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ENERGY LOSS IN TWO STAGE MEANDERING AND STRAIGHT COMPOUND CHANNELS

Prof. Kanhu Charan Patra[1] **Mr. Kishanjit Kumar Khatua**[2]

ABSTRACT

Suggested values for Manning's n are found tabulated in Chow (1959), Henderson (1966), and Streeter (1971). Roughness characteristics of natural channels are given by Barnes (1967). 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. Patra (1999), Patra and Kar (2000), and Pang (1998) have shown that Manning's coefficient n not only denotes the roughness characteristics of a channel but also the energy loss in the flow. The larger the value of n, the higher is the loss of energy within the flow. 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 and also for meandering channels with floodplains. An investigation concerning the loss of energy of flows with depths ranging from in bank to the over bank flow, spreading the water to floodplains for meandering and straight compound channels are presented. The loss of energy in terms of Manning's n, Chezy's C, and Darcy-Weisbatch coefficient f are evaluated.

INTRODUCTION

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. Usually Chezy's, Manning's or Darcy-Weisbach equation is used to calculate the velocity of flow in an open channel. 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. 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. 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. 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 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. 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. In densely vegetated flood plains, the major roughness is caused by trees, vines, and brush. The *n* value for this type of flood plain can be determined by measuring the vegetation density of the flood plain. Photographs of flood-plain segments where *n* values have been verified can be used as a comparison standard to aid in assigning *n* values to similar floodplains.

[1]Professor, Department of Civil Engineering, National Institute of Technology, Rourkela-769008, Orissa, India
[2]Sr. Lecturer, Department of Civil Engineering, National Institute of Technology, Rourkela-769008, Orissa, India

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. 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, Se = 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, but many textbooks and technique manuals contain discussions of the factors involved in the selection. Three publications that augment this guide are Barnes (1967), Chow (1959), and Ree (1954). Although much research has been done to determine roughness coefficients for open-channel flow (Carter and others, 1963), less has been done to study the variation of n with flow depth for the same channel, more so when the channel flows overtop the banks. The roughness coefficients for these channels are typically very different from those for in bank flows. There is a tendency to regard the selection of roughness coefficients as either an arbitrary or an intuitive process. Specific procedures can be used to determine the values for roughness coefficients in channels and flood plains. 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 discussion made in this paper is limited to show the variation of the channel roughness coefficient for application to one-dimensional open-channel flow problems.

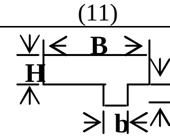
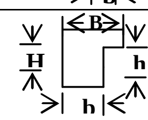
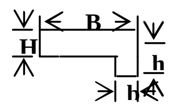
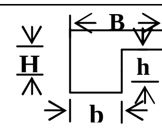
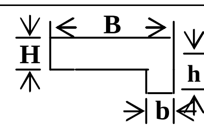
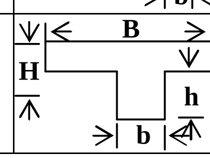
Almost all natural rivers meander. In fact straight rivers reaches of lengths exceeding ten times its width is rather rare. Meandering is a degree of adjustment of water and sediment laden river with its size, shape, and slope such that a flatter channel can exists in a steeper valley. During floods, part of the discharge of a river is carried by the main channel and the rest are carried by the floodplains located to its sides. Once a river stage overtops its banks, the cross sectional geometry of flow undergoes a steep change. The channel section becomes compound and the flow structure for such section is characterized by large shear layers generated by the difference of velocity between the main channel and the floodplain flow. Due to different hydraulic conditions prevailing in the river and floodplain, mean velocity in the main channel and in the floodplain are different. Therefore flood estimation of natural channels cannot be correct unless we incorporate a procedure to obtain the correct values of n or c for the main channel and floodplains. The usual procedure in such a compound channel using one dimensional flow analysis is to separate the compound channel into sections using a vertical, horizontal or a diagonal interface plane. Since the hydraulic parameters affecting the main channel and floodplains of a compound section are different, there is a marked difference in the values of coefficient n from in bank to over bank flow. Moreover, when the compound channel is used as single section, the value of n again becomes different. This paper also discusses the variation of n using a section as single channel and also using it as sum of more than one subsection.

