained the depth-averaged velocity equation by integrating Equations over the water depth H based on the eddy viscosity approach and, by ignoring the secondary flow contribution, arrived at

$$\rho g H S_0-\frac{1}{8}\rho f U_d^2\left(1+\frac{1}{s^2}\right)^{1/2}+\frac{\partial}{\partial y}\left[\rho\lambda H^2\left(\frac{f}{8}\right)^{1/2}U_d\frac{\partial U_d}{\partial y}\right]=0 \tag{28}$$

where Ud is the depth-averaged mean velocity; k is the dimensionless eddy viscosity; f is the Darcy–Weisbach friction factor and s is the main channel lateral side slope. Shiono and

Knight solved the above equation analytically and obtained the following equation for the case of H = constant in the form:

$$U_d = \left[A_1 e^{yy} + A_2 e^{-yy} + \frac{8 g S_0 H}{f} \right]^{1/2} \tag{29}$$

and for linearly varying depth as

$$U_d = \left[A_3 Y^{\alpha_1} + A_4 Y^{-\alpha_2} + wY \right]^{1/2} \tag{30}$$

where A_1, A_2, A_3 and A_4 are unknown constants; and γ, α_1, α_2 and ε are the ancillary terms of the equations and are given elsewhere by Shiono and Knight. These equation is only valid when secondary flows are not considered. However, secondary flows are important in many cases. In such a case, the right-hand side of above equation is not zero and then above equation will be;

$$\rho g H S_0 - \frac{1}{8} \rho f U_d^2 \left(1 + \frac{1}{s^2} \right)^{1/2} + \frac{\partial}{\partial y} \left[\rho \lambda H^2 \left(\frac{f}{8} \right)^{1/2} U_d \frac{\partial U_d}{\partial y} \right] = \frac{\partial}{\partial y} \left[H (\rho U V)_d \right] = \gamma \tag{31}$$

Shiono and Knight used the approximation in the right hand side of the above equation to solve it analytically. The Shiono–Knight method (SKM) was originally developed for straight and nearly straight channels. Attempts have been undertaken to use the SKM in modeling non-prismatic and meandering channels.

CHAPTER 3

ARTIFICIAL NEURAL NETWORK

3.1 Working Of Artificial Neural Network:

The ANNs have been widely used in modeling hydrological processes. For some hydraulics problems Minns, Babovic , and Ervine and Macleod have obtained encouraging results using ANN. Cobaner et al. have applied the ANN method successfully to the assessment of backwater through bridge waterways. In the current work, we have developed an ANN algorithm to predict discharge capacity of compound channels observed at 190 comprehensive laboratory data of various experiments done by re-knowned researchers across the including ingenious laboratory experiment done in the NIT Raourkela FM/Hydraulics LAB.

3.2 Design of the ANN Model:

The basic steps involved in designing the network are Collection/generation of input/output dataset; Preprocessing of data (normalization and partitioning of dataset); Design of the neural network objects; Training and testing of the neural network; simulation and prediction with new input data sets; and Analysis & post-processing of predicted result.

3.3 Pre-processing of Data:

Prior to the training of the network, the input/output dataset was normalized usuing simple formula of mathematics. The dataset was scaled to range between 0 and 1. The normalized input/output dataset was then partitioned into two subsets consisting training dataset, 75% (190data), and the test dataset, 25% (40data).

The data normalization is done with the formula given below:

$$n_{data} = \frac{X_i - X_{\min}}{X_{\max} - X_{\min}} \quad (32)$$

Where X_i = datas in a column, X_{max}=maximum data in the column, X_{min} = minimum data value in the column.

3.4 Design of the Network Object:

The networks consisted of three layers: input layer; hidden layer; and output layer. There were five input parameters into the network: the two roughness coefficients namely, floodplain (f_{fp}) and main channel (f_{mc}), the flow area (A), the hydraulic radius (R), the channel slope (S_0) ,discharge through the main channel (Q_{mc}) ,discharge through the flood plain(Q_{fp}),Reynold's no for the main channel (Re_{mc}),Reynold's no for the floodplains (Re_{fp}) and one output parameter i.e. total discharge. Different networks with single or double hidden layer topologies were used. The schematic of typical network architecture is depicted in figure.

