Paper is communicated for publication in the National conference Advances in Environmental Engineering, 14-15, Nov -2009, at NIT, Rourkela.

Variation of Resistance Coefficients in a Meandering Channel

P.P.Nayak[*] **K.K.Khatua** [*] **K. C. Patra**[*]

ABSTRACT

During uniform flow in open channels the resistance to the flow is dependant on a number of flow and channel parameters. The usual practice in one dimensional analysis is to select a value of n depending on the channel surface roughness and take it as uniform for the entire surface for all depths of flow. The influences of all the parameters are assumed to be lumped into a single value of n. The larger the value of n, the higher is the loss of energy within the flow. Although much research has been done on Manning's n, for straight channels, very little has been done concerning the roughness values for simple meandering channels. An investigation concerning the variation of roughness coefficients with for simple meandering channels with slope, sinuosity and geometry are presented. The loss of energy in terms of Manning's n, Chezy's C, and Darcy-Weisbach coefficient f are evaluated.

Key words: Meandering channel, Sinuosity, Resistance, aspect ratio, Bed slopeManning's n, Chezy's C, and Darcy-Weisbach coefficient f,

---

[*] Department of Civil Engineering, N.I.T.Rourkela, Orissa, India email: contact.pinaki@gmail.com/ kkkhatua@yahoo.com

1. INTRODUCTION

Natural streams, rivers, and man-made surface drainage channels often overflow their banks during the occurrence of high rainfall thus, causing loss of life and extensive damage to nearby properties in many parts of the world. Accurate assessment of the discharge capacity of meandering channels are therefore essential in suggesting structures for flood control and in designing artificial waterways etc. A river is the author of its own geometry. It is an established fact that meandering represents a degree of adjustment of water and sediment laden river with its size, shape, and slope such that a flatter channel can exist in a steeper valley. Distribution of roughness coefficients in a channel section is an important aspect that needs to be addressed properly. A roughness value underestimates the discharge and a low value can overestimate. Sinuosity and slope have significant influences for the evaluation of channel discharge. 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. 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. 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.

Hydraulic resistance of the water course determines the water level and flow distribution in the basin. Such resistance is commonly represented by parameters such as manning`s roughness coefficient (n), Chezy`s resistance factor (C), or the Darcy-Weisbach friction factor (f). Distribution of flow and velocity in a meandering river are important topics in river hydraulics to be investigated from a practical point of view in relation to the bank protection, navigation, water intakes, and sediment transport-depositional patterns. Knowledge on velocity distribution in a channel also helps to determine the energy expenditure, bed shear stress distribution, and the associated heat and mass transport problems. The energy loss is manifested in the form of variation of resistance coefficients of the channel with depth of flow. 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.

Manning's formula is written as

$$V = \frac{1}{n} R^{2/3} S^{1/2} \tag{1}$$

Where,

V = mean velocity of flow, in meters per second, R = hydraulic radius, in meters, S = slope of energy grade line, in meters per meter and n = Manning's roughness coefficient.

The n values for channels are determined by evaluating the effects of certain roughness factors in the channels. Values of the roughness coefficient, n may be assigned for conditions that exist at the time of a specific flow event, for average conditions over a range in stage, or for anticipated conditions at the time of a future event. The variation of resistance coefficients for the present experimental meandering channels are found to vary with depth, aspect ratio, slope and sinuosity and are all linked to the stage-discharge relationships. This paper discusses the variation of n using a section as single channel.

2. PREVIOUS WORK DONE

Visual estimation of *n* values can be made at each site using Barne’s (1976) guideline. Jarrett (1984) developed a model to determine Manning’s *n* for natural main channels having stable bed and in bank flow without meandering coefficient. James and Wark (1992) proposed a simple relationship for determination of Manning’s *n*, which is called LSCS method, considering different value of meandering effect in simple meandering channel. A summary of floodplain hydraulics is given by Knight and Shiono (1996). Jana & Panda et.al (2006) have performed dimensional analysis and predicted the stage-discharge relationship in simple meandering channels of low sinuosity. Pang (1998), Patra (1999), Patra and Kar (2000), Khatua and Patra (2006), Khatua (2007) have shown that Manning’s *n* not only denotes the roughness characteristics of a channel but also the energy loss in the flow.