EXPERIMENTAL SETUP

Experimental data from three types of channels are presented in this paper. Plan forms of the three types of meandering experimental channels with floodplains are shown in Fig.1. The summery of experiments conducted are given in Table 1. The experimental results concerning the Manning's n, Chezy's C and Darcy - Weisbach friction factor f for simple meander channels (in-bank flow) for all the three types are given in Table.2, where as for meander channels with floodplains (over-bank flow) the corresponding results are given in Table. 3. In Type-I, series-I channel, the flow is confined to in- bank only, whereas data for the over-bank flow for the same channel is given in series-II of Table 3. Type I channel is asymmetrical with two unequal floodplains attached to both sides of the main channel. Similarly Type-II and IIR channels are asymmetrical with only floodplain attached to one side of the main channel. All surfaces of the channel IIR are roughened with rubber beads of 4 mm diameter at 12 mm centre to centre. The in bank flow data of Type-II and IIR are given in series-III and V of Tables 2 and 3, while the over bank flow data are given in series IV and VI respectively in these tables. Type-III channel is symmetrical with two equal floodplains attached to both sides of the main channel. Like wise the details of in bank flow are given in series VII of Table 2 and the over bank flow are given in series VII of Table 3.

Details of the experimental setup and procedure concerning the flow and velocity observations in meandering channels with floodplains are reported earlier (Patra 1999; Patra and Kar, 2000; and Patra and Kar, 2004). The ratio α between overall width *B* and main channel width *b* of the meandering compound channels could be varied from 2.13 to 5.25 for the three types of channels. The channel sections are made from Perspex sheets for which the roughness of floodplain and main channel were identical. The observations are made at the section of maximum curvatures (bend apex) of the meandering channel geometries. Experiments are conducted utilizing the facilities available at the Water Resources and Hydraulic Engineering Laboratory of the Civil Engineering Department of the Indian Institute of Technology, Kharagpur, India.

Table 1 Summary of Experimental Runs for Meandering Channel with Floodplains at Bend Apex

Experi-ment Type	Channel surface	Bed slope	Top width *B*(cm)	Main channel width *b*(cm)	Main channel depth *h*(cm)	Depth of lower main channel	α = *B/b*	β = *(H-h)/H*	Sinuo-sity S_r	Shape of the compound channel section
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Type -I	smooth smooth smooth	0.0061 0.0061 0.0061	52.5 52.5 52.5	10 10 10	11.6 14.9 16.8	10 10 10	5.25 5.25 5.25	0.137 0.328 0.404	1.22 1.22 1.22	
Type –II a First Curvature	smooth smooth smooth	0.004 0.004 0.004	21.3 21.3 21.3	10 10 10	12.19 13.81 15.24	10 10 10	2.13 2.13 2.13	0.180 0.275 0.343	1.21 1.21 1.21	
Type -I I at next Curvature	smooth smooth	0.004 0.004	41.8 41.8	10 10	12.19 14.08	10 10	4.18 4.18	0.1796 0.2898	1.21 1.21	
Type -I IR at First Curvature	rough rough rough	0.004 0.004 0.004	21.3 21.3 21.3	10 10 10	12.22 13.71 15.24	10 10 10	2.13 2.13 2.13	0.181 0.270 0.343	1.21 1.21 1.21	
Type -I IR at next Curvature	rough rough rough	0.004 0.004 0.004	41.8 41.8 41.8	10 10 10	12.49 14.23 15.84	10 10 10	4.18 4.18 4.18	0.209 0.301 0.369	1.21 1.21 1.21	
Type -I II	smooth smooth smooth	0.00278 0.00278 0.00278	138 138 138	44 44 44	29.5 30.7 31.6	25 25 25	3.136 3.136 3.136	0.1525 0.1857 0.2089	1.043 1.043 1.043	

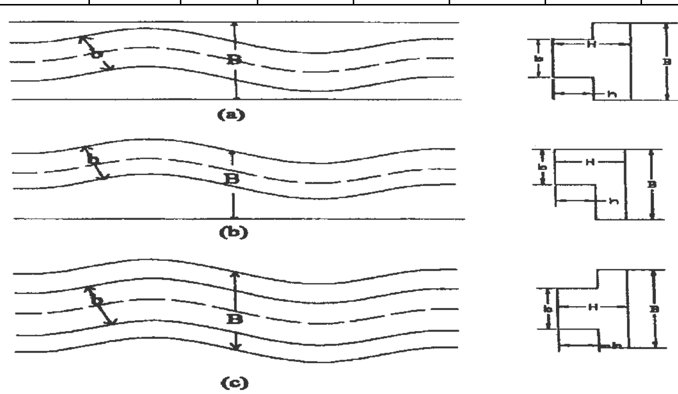


Fig. 1 Plan Forms of Meandering Experimental Channels with Floodplains

Methods to Evaluate Manning's *n*

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 use full.

1. Jarrett's (1984) equation for high gradient channels $n = \dfrac{0.32\,S^{\,0.38}}{R^{\,0.16}}$ (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) with out 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.

2. Limerions's (1970) equation for natural alluvial channels $n = \dfrac{0.0926 R^{0.17}}{1.16 + 2\log(R / d_{84})}$ (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 m^3/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 (1976) as a guideline.
4. The Cowan (1956) method for estimation of *n*, as modified by Arcement and Schneider (1989) 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); n_4 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). 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.