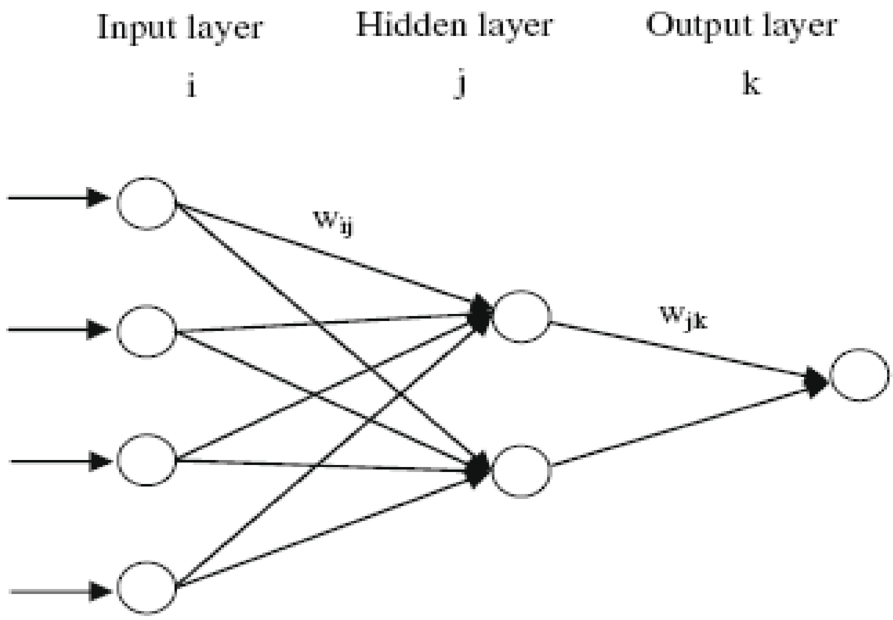


Fig.6 : A typical design of a general feed forward back propagation neural network used for prediction of total discharge in compound channel.

3.4.1 Training of the Neural Network:

The network was trained by feeding in some teaching patterns (training dataset) and letting it change its weights according to some learning rule. Levenberg-Marquardt backpropagation training algorithms is used ' in training the different networks:, The neurons with tan sigmoid transfer function '*tansig*' were used in the hidden layer(s), while neurons with linear transfer function '*purelin*' were used in the output layer. The '*purelin*' transfer function was used so that the output would not be limited like the '*tansig*' function which generates output between 0 and +1. If linear output neurons were used, the output can take on any value.

3.4.2 Testing of the ANN Model:

The training was terminated when the threshold of RMSE = 0.001 or when the number of iterations is equal to 1000. The test dataset, 25% (190 data) was used to test the validity of the proposed model. The Root mean square error (RMSE), and mean absolute Root error (MARE), and correlation coefficient (*R*-value) between the network predicted outputs and the desired outputs were used as the performance parameters to determine the network structure with optimal predictive capability.

3.5 Feed Forward Back Propagation (FFBP):

Models based on the principle of ANN have been considered an alternate to physically-based models due to their simplicity. ANN models are specified by the net topology, node characteristics, training and learning rules. Of the many ANN paradigms, the feed-forward network (FFN) is by far the most popular. The network consists of layers of parallel processing elements, called neurons, with each layer being fully connected to the proceeding layer by interconnection fully connected to the proceeding layer by interconnection strengths, or weights. Figure 6 illustrates a three-layer neural network consisting of layers i, j, and k, with the interconnection weights W_{ij} and W_{jk} between layers of neurons. At the beginning of training, the weights are initialized, either with set of random values or based on some previous experience. Next, weights are systematically changed by the learning algorithm. The FFBP was trained using Levenberg–Marquardt technique here due to that this technique is more powerful and faster than the conventional gradient descent technique. Basically three steps can be used for selecting a suitable architecture for a required problem.

1. Fixing the architecture;
2. Training the network; and
3. Testing the network.

CHAPTER 4

RESULTS

4.1 Results:

In this study, an ANN approach versus other physically-based models is devised to estimate the discharge value of the compound channels. For this purpose, three hidden-layered feed-forward back propagation neural network model was used. The data used in developing this ANN model were obtained from the comprehensive stage–discharge model studies performed as mentioned in Section 2. These data were randomly divided into two independent parts. The first data set (167 data) was used for model training, and the second data set (72 data) was used for model verification. The problem is adapted to the model by means of five input parameters representing the two roughness coefficients namely, floodplain (f_{fp}) and main channel (f_{mc}), the flow area (A), the hydraulic radius (R), the channel slope (S_0) ,discharge through the main channel (Q_{mc}) ,discharge through the flood plain(Q_{fp}),Reynold's no for the main channel (Re_{mc}),Reynold's no for the floodplains (Re_{fp}) and one output parameter, which is the discharge of the compound channels (Q).

A difficult task with ANNs involves choosing parameters such as the number of hidden nodes, the learning rate, and the initial weights. The optimum network geometry is obtained utilizing a trial-and-error approach in which ANNs are trained with one hidden layer. It should be noted that one hidden layer could approximate any continuous function, provided that sufficient connection weights are used. The hidden layer node numbers of model was determined after trying various network structures since there is no theory yet to tell how many hidden units are needed to approximate any given function. In the training stage, the adaptive learning rates and the same initial weights were used for each ANN networks as used by Kisi. The tangent sigmoid, logarithmic sigmoid and pure linear transfer functions were tried as activation functions for hidden and output layer neurons to determine the best network model. The appropriate number of hidden nodes is set to 10 in terms of trial and error using the logarithmic sigmoid and linear activation functions for the hidden and output layer neurons, respectively.