3. EXPERIMENTAL SETUP

The experiments are carried out using in the Fluid Mechanics and Hydraulics Laboratory of the Civil Engineering Department at the National Institute of Technology, Rourkela. Four types of flumes are cast with channels of varying sinuosity, geometry and slope. Out of this data 12 m long tilting flume having trapezoidal cross section with side slope 1:1, constructed of transparent perspex sheets with smooth walls, has been used for the present work. Details of the geometrical parameters of the channel are given in Table- 1. A hand-operated tailgate weir is constructed at the downstream end of the channel to regulate and maintain the desired depth of flow in the flume. Manning's n, Chezy`s C and Darcy- Weisbach f are determined for the flume by measuring the depth and discharge. The bed slope is set by adjusting the whole structure, tilting it upwards or downwards with the help of a leaver, which is termed as slope changing leaver. Readings are taken for the different slopes.

Water is supplied to the experimental channel from an overhead tank. A glass tube indicator with a scale arrangement in the overhead tank enables to draw water with constant flow head. The stilling tank located at the upstream of the channel has a baffle wall to reduce turbulence of the incoming water. An arrangement for the smooth transition of water from the stilling tank to the experimental channel is made. The water surface slope measurement was carried out using a pointer gauge, operated manually and reading to the nearest 0.1 mm at the centre of the crossover sections. At the end of the experimental channel, water is allowed to flow over a tailgate and into a sump. From the sump water is pumped back to the overhead tank, thus setting a complete re-circulating system of water supply for the experimental channel. The tailgate helps to establish uniform flow in the channel. The discharge is measured in the collecting tank. The water flowing out of the exit end of the experimental channel is allowed to accumulate in a collecting tank and the change in the depth of water with time is measured (using a stop watch) by a glass tube indicator system with a scale of accuracy 0.01cm.

All measurements are carried out under quasi-uniform flow condition by maintaining the out flow through downstream tailgate. Experimental results are accessed concerning stage-discharge-resistance relationships for meandering channels with rigid and smooth boundaries. Sinuosity and slope have significant influences for the evaluation of channel discharge. The variation of resistance coefficients for the present experimental meandering channels are found to vary with depth, aspect ratio, slope and sinuosity and are all linked to the stage-discharge relationships.

Table- 1 Details of geometrical parameters of the experimental channels

Sl.No	Item description	Highly Meander Channel (Type-III)
1.	Wave length in down valley direction	2185 mm
2.	Amplitude (e)	685 mm
3.	Geometry of Main channel section	Trapezoidal (side slope 1:1)
4.	Main channel width(b)	120 mm at bottom and 280 mm at top
5.	Bank full depth of main channel	80 mm
7.	Bed Slope of the channel	Varying
8.	Meander belt width	1650 mm
9.	Minimum radius of curvature of channel centerline at bend apex	420 mm
11.	Sinuosity	1.91
12.	Cross over angle in degree	102
13.	Flume size	2.0m×0.6m×12m long

4. MANNING’S RESISTANCE FACTORS FOR VARIOUS CHANNEL SURFACES

Distribution of energy 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. 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. Manning’s n not only denotes the roughness characteristics of a channel but also the energy loss in the flow. 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.

Suggested values for Manning's n are tabulated in Chow (1959), and Henderson (1966). Roughness characteristics of natural channels are given by Barnes (1967). 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

$$n = \frac{0.32\ S^{0.38}}{R^{0.16}} \tag{2}$$

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.

2. Limerions’s (1970) equation for natural alluvial channels

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

Where, R is the hydraulic radius and d84 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/R0.17 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.
4. LSCS method for inbank flows in meandering channels, given by James and Wark (1992):

$$\frac{n`}{n} = 0.43s + 0.5 \quad \text{for} \quad s < 1.7 \quad \text{and} \quad \frac{n`}{n} = 1.3 \quad \text{for} \quad s > 1.7 \tag{9}$$

Where, n = value of Manning coefficient due to friction only; and $n`$ = value of Manning coefficient including bend losses.

The above methods give a general guidance for the selection of n for the surface of a channel. The variation of the selected n, c, f values with depth of flow characterizing the loss of energy from in-bank depths as discussed in this paper.

