Variation of Roughness in a Non-Prismatic Converging Compound Channel

Deepika P. Palai, Abinash Mohanta, K.C.Patra
Department of Civil Engineering
NIT Rourkela
Rourkela, India
Email: dpalai22@gmail.com, abinash07552@gmail.com, kcpatra@nitrkl.ac.in

Abstract— For the river management, it is important to understand the behavior of river flow within compound channel. Flooding situation in rivers is a complex phenomenon which affects the livelihood and economic condition of the region. The modeling of river flow is very important for river engineers and scientists working in this field. As a result of topographic changes along the open channels, designing the converging compound channel is important task. Open channel flows are strongly influenced by geometric complexity and large overall uncertainty on every single measurable property, such as roughness or velocity distribution on different sectional parameters like width ratio, aspect ratio and hydraulic parameter such as relative depth. Generally flow structure in a non-prismatic converging compound channels are more complex due to 3-dimentional nature of flow. The usual practice in one dimensional analysis is to select a value of n depending on the channel surface roughness and take it as uniform for the entire surface for all depths of flow. The roughness of the main channel was determined by measuring the velocity of water flowing along the main channel. In this paper, the Manning's n and Chezy's c coefficient denote the roughness characteristics of the converging compound channel which show the energy losses within the open channel. Generally the coefficients for Chezy's and Darcy-Weisbach friction factors from in bank flow to over bank flow are found to be in line with the behavior of Manning's n. The larger the value of Manning's n, the higher is the energy loss. In this paper, an experimental investigation of a non-prismatic compound channel with converging flood plains is investigated. Here five different sections with different cross-sections along the longitudinal direction of the non-prismatic converging compound channel are analyzed to study the change in the value of Manning's n, Chezy's c and Darcy-Weisbach friction factor f along the path of the channel.

***Keywords**-compound channel,non-prisamatic channel,roughness,manning's n coefficient, Chezy's C coefficient, Darcy-Weisbach Friction Factor* f, converging compound channel.

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INTRODUCTION

Water is very necessary for the most basic of needs of human beings. So for this reason; people have always flourished where there has been a ready supply of water. Rivers play an integral part in the day to day functioning of our planet. It is the main source of providing water supply for domestic, irrigation, industrial consumption or transportation and recreation uses. Therefore it is important to understand the flow characteristics of rivers in both their in bank and overbank flow condition. River channels do not remain straight for any appreciable distance. Flow separation in open channel expansion has been identified as one of the major problems encountered in many hydraulic structures such as irrigation networks, bridges, flumes, aqueducts, power tunnels and siphons. Due to the existence of secondary flow, flow characteristics in channel bends are much more complicated than those in straight channels[1].

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. 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[2]. This extra momentum exchange should also be taken into account in the flow modeling. 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. Distribution of roughness coefficients in a compound channel section is an important aspect that needs to be addressed properly. Water that flows in a natural channel is a real fluid for which the action of viscosity and other forces cannot be ignored completely. Owing to the viscosity, the flow in a channel consumes more energy. Usually Chezy's, Manning's or Darcy-Weisbach equation is used to calculate the velocity of flow in an open channel[3]. The roughness coefficient in these cases is represented as c, n and f respectively. Due to its popularity, the field engineers mostly use Manning's equation to estimate the velocity and discharge in an open channel. While using Manning's equation, the selection of a suitable value of n is the single most important parameter for the proper estimation of velocity in an open channel[4]. Major factors affecting Manning's roughness coefficient are the (i) surface roughness,(ii) vegetation, (iii)channel irregularity, (iv) channel alignment, (v) silting and scouring, (vi) shape and the size of a channel, and (vii) stage-discharge relationship. However, in one dimensional analysis, it is difficult to model the influence of all these parameters individually to formulate a simple equation for the estimation of velocity and discharge rate in an open channel under uniform flow conditions[5]. Pang (1998) and Patra (1999) have shown that Manning's coefficient n not only denotes the roughness characteristics of a channel but also the energy loss of the flow[6]. The influences of all the forces that resist the flow in an open channel are assumed to have been lumped to a single coefficient n. Due to flow interaction between the main channel and floodplain, 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. The variation of Manning’s roughness coefficient n, Chezy’s C and Darcy - Weisbach friction factor f with depths of flow ranging from in-bank channel to the over-bank flow are discussed[7]. Flood plains of river basins are densely vegetated. The values of n are determined from the factors that influence the roughness of a channel and flood plain[8]. The results of Manning's formula, an indirect computation of stream flow, have applications in floodplain management, in flood insurance studies, and in the design of bridges and highways across flood plains[9].