The root mean square error (RMSE), mean absolute relative error (MARE) and determination coefficient (R^2) values of these equations for both testing phases are given in Table . The RMSE and MARE shown in Table are defined as follows:

$$RMSE = \sqrt{1/N(\sum_{i=1}^{N}\left[Q_{measured} - Q_{predicted}\right]^2}$$

$$MARE = 1/N\sum_{i=1}^{N}\left|\frac{Q_{measured} - Q_{predicted}}{Q_{measured}}\right| \times 100$$

Where n is the number of datas.

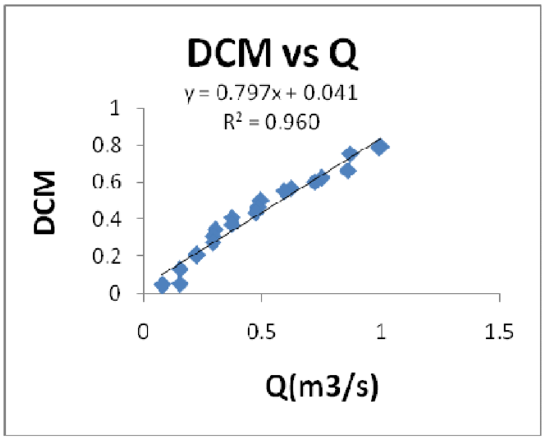


Fig.6(a) : Figure showing comparison between DCM &Actual Discharge(Q)

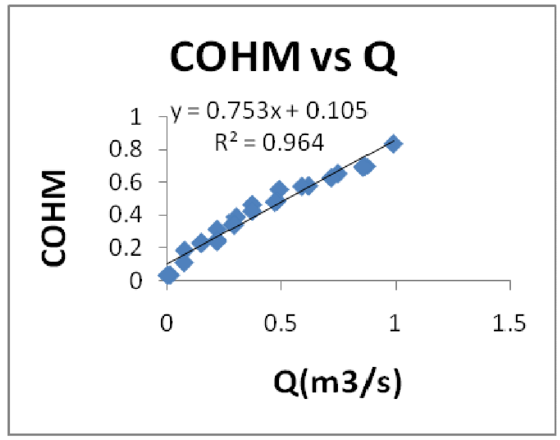


Fig 6(b): Figure showing comparison between COHM &Actual Discharge(Q)

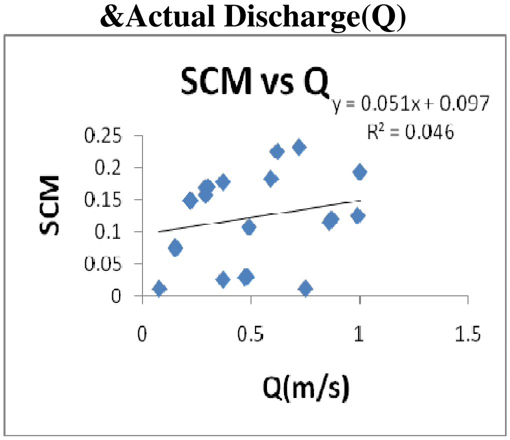


Fig7(a): Figure showing comparison between SCM &Actual Discharge(Q)

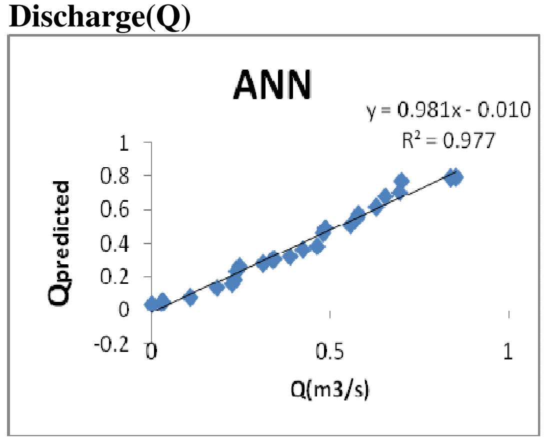


Fig7(b): Figure showing comparison between ANN &Actual Discharge(Q)

4.2Testing data:

Methods	RMSE	MARE	R^2
SCM	0.146017	11.0258	0.647
DCM	0.167459113	60.26609959	0.961
COHM	0.05698	0.15896	0.964
ANN	8.90106E-22	0.225048886	0.977

4.3Conclusions:

A practical ANN based generalized Feed forward Back propagation technique is used for prediction of total discharge in straight open channel. In terms of MSE and RSME ANN yield the discharge data with acceptable yield. The models compared here are SCM, DCM, and COHM with ANN. The testing results of ANN data shows statistically more acceptable than other former developed methods. The R^2 of ANN technique is 0.977 which is 1.3% more acceptable than COHM, 1.6% more acceptable than DCM and far better result i.e 30% more acceptable than SCM. Hence from above observations it is concluded that ANN based prediction providing not only good result but also better prediction than other widely used methods.