5. RESULTS AND DISCUSSION

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

The experimental results for Manning’s *n* with depth of flow for in-bank flows of meander channels are plotted in Fig. 2. Manning’s *n* is found to decrease with increase of aspect ratio (ratio of width of the channel to the depth of flow) indicating that simple meander channel consumes more energy as the depth of flow increases. For this reason, with increase of aspect ratio Manning’s *n* decreases. For different slopes also Manning’s *n* varies with aspect ratio. For narrow channels the decrease in the value of *n* with depth can be mainly due to the decrease of the resistance to flow and wider channels of type III the values of *n* increases with sinuosity and channel slope. It can also be seen from Fig. 1 & 2 that for these wider channels the values of n increases with sinuosity and channel slope. Therefore it can be noted that steeper channels consume more energy than the milder/flatter channels. Again, for highly sinuous channels the values of *n* become large indicating that the energy loss is more for such channels

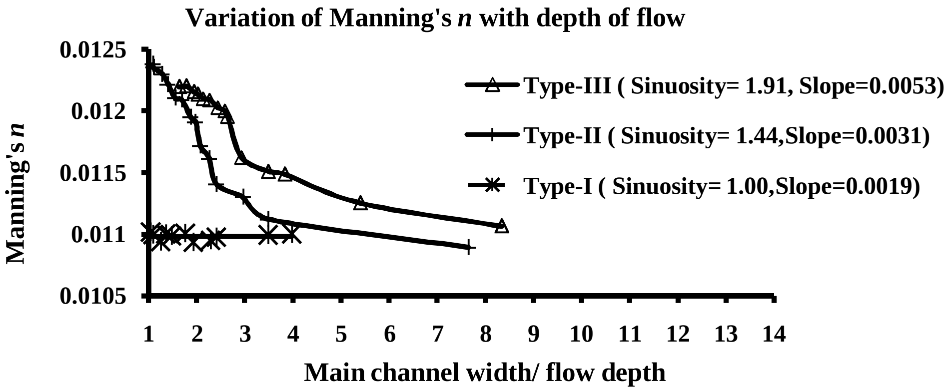

Fig-1 Variation of Manning *n* for Simple Meander Channel with varying Sinuosity

Variation of Chezy`s C with Depth of Flow for Simple Meandering Channel

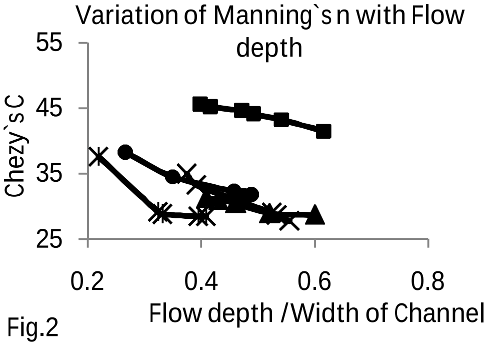

Fig-2 Variation of manning`s *n* with flow depth

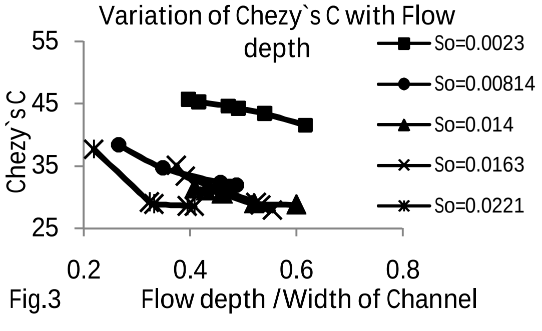

Fig-3 Variation of Chezy`s *C* with flow depth

The variation of Chezy’s *C* with depth of flow for the channels investigated for different slopes is shown in Fig.3. It can be seen from the figure that the simple meandering channels, exhibits a continuous decrease in the value of *C* with depth of flow (fig 3). Chezy`s *C* is found to decrease with increase of aspect ratio indicating that the simple meander channel consumes more energy as the depth of flow increases. For the simple meander channel flow, 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. For all depths of in-bank flow in this channel, there is additional loss of energy which continues till bank-full stage.