Manning's formula is written as

$$V = \frac{1}{n} R^{2/3} S_e^{1/2} \quad (1)$$

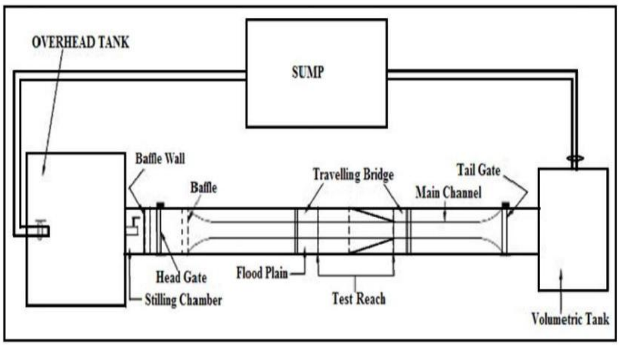
Where V= mean velocity of flow, in meters per second, R= hydraulic radius, in meters, S_e=slope of energy grade line, in meters per meter. n = Manning's roughness coefficient It would be impractical in this guide to record all that is known about the selection of the Manning's roughness coefficient.

I. Experimental Procedure

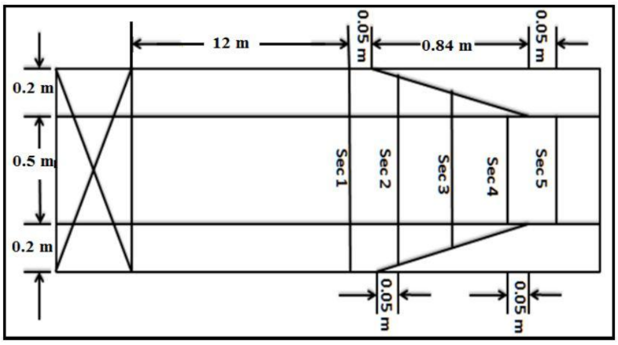
Experiments are conducted in a non-prismatic compound channels having symmetrically converging flood plains with varying cross section built inside a concrete flume measuring 15m×.9m×0.5m in the hydraulic engineering lab of the National Institute of Technology Rourkela, India[10]. The width ratio (α) i.e. the ratio of top width to main channel width of the channel varies from 1.8 to 1 and the aspect ratio (δ) i.e. the ratio of top width to the bank full depth of main channel varies from 5 to 9. The converging angle of the channel is 13.39°. The total converging length of the channel is 0.84m.The channel is made up of cement concrete.

Water is supplied through a Centrifugal pumps (15 hp) discharging into a RCC overhead tank. In the downstream end there will be a measuring tank followed by a sump which will feed to over head tank through pumping thus completing recirculation path. The Fig.1 shows a schematic diagram of experimental setup and dimensions of channel with test section respectively. Fig.2 shows the plan view of five different experimental sections of the channel. Water was supplied to the flume from an underground sump via an overhead tank by centrifugal pump (15 hp) and recirculation to the sump after flowing through the compound channel and a downstream volumetric tank fitted with closure valves for calibration purpose[11].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 strengtheners 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[12].