Data details:

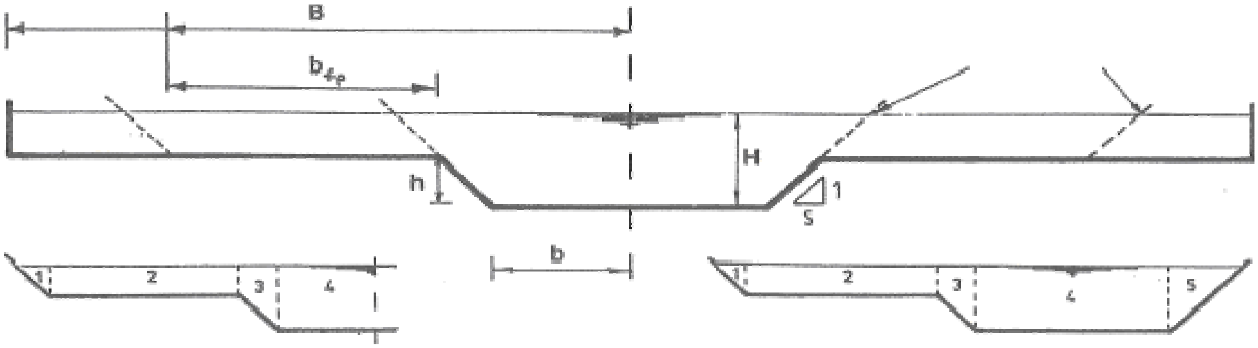


Fig.8 Geometrical Parameter of Data series

Table 3 Details of geometrical parameters of the applied experimental channels

Verified test channel	Series No.	Longitudinal slope (*S*)	Main channel Width (*b*) in mm	Width ratio (*α*)	Main channel depth (*h*) in mm	Main channel side slope, *s*	Floodplain type	Roughness
Present Channel	Type-I	0.0019	120	B/b =3.667	120	0	Symmetric	Smooth
Knight & Demetriou (1983)	01	0.00096	304	B/b =2	76	0	Symmetric	Smooth
	02	0.00096	456	B/b =3	76	0	Symmetric	Smooth
	03	0.00096	608	B/b =4	76	0	Symmetric	Smooth
FCF Series-A channels	01	1.027×10^{-3}	3000	B/b = 6.67	150	1.0	Symmetric	Smooth
	02	1.027×10^{-3}	3000	B/b = 4.20	150	1.0	Symmetric	Smooth
	03	1.027×10^{-3}	3000	B/b = 2.20	150	1.0	Symmetric	Smooth
	06	1.027×10^{-3}	3000	B/b = 4.20	150	1.0	Asymmetric	Smooth
	08	1.027×10^{-3}	3000	b_{fp}/b = 3.0	150	0	Symmetric	Smooth
	10	1.027×10^{-3}	3000	b_{fp}/b = 3.0	150	2.0	Symmetric	Smooth
Tang's data		0.002024	1212.6	3.046734	0.05	0	Symmetric	smooth
Atabay'data		0.002024	398	3.046734	0.05	0	Symmetric	smooth

Table 1(Atabay's Data):

Q_{fc}	Q_{mc}	A(t)	R(t)	f_{mc}	f_{fp}	Re_{mc}	Re_{fp}	S_0
0.091	0.036	0.193	0.141	0.024	0.029	72289.157	104214.384	0.055
0.074	0.035	0.174	0.128	0.023	0.026	70281.125	85529.357	0.055
0.055	0.031	0.151	0.112	0.022	0.026	62248.996	64387.731	0.050
0.018	0.031	0.067	0.048	0.021	0.025	61445.783	19693.654	0.050
0.016	0.029	0.065	0.047	0.021	0.025	58634.538	17621.145	0.045
0.013	0.029	0.063	0.046	0.021	0.025	58232.932	14508.929	0.044
0.012	0.027	0.059	0.042	0.021	0.024	54618.474	13870.095	0.040
0.011	0.027	0.057	0.041	0.020	0.024	54216.867	12443.439	0.039
0.011	0.026	0.056	0.041	0.020	0.024	52208.835	12369.496	0.035
0.009	0.025	0.054	0.039	0.020	0.023	50602.410	11040.236	0.034
0.009	0.023	0.052	0.038	0.020	0.023	46184.739	10250.569	0.034
0.008	0.022	0.051	0.037	0.020	0.023	44979.920	9174.312	0.030
0.006	0.022	0.045	0.033	0.020	0.022	44176.707	6960.557	0.030
0.005	0.021	0.043	0.032	0.020	0.021	42168.675	5868.545	0.027
0.005	0.021	0.043	0.032	0.020	0.020	41767.068	5841.121	0.027
0.005	0.020	0.041	0.030	0.019	0.020	40160.643	5305.353	0.027
0.004	0.020	0.040	0.030	0.019	0.019	40160.643	4728.132	0.024
0.004	0.020	0.040	0.029	0.019	0.018	39156.627	4716.981	0.024
0.004	0.019	0.039	0.029	0.019	0.018	38152.610	4391.170	0.024
0.003	0.018	0.037	0.028	0.019	0.017	36947.791	3818.616	0.021
0.003	0.017	0.037	0.028	0.019	0.016	34136.546	3562.945	0.021
0.002	0.017	0.034	0.026	0.019	0.016	33734.940	2886.697	0.018
0.002	0.015	0.034	0.025	0.018	0.015	30120.482	2409.639	0.018
0.002	0.014	0.031	0.023	0.018	0.015	28112.450	1942.691	0.016