Variation of Darcy- Weisbach *f* with Depth of Flow for Simple Meandering Channel

The variation of friction factor *f* with depth of flow for the simple meandering channel is shown in Fig.4. The behavioral trend of friction factor *f* is nearly similar to that of the variation of Manning's *n*.

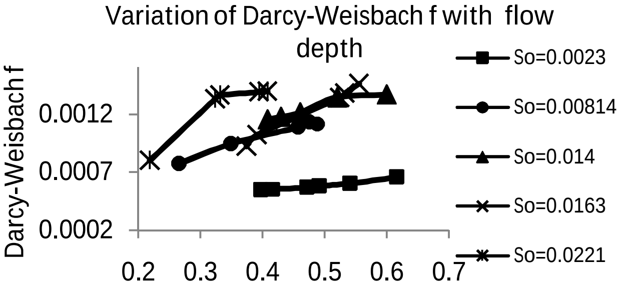

Fig.4

Fig-4 Variation of Darcy- Weisbach *f* with flow depth

Stage-Discharge Curves

The factors influencing the conveyance of meandering channels are often investigated through the mathematical technique of dimensional analysis. The stage discharge curves plotted for different bed slopes for a particular sinuosity of channel. The discharge increases with an increase in bed slope for the same stag*e*. However it should be remembered that this relationship is obtained using the available data, and therefore will be limited to the range of sinuosity used in the original experiments.

6. CONCLUSION

The following conclusions can be drawn :

1. The flow resistance in terms of Manning's n, Chezy's c and Darcy-Weisbach friction factors f changes abruptly at the bankfull stage, and varies significantly with flow depth.
2. The resistance coefficient 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 resistance coefficient in terms of n, C and f.
3. Even for simple meandering channels carrying in bank flows, the resistance 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.

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

REFERENCES

1. Acrement,G.J ., Jr; and Schneider,V.R.(1989) .''*Guide for selecting Manning's roughness coefficients for natural channels and flood plains*'' U.S. Geological Survey Water-Supply paper 2339, Federal Center,Colo.
2. Barnes, H.H., Jr.(1967) "*Roughness Characteristics of Natural Channels"* U.S. Geological Survey Water-Supply Paper 1849, 213
3. Chow, Ven Te (1959), "*Open-Channel Hydraulics*" New York, McGraw- Hill Book Co.
4. Cowan,W.L.. (1956). ''*Estimating Hydraulic roughness Coefficients.*'' Agric. Engrg, 37, 473-475.
5. Gilley, J. E. and Finkner S. C. (1991), "*Hydraulic Roughness Coefficients as Affected by Random Roughness*" Transactions of the ASAE, 34, 897–903
6. James, C. S. (1994). ''*Evaluation of methods for predicting bend loss in meandering channels*.'' Journal of Hydraulics Engg., ASCE, 120(2), 245–253.
7. James, C. S., and Wark, J. B. (1992). ''Conveyance Estimation For Meandering Channels'', Rep. SR 329, HR Wallingford, Wallingford, U.K., Dec.
8. Jana Sukanta (2007) "*Stage-Discharge Relationship in Simple Meandering Channels*", M.Tech thesis submitted at IIT, Kharagpur, India.
9. Jarrett,R.D. (1984). ''*Hydraulics of high gradient streams*'' J. Hydr. Engrg., ASCE, 110, 1519–1539.
10. Limerinos,J.T..(1970). ''*Determination of Manning's coefficients from measured bed roughness in natural channels.*'' U.S.Geological survey Water-Supply paper 1898 -B,Federal Center, Colo.
11. Pang, B. (1998). ''*River flood flow and its energy loss*.'' J. Hydr. Engrg., ASCE, 124(2), 228–231Patra, K.C., and Khatua, K. K. (2005)" *Channel Roughness in the Estimation of Discharge for Various Channel Sections",* published in the conference of HYDRO -2005.
12. Patra, K.C., and Khatua, K. K. (2005) "*Energy loss in two stage meandering and straight compound channels*" Hydro, December.2005, at Tumkur, Karnataka, India
13. Patra, K.C., and Khatua, K. K. (2006), "*Energy Loss and Discharge Estimation in Two Stage Meandering and Straight Compound Channel*", EWRI of American Society of Civil Engineers and IIT Kanpur, ASCE.