Experimentation is taken place in the compound channel by taking three different relative depth (Dr) values i.e. 0.2Dr, 0.3Dr and 0.4Dr in different positions and depths. Experimentations are taking place at various depth and position longitudinally in five different sections. Where first section is taken before start of converging area, second, third and fourth sections are taken inside the convergence area and fifth section is situated after the end of converging area. In section 1 width ratio is more which is equal to 1.8 where in section 5 width ratio is less and the value is 1 as there is no flood plain. From section 1 to section 5 width ratio and aspect ratio decreases such as width ratio lies between 1.8 to 1 and aspect ratio varies between 9 to 5. It means after section 1 flood plain converges towards longitudinal direction.The summery of experiments conducted are given in Table 1. In this paper the experimental results concerning the Manning’s *n*, Chezy’s *C* and Darcy - Weisbach friction factor *f* for the converging compound channel.



(Fig.1 Plan view of experimental setup of the channel)



(Fig.2 Plan view of five different experimental sections)

II. Results

The experimental results concerning the distribution of velocity along the compound channel section, boundary shear along the wetted perimeter and flow has been presented in this chapter. Analysis is also done for depth averaged velocity and longitudinal velocity distribution in the converging compound channel with two different flow depth i.e. relative depth (Dr)[13].

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$$\text{Relative Depth}(Dr) = \frac{\text{Total flow depth of Water}(H) - \text{Height of main channel}(h)}{\text{Total flow depth of water}(H)}$$

Analysis of results is done for distribution of boundary shear stress in a non-prismatic converging compound channel and shear force results are derived accordingly for the relative depth (Dr) of 0.2. In this study, various flow variables are studied in a converging compound channel with five different sections, which are discussed separately below. The positions of different experimental five sections are clearly shown in Fig 2. Positions of five different sections are decided to analyze the effect of convergence of the flood plain in a non-prismatic compound channel. To see the effect of turbulence and boundary shear and to compare these effects two sections are taken outside the converging part[14]. One is section 1 which is situated before the converging part and other section is taken after the converging part (section 5).Other three different sections are taken inside the convergence area. Section 2 is located just after the start of convergence and section 4 is taken just before end of convergence. Section 3 is situated in the middle of the converging part of the channel. Velocity measurements were carried out in the compound channel transition with the 55% compression of flood plain. The data obtained from Pitot tube measurements of the velocity were analyzed and velocity profiles were drawn. Then experimental analyzed results were compared. The overall Summery of experimental run for non-prismatic compound channel with converging flood plain is given in Table-1.

Exp. Type	Distance From u/s (D)	Dr	Top width(B)	Bottom width (b)	Total flow Depth (H)	Width Ratio $\alpha = \left({}^{B}/_{b}\right)$	Aspect Ratio (δ)=(B/H)
Section-1	11.95	0.4	0.9	0.5	0.1671	1.8	9
Section-2	12.05	0.4	0.87	0.5	0.1666	1.75	8.76
Section-3	12.42	0.4	0.7	0.5	0.1614	1.4	7
Section-4	12.79	0.4	0.52	0.5	0.1555	1.05	5.24
Section-5	12.89	0.4	0.5	0.5	0.1546	1	5
Section-1	11.95	0.3	0.9	0.5	0.1435	1.8	9
Section-2	12.05	0.3	0.87	0.5	0.1427	1.75	8.76
Section-3	12.42	0.3	0.7	0.5	0.1416	1.4	7
Section-4	12.79	0.3	0.52	0.5	0.1325	1.05	5.24
Section-5	12.89	0.3	0.9	0.5	0.1286	1	5
Section-1	11.9	0.2	0.9	0.5	0.1261	1.8	9
Section-2	12.07	0.2	0.87	0.5	0.1246	1.75	8.76
Section-3	12.42	0.2	0.7	0.5	0.1215	1.4	7
Section-4	12.79	0.2	0.52	0.5	0.1149	1.05	5.24
Section-5	12.89	0.2	0.5	0.5	0.1137	1	5