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Table 2(FCF Data):

Q_{fc}	Q_{mc}	A(t)	R(t)	f_{mc}	f_{fp}	Re_{mc}	Re_{fp}	S_0
0.635	0.615	14776.080	18.714	0.282	0.037	20302.024	97921.983	1.114
0.609	0.611	14454.870	18.684	0.282	0.037	20227.212	92197.902	1.103
0.573	0.580	14451.990	18.098	0.282	0.038	19046.454	85547.076	1.015
0.506	0.541	14314.290	17.031	0.282	0.038	18554.828	83446.049	0.929
0.349	0.474	14204.040	17.009	0.282	0.038	18547.576	81480.495	0.836
0.340	0.468	14105.670	16.873	0.282	0.039	17354.990	77244.784	0.835
0.335	0.441	14011.710	16.653	0.282	0.039	17312.461	75071.946	0.807
0.333	0.441	13955.910	16.591	0.282	0.039	16793.517	73051.496	0.763
0.285	0.428	9668.700	16.057	0.281	0.039	16760.383	72722.187	0.690
0.275	0.426	9566.550	15.976	0.281	0.039	16203.623	72059.865	0.605
0.225	0.406	9358.110	15.939	0.281	0.039	15839.391	71827.933	0.600
0.220	0.362	9227.970	15.929	0.281	0.039	15468.851	68173.663	0.593
0.179	0.350	9222.570	15.735	0.281	0.039	15433.364	65734.794	0.558
0.167	0.336	9211.950	15.610	0.281	0.040	15055.523	65675.867	0.558
0.160	0.330	9108.090	15.475	0.281	0.040	14793.468	63629.790	0.522
0.155	0.325	9013.860	15.427	0.281	0.040	14635.340	63585.495	0.480
0.155	0.324	8924.400	15.427	0.281	0.040	14631.071	62217.175	0.451
0.117	0.319	8895.150	15.392	0.281	0.040	14357.319	61843.681	0.429
0.117	0.315	8847.270	15.319	0.278	0.040	14340.626	61123.662	0.427
0.106	0.298	8776.980	15.270	0.278	0.040	14219.510	56706.834	0.395
0.105	0.294	8756.640	15.267	0.278	0.040	14155.116	53980.807	0.392
0.101	0.289	8657.550	15.232	0.278	0.040	14139.936	52218.093	0.383
0.098	0.285	8655.840	15.213	0.278	0.040	14073.030	50364.710	0.354
0.076	0.279	8575.560	15.187	0.278	0.040	13836.813	49464.364	0.351

Table 4(Tang's Data):

Q_{fc}	Q_{mc}	A(t)	R(t)	f_{mc}	f_{fp}	Re_{mc}	Re_{fp}	S_0
0.088	0.033	0.203	0.126	0.217	1.413	65959.300	16680.500	0.050
0.073	0.029	0.163	0.105	0.196	1.250	59033.000	14368.000	0.044
0.069	0.027	0.163	0.105	0.179	1.089	55067.550	12724.030	0.041
0.066	0.027	0.157	0.102	0.173	1.000	54247.680	12620.250	0.039
0.066	0.024	0.141	0.093	0.160	0.912	48319.560	12243.120	0.034
0.055	0.023	0.134	0.089	0.149	0.814	46523.550	10939.500	0.034
0.052	0.022	0.130	0.087	0.147	0.712	44380.680	10254.890	0.034
0.008	0.021	0.124	0.084	0.135	0.676	42243.470	9894.430	0.030
0.008	0.019	0.122	0.082	0.133	0.594	39027.160	9890.430	0.030
0.007	0.019	0.114	0.077	0.123	0.550	38689.320	8597.700	0.027
0.005	0.019	0.108	0.074	0.121	0.515	37509.120	8568.280	0.027
0.005	0.018	0.103	0.071	0.113	0.500	35197.650	7734.630	0.024
0.004	0.018	0.099	0.068	0.112	0.450	35157.690	7150.500	0.024
0.004	0.017	0.093	0.065	0.102	0.436	34925.760	6597.500	0.024
0.004	0.016	0.089	0.062	0.099	0.404	31824.120	6030.920	0.022
0.003	0.016	0.083	0.059	0.088	0.394	31570.020	5594.300	0.021
0.003	0.015	0.078	0.056	0.083	0.375	30714.090	5527.200	0.021
0.003	0.014	0.069	0.049	0.078	0.359	28576.800	4576.000	0.018
0.003	0.014	0.068	0.049	0.070	0.348	27869.260	4426.470	0.018
0.003	0.013	0.068	0.049	0.058	0.306	26736.840	4412.640	0.018
0.002	0.013	0.057	0.042	0.050	0.266	25166.400	3334.080	0.015
0.002	0.012	0.046	0.034	0.039	0.207	24280.860	2980.440	0.015
0.002	0.011	0.046	0.034	0.034	0.177	22679.800	1896.470	0.015
0.002	0.009	0.045	0.033	0.032	0.152	18732.640	1887.480	0.011