MANNING'S RESISTANCE FACTORS FOR VARIOUS CHANNEL SURFACES

Major factors affecting Manning's roughness coefficient are the (i) surface roughness, (ii) vegetation, (iii) channel irregularity, (iv) channel alignment, (v) silting and scouring, (vi) shape and the size of a channel, and (vii) stage-discharge relationship. Patra (1999)[4], Patra and Kara (2000)[7], Pang (1998)[6], and Willets & Hardwick (1993)[15] have shown that Manning's *n* not only denotes the roughness characteristics of a channel but also the energy loss in the flow[16]. The influences of all the forces that resist the flow in an open channel are assumed to have been lumped to a single coefficient *n*.

Due to flow interaction between the main channel and floodplain, 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. The variation of Manning's roughness coefficient *n*, Chezy's *C* and Darcy - Weisbach friction factor *f* with depths of flow ranging from in-bank channel to the over-bank flow are discussed. Floodplains of river basins are densely vegetated. The values of *n* are determined from the factors that influence the roughness of a channel and floodplain. Suggested values for Manning's *n* are tabulated in Chow (1959)[12], and Henderson

(1966)[17]. Roughness characteristics of natural channels are given by Barnes (1967)[8]. Though there are large numbers of formulae/procedures available to calculate Manning's n for a river reach, the following four methods are found to be more useful.

1. Jarrett's (1984) equation for high gradient channels[18].

$$n = \frac{0.32\, S^{0.38}}{R^{0.16}} \qquad (2)$$

Where, *S* is the channel gradient, *R* the hydraulic radius in meters. The equation was developed for natural main channels having stable bed and bank materials (boulders) without bed rock. It is intended for channel gradients from 0.002 – 0.04 and hydraulic radii from 0.15 – 2.1m, although Jarrett noted that extrapolation to large flows should not be too much in error as long as the channel substrate remains fairly stable[15].

2. Limerions's (1970) equation for natural alluvial channels[9].

$$n = \frac{0.0926 R^{0.17}}{1.16 + 2\log(R/d_{84})} \qquad (3)$$

Where, *R* is the hydraulic radius and *d*84 the size of the intermediate particles of diameter that equals or exceeds that of 84% of the streambed particles, with both variables in feet. This equation was developed for discharges from 6 – 430 m3/s, and *n/R*0.17 ratios up to 300 although it is reported that little change occurs over *R* > 30.

3. Visual estimation of *n* values can be performed at each site using Barne's (1967) as a guideline[8].

4. The Cowan (1956)[16] method for estimation of *n*, as modified by Arcement and Schneider (1989)[3] is designed specifically to account for floodplain resistance given as

$$n = (n_b + n_1 + n_2 + n_3 + n_4)m \qquad (4)$$

where n_b is the base value of *n* for the floodplain's natural bare soil surface; n_1 a correction factor for the effect of surface irregularities on the flood plain (range 0-0.02); n_2 a value for variation in shape and size of floodplain cross section, assumed equal to 0.0; n_3 a value for obstructions on the floodplain (range 0-0.03); *n4* a value for vegetation on the flood plain (range 0.001-0.2); and *m* a correction factor for sinuosity of the floodplain, equal to 1.0. Values for each of the variables are selected from tables in Arcement and Schneider (1989)[3]. This equation was verified for wooded floodplains with flow depths from 0.8-1.5 m. The above four methods give a general guidance for the selection of *n* for the surface of a channel. The variation of the selected *n* values with depth of flow characterizing the loss of energy with flow depth from in-bank to over-bank flow depths as discussed in this paper.

Variation of Manning's n with Depth of Flow for Simple Meandering Channel

Sellin et al. (1993)[19], Pang (1998)[6], and Willetts and Hardwick (1993)[15] reported that the Manning's roughness coefficient not only denotes the characteristics of channel roughness but also influences the energy loss of the flow. For highly sinuous channels the values of *n* become large indicating that the energy loss is more for such channels.

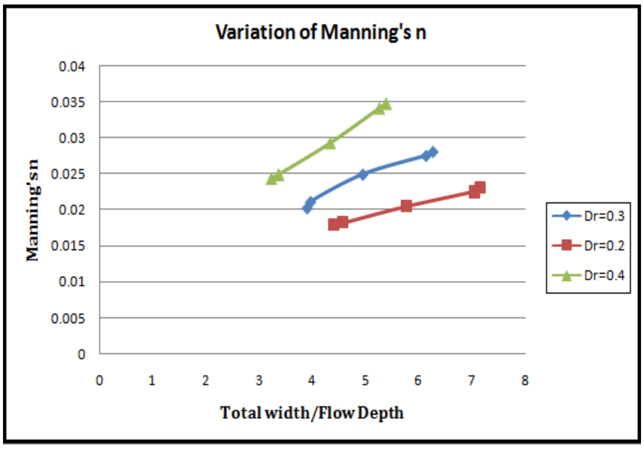

Fig.3. Variation of Manning's *n* with Depth of Flow

The experimental results for Manning's *n* with depth of flow for simple meander channels are plotted in Fig. 3. The plot indicates that the value of *n* increases as the flow depth increases. An increase in the value of *n* can be mainly due to the increase in resistance to flow for wider channel with shallow depth consuming more energy than narrower and deep channel. It can also be seen from Fig. 3 is that steeper channels consume more energy than the flatter channels.

Variation of Chezy's C with Depth of Flow

The variation of Chezy's *C* with depth of flow for the three different types of relative depth of non prismatic compound channel investigated is shown in Fig. 4. It can be seen from the figure that the non prismatic compound channel with increase in depth of flow the variation of Chezy's C increases continuously. A sudden decrease in the value of C can be noticed when the flow in 0.2Dr. As the depth of flow in the floodplain increases, the value of C also increases and tries to attain a steady state.

A sudden decrease in the value of *C* is noticed, when the flow spills over to the floodplain. It is expected that the value of *C* will decrease further and reach a steady state at still higher depths of flow in the floodplain. For this channel, the decrease in Chezy's *C* is mainly due to the increase in strength of secondary flow induced by curvature resulting in higher loss of energy.

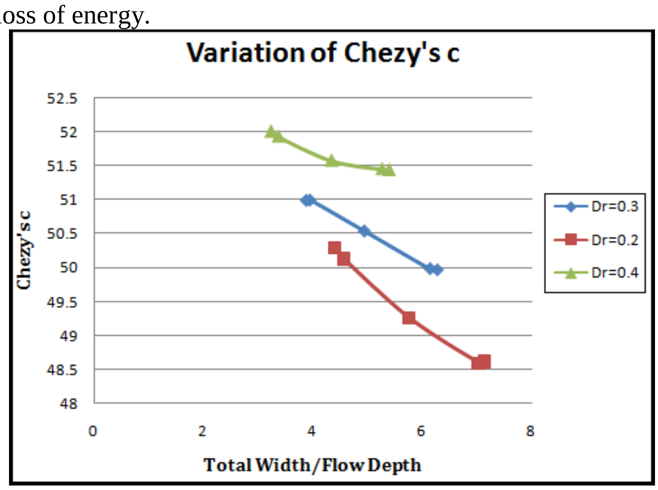

Fig.4. Variation of Chezy's C with Depth of Flow Variation of Darcy-Weisbach Friction Factor *f* with Depth of Flow.

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The variation of friction term *f* with depth of flow for the non prismatic compound channel according to relative depths like 0.3 Dr, 0.2 Dr and 0.4 Dr are shown in Fig.5. The behavioural trend of friction factor *f* is nearly similar to that of the variation of Manning's *n*.