Table 5(Tang's Mobile Channel Data)

Q_{fc}	Q_{mc}	A(t)	R(t)	f_{mc}	f_{fp}	Re_{mc}	Re_{fp}	S_0
0.012	0.030	0.030	0.217	0.032	36.917	59235.799	12583.337	0.033
0.011	0.021	0.021	0.090	0.029	0.590	42613.211	11948.187	0.031
0.011	0.020	0.020	0.073	0.026	0.534	40197.831	11737.189	0.030
0.011	0.019	0.019	0.071	0.025	0.469	38654.618	11553.224	0.029
0.010	0.019	0.019	0.070	0.024	0.406	38489.526	10793.314	0.029
0.009	0.019	0.019	0.069	0.024	0.251	37862.856	10279.339	0.026
0.007	0.018	0.018	0.066	0.023	0.215	36866.859	8302.137	0.026
0.007	0.018	0.018	0.062	0.022	0.170	36691.184	7617.687	0.025
0.006	0.017	0.017	0.061	0.022	0.156	34177.230	6745.436	0.024
0.006	0.016	0.016	0.058	0.021	0.142	32229.677	6319.344	0.023
0.006	0.016	0.016	0.058	0.021	0.131	31970.212	6257.655	0.023
0.006	0.016	0.016	0.054	0.019	0.103	31714.752	6131.796	0.023
0.006	0.016	0.016	0.054	0.018	0.081	31312.325	6085.684	0.021
0.006	0.015	0.015	0.052	0.018	0.075	30811.683	6075.827	0.021
0.005	0.014	0.014	0.051	0.018	0.071	27686.428	5978.247	0.021
0.005	0.014	0.014	0.051	0.017	0.060	27369.417	5776.599	0.020
0.005	0.014	0.014	0.045	0.016	0.053	27070.173	5703.239	0.019
0.005	0.013	0.013	0.043	0.016	0.049	26730.937	5456.062	0.018
0.005	0.013	0.013	0.041	0.015	0.048	26485.546	4894.719	0.018
0.005	0.013	0.013	0.040	0.015	0.034	25622.349	4727.479	0.017
0.004	0.013	0.013	0.038	0.015	0.034	25171.867	4088.452	0.016
0.004	0.012	0.012	0.035	0.015	0.033	24952.055	3418.604	0.016
0.003	0.012	0.012	0.034	0.014	0.023	24650.588	3117.324	0.015
0.003	0.011	0.011	0.032	0.014	0.015	23697.016	2984.793	0.015

Data After Normalization:

Table 6(Atabay's data):

Q_{fc}	Q_{mc}	A(t)	R(t)	f_{mc}	f_{fp}	Re_{mc}	Re_{fp}	S_0
1	1	0.99	1	1	1	1	1	
0.81	0.96	0.88	0.89	0.85	0.83	0.95	0.81	0.002
0.6	0.78	0.74	0.76	0.68	0.82	0.78	0.61	0.002
0.19	0.76	0.24	0.23	0.56	0.75	0.76	0.18	0.002
0.17	0.7	0.23	0.22	0.49	0.75	0.7	0.16	0.002
0.13	0.69	0.22	0.21	0.49	0.73	0.69	0.13	0.002
0.125	0.61	0.19	0.19	0.47	0.68	0.61	0.12	0.002
0.11	0.6	0.17	0.17	0.39	0.68	0.6	0.11	0.002
0.11	0.56	0.17	0.16	0.33	0.65	0.56	0.11	0.002
0.125	0.52	0.161	0.153	0.33	0.61	0.52	0.095	0.002
0.089	0.43	0.15	0.142	0.33	0.61	0.41	0.087	0.002
0.078	0.4	0.14	0.134	0.33	0.59	0.4	0.077	0.002
0.056	0.38	0.11	0.1	0.33	0.51	0.38	0.055	0.002
0.044	0.34	0.09	0.09	0.33	0.47	0.34	0.045	0.002
0.044	0.33	0.09	0.08	0.31	0.44	0.33	0.044	0.002
0.038	0.296	0.08	0.078	0.19	0.41	0.29	0.039	0.002
0.033	0.296	0.07	0.075	0.16	0.34	0.29	0.039	0.002
0.033	0.27	0.07	0.07	0.16	0.29	0.27	0.035	0.002
0.03	0.25	0.067	0.066	0.16	0.27	0.25	0.03	0.002
0.024	0.22	0.057	0.056	0.15	0.19	0.22	0.025	0.002
0.022	0.16	0.056	0.055	0.11	0.13	0.16	0.021	0.002
0.015	0.15	0.04	0.04	0.098	0.1	0.15	0.016	0.002
0.011	0.074	0.03	0.036	0	0.068	0.074	0.015	0.002
0.067	0.038	0.02	0.021	0	0.041	0.03	0.0065	0.002

Table 7(FCF data):

Q_{fc}	Q_{mc}	A(t)	R(t)	f_{mc}	f_{fp}	Re_{mc}	Re_{fp}	S_0	Q_{fc}
1	1	1	1	1	1.000	1.00	1.00	0.001	1.00
0.96	0.99	0.97	0.99	1	0.995	0.99	0.94	0.001	0.99
0.9	0.92	0.97	0.87	1	0.887	0.87	0.87	0.001	0.89
0.79	0.83	0.96	0.64	1	0.678	0.82	0.85	0.001	0.80
0.55	0.675	0.94	0.63	1	0.674	0.82	0.83	0.001	0.70
0.54	0.66	0.94	0.60	1	0.646	0.70	0.79	0.001	0.70
0.53	0.599	0.93	0.55	1	0.600	0.69	0.76	0.001	0.67
0.53	0.599	0.92	0.54	1	0.587	0.64	0.74	0.001	0.62
0.44	0.569	0.53	0.43	0.996	0.472	0.64	0.74	0.001	0.54
0.44	0.564	0.521	0.41	0.996	0.454	0.58	0.73	0.001	0.45
0.35	0.52	0.51	0.40	0.996	0.446	0.54	0.73	0.001	0.45
0.34	0.42	0.49	0.40	0.996	0.444	0.50	0.69	0.001	0.44
0.28	0.39	0.48	0.36	0.996	0.400	0.50	0.67	0.001	0.40
0.26	0.36	0.488	0.33	0.996	0.372	0.46	0.67	0.001	0.40
0.25	0.34	0.479	0.30	0.996	0.341	0.43	0.65	0.001	0.36
0.24	0.33	0.47	0.29	0.996	0.330	0.42	0.65	0.001	0.32
0.24	0.33	0.462	0.29	0.996	0.330	0.42	0.63	0.001	0.29
0.18	0.32	0.459	0.28	0.996	0.322	0.39	0.63	0.001	0.26
18	0.31	0.455	0.27	0.982	0.305	0.39	0.62	0.001	0.26
0.16	0.27	0.448	0.26	0.982	0.293	0.38	0.58	0.001	0.23
0.16	0.26	0.446	0.25	0.982	0.292	0.37	0.55	0.001	0.22
0.156	0.25	0.44	0.25	0.982	0.284	0.37	0.53	0.001	0.21
0.15	0.24	0.44	0.24	0.982	0.280	0.36	0.51	0.001	0.18
0.12	0.23	0.43	0.24	0.982	0.273	0.34	0.50	0.001	0.18
0.096	0.21	0.423	0.22	0.982	0.258	0.32	0.50	0.001	0.17
0.096	0.21	0.422	0.21	0.982	0.244	0.32	0.48	0.001	0.17
0.094	0.19	0.42	0.21	0.982	0.243	0.31	0.43	0.001	0.16
0.094	0.18	0.412	0.20	0.982	0.235	0.29	0.42	0.001	0.15

Table 8:(Tang's rigid channel Data)