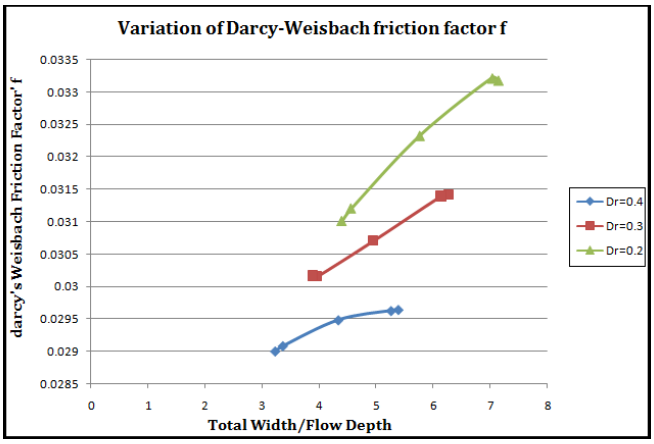

Fig.5. Variation of Darcy-Weisbach Friction Factor *f* with Depth of Flow

III. CONCLUSION

In the present study, the experimental and numerical modelling of the flow pattern at a non-prismatic compound channel with a converging flood plain has been carried out. On the basis of the investigations concerning flow, velocity distribution, depth average velocity distribution and boundary shear stress distribution along the channel bed for three different relative depth(0.2 Dr, 0.3 Dr and 0.4Dr) in a non-prismatic converging compound channel having 13.39 converging angle, the point to point observations are drawn for different experimental sections. Findings of the work are as follows:

1. Three dimensional modelling of the free surface flow in non-prismatic compound channel having narrowing floodplains as relatively complex geometry have been successfully verified with a mesh refinement studies and validated with experiments.

2. Experimental results related to longitudinal velocities are compared with the corresponding values obtained from Numerical analysis for 5 different sections i.e. sec-1, sec-2, sec-3, sec-4, sec-5 of the non-prismatic compound channel for two different relative depth of flow and concluded that the variation of longitudinal velocity in main channel region is found to be less as compared to that in the flood plain region.

3. By experimental and numerical simulation it is clearly concluded that, in main channel region the velocity magnitude is nearly constant after the solid boundary however at flood plain region there is rapid variation found and maximum velocity occurs just below the free surface of the converging compound channel because a boundary layer is formed due to interaction of air and top water surface which retards the flow velocity of the top layer.

4. Manning's or Chezy's coefficient n not only denotes the roughness characteristics of a channel but also the energy loss of the flow. It is an established fact that the influences of all the forces that resist the flow in an open channel are assumed to have been lumped to a single coefficient n.

5. Even for simple meandering channels carrying in bank flows, these coefficients are found to vary with depth of flow in the channel. Manning's n is found to decrease with depth for narrow channels while for wide channels it is found to increase with depth of flow in the channel. The behaviour of Manning's n is also found to be erratic in the over bank flow conditions for the three types of channels investigated.

6. The coefficients for Chezy's c and Darcy-Weisbach f friction factors from in bank flow to over bank flow are found to be in line with the behaviour of Manning's n.

7. The assumption of an average value of flow resistance coefficient in terms of Manning's n for all depths of flow result in significant errors in discharge estimation.

8. No trend in the energy loss parameter S n f / could be established for the three different types of relative depths in non prismatic compound channel investigated when plotted for their values ranging from in bank to over bank flows.

9. The interaction of flow between the main channel and floodplain, the channel size, shape, and slope are found to influence the coefficients n, c, and f more than the other forces.

10. The main reason for discharge decrease in the main channel and increase in the floodplain is because of the change in energy distribution in the flow field. The river flow consumes more energy in the main channel and less energy in the floodplain. When the river flow consumes more energy, it also passes less discharge. On the contrary, when the flow consumes less energy, it passes more discharge.

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