Q_{fc}	Q_{mc}	A(t)	R(t)	f_{mc}	f_{fp}	Re_{mc}	Re_{fp}	S_0	Q
0.219	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.002	1.000
0.181	0.860	0.760	0.792	0.888	0.872	0.858	0.847	0.002	0.852
0.171	0.778	0.757	0.789	0.794	0.746	0.777	0.738	0.002	0.764
0.163	0.761	0.719	0.754	0.762	0.676	0.760	0.731	0.002	0.729
0.163	0.642	0.621	0.664	0.696	0.606	0.639	0.706	0.002	0.604
0.135	0.605	0.582	0.626	0.634	0.529	0.602	0.620	0.002	0.604
0.128	0.560	0.558	0.602	0.623	0.448	0.559	0.574	0.002	0.604
0.017	0.514	0.523	0.568	0.560	0.420	0.515	0.551	0.002	0.496
0.017	0.449	0.508	0.553	0.551	0.355	0.449	0.550	0.002	0.491
0.014	0.444	0.458	0.504	0.496	0.321	0.442	0.465	0.002	0.416
0.009	0.420	0.421	0.467	0.483	0.293	0.418	0.463	0.002	0.416
0.009	0.370	0.393	0.438	0.440	0.281	0.371	0.408	0.002	0.348
0.007	0.370	0.366	0.409	0.435	0.242	0.370	0.369	0.002	0.346
0.007	0.366	0.332	0.374	0.379	0.231	0.365	0.332	0.002	0.341
0.006	0.305	0.306	0.346	0.367	0.206	0.302	0.295	0.002	0.293
0.005	0.296	0.273	0.311	0.307	0.198	0.297	0.266	0.002	0.271
0.005	0.280	0.242	0.278	0.278	0.184	0.279	0.261	0.002	0.268
0.004	0.235	0.185	0.214	0.251	0.170	0.235	0.198	0.002	0.195
0.003	0.222	0.180	0.208	0.206	0.162	0.221	0.188	0.002	0.195
0.003	0.198	0.178	0.206	0.143	0.129	0.198	0.187	0.002	0.193
0.002	0.165	0.113	0.133	0.100	0.097	0.166	0.116	0.002	0.125
0.002	0.148	0.046	0.054	0.042	0.051	0.147	0.093	0.002	0.120
0.002	0.115	0.043	0.051	0.016	0.028	0.115	0.021	0.002	0.115
0.001	0.033	0.041	0.049	0.001	0.008	0.034	0.020	0.002	0.013
0.219	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.002	1.000
0.181	0.860	0.760	0.792	0.888	0.872	0.858	0.847	0.002	0.852
0.171	0.778	0.757	0.789	0.794	0.746	0.777	0.738	0.002	0.764
0.163	0.761	0.719	0.754	0.762	0.676	0.760	0.731	0.002	0.729
0.163	0.642	0.621	0.664	0.696	0.606	0.639	0.706	0.002	0.604
0.135	0.605	0.582	0.626	0.634	0.529	0.602	0.620	0.002	0.604

Table 9:(Tang's mobile channel Data)

Q_{fc}	Q_{mc}	A(t)	R(t)	f_{mc}	f_{fp}	Re_{mc}	Re_{fp}	S_0	Q
1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.002	1.000
0.966	0.575	0.575	0.365	0.864	0.016	0.575	0.948	0.002	0.908
0.905	0.514	0.514	0.282	0.764	0.014	0.514	0.931	0.002	0.859
0.888	0.474	0.474	0.268	0.702	0.013	0.474	0.916	0.002	0.852
0.853	0.470	0.470	0.265	0.678	0.011	0.470	0.855	0.002	0.837
0.793	0.456	0.456	0.261	0.669	0.007	0.454	0.813	0.002	0.699
0.603	0.431	0.431	0.245	0.620	0.006	0.429	0.652	0.002	0.695
0.569	0.424	0.424	0.226	0.579	0.004	0.424	0.597	0.002	0.655
0.509	0.360	0.360	0.220	0.574	0.004	0.360	0.526	0.002	0.629
0.500	0.310	0.310	0.204	0.566	0.004	0.310	0.491	0.002	0.579
0.491	0.303	0.303	0.204	0.545	0.003	0.303	0.486	0.002	0.576
0.474	0.297	0.297	0.187	0.450	0.003	0.297	0.476	0.002	0.557
0.474	0.287	0.287	0.185	0.421	0.002	0.287	0.472	0.002	0.486
0.457	0.272	0.272	0.177	0.409	0.002	0.274	0.472	0.002	0.480
0.448	0.195	0.195	0.171	0.405	0.002	0.194	0.464	0.002	0.463
0.431	0.186	0.186	0.168	0.388	0.001	0.186	0.447	0.002	0.423
0.405	0.179	0.179	0.138	0.322	0.001	0.178	0.441	0.002	0.387
0.388	0.169	0.169	0.132	0.322	0.001	0.170	0.421	0.002	0.343
0.379	0.164	0.164	0.122	0.306	0.001	0.163	0.376	0.002	0.338
0.371	0.142	0.142	0.113	0.306	0.001	0.141	0.362	0.002	0.312
0.345	0.130	0.130	0.107	0.293	0.001	0.130	0.310	0.002	0.245
0.302	0.118	0.118	0.091	0.289	0.001	0.124	0.256	0.002	0.237
0.241	0.092	0.092	0.084	0.248	0.001	0.116	0.232	0.002	0.232
0.216	0.074	0.074	0.076	0.244	0.000	0.092	0.221	0.002	0.225
0.198	0.047	0.047	0.054	0.161	0.000	0.074	0.153	0.002	0.183
0.086	0.046	0.046	0.039	0.062	0.000	0.047	0.091	0.002	0.108
0.009	0.032	0.032	0.034	0.054	0.000	0.032	0.005	0.002	0.031
1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.002	1.000

CHAPTER 5

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