Table 2 Experimental and Computed Results for Simple Meander Channels

Channel Type	Run No	Discharge (Cm^3/sec)	Flow depth (cm)	Channel Width (cm)	Cross section Area (Cm^2)	Wetted Perimeter (cm)	Average Velocity (Cm/sec)	Channel Slope	Manning's Roughness *n*	($\sqrt{S_f}/n$)	Chezy's *C*	Friction Factor *f*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Type-I	1	745	5.03	10	50.3	20.06	14.89	0.0061	0.0449	1.739	12.04	0.541
Series-I	2	1470	7.52	10	75.2	25.04	19.54	0.0061	0.0386	2.023	14.44	0.376
Smooth	3	3100	9.85	10	98.5	29.70	31.47	0.0061	0.0256	3.051	22.13	0.160
Type-II	1	750	4.08	10	40.8	18.16	18.38	0.0040	0.0274	2.308	19.39	0.209
Series III	2	1088	5.09	10	50.9	20.18	21.38	0.0040	0.0254	2.490	21.28	0.173
Smooth	3	2350	7.59	10	75.9	25.18	30.96	0.0040	0.0197	3.210	28.19	0.099
	4	2900	8.65	10	86.5	27.30	34.22	0.0040	0.0185	3.419	30.40	0.085
	5	3300	9.40	10	94.0	28.80	35.11	0.0040	0.0184	3.437	30.73	0.083
Type-IIR	1	1070	4.96	10	49.6	19.92	21.69	0.0040	0.0248	2.550	21.73	0.166
Series-V	2	1520	5.94	10	59.4	21.88	25.60	0.0040	0.0223	2.836	24.57	0.130
Rough	3	1975	6.97	10	69.7	23.94	28.33	0.0040	0.0211	2.997	26.25	0.114
	4	2500	8.16	10	81.6	26.32	30.64	0.0040	0.0203	3.115	27.51	0.104
	5	2975	9.23	10	92.3	28.46	32.23	0.0040	0.0199	3.178	28.30	0.098

Type-III	1	22937	8.60	44	378.4	61.20	60.62	0.00278	0.0136	3.877	46.23	0.037
Series-VII	2	30598	10.50	44	462.0	65.00	66.23	0.00278	0.0137	3.875	47.11	0.035
Smooth	3	51675	16.20	44	712.8	76.40	72.50	0.00278	0.0149	3.539	45.02	0.039
	4	68294	20.00	44	880.0	84.00	77.61	0.00278	0.0151	3.492	45.48	0.038
	5	82822	24.00	44	1056.0	92.00	78.43	0.00278	0.0159	3.324	43.89	0.041

Table 3 Experimental and Computed Results for Meander Channels with Floodplains

Channel Type	Run No	Disch -arge (Cm^3/ sec)	Flow depth (cm)	Width of Flood Plain (cm)	Area of F.P. (Cm^2)	Perimeter of F.P. (cm)	Area of M. C. (Cm^2)	Perimeter of M.C. (cm)	Total Peri meter (cm)	Total Area (cm^2)	Average Velocity	*n*	($\sqrt{S_f}/n$)	Chezy's *C*	Friction Factor *f*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Type-I	1	3960	11.50	42.5	63.7	45.5	115.0	30.0	75.5	178.7	22.15	0.029	2.69	18.43	0.231
Series-II	2	14000	14.80	42.5	204.0	52.1	148.0	30.0	82.1	352.0	39.77	0.024	3.25	24.59	0.129
Smooth	3	19500	16.68	42.5	283.9	55.9	167.0	30.0	85.9	450.9	43.25	0.025	3.09	24.16	0.134
Type-II	1	5800	12.19	21.55	47.2	23.7	121.9	32.2	55.9	169.1	34.3	0.0179	3.53	31.20	0.0807
Series-IV	2	8450	13.95	21.55	85.1	25.5	139.5	34.0	59.5	224.6	37.62	0.0189	3.35	30.6	0.0838
Smooth	3	11200	15.43	21.55	117.0	27.0	154.3	35.4	62.4	271.3	41.28	0.0189	3.35	31.3	0.0801
Type-IIR	1	5800	12.46	21.55	53.1	24.0	124.6	32.5	56.5	177.7	32.91	0.0191	3.31	29.33	0.0912
Series-VI	2	8300	14.02	21.55	86.5	25.6	140.2	34.0	59.6	226.7	36.62	0.0195	3.24	29.69	0.0890
All Rough	3	11000	15.55	21.55	119.7	27.1	155.6	35.6	62.7	275.3	39.96	0.0197	3.21	30.14	0.0864
Type-III	1	94535	29.5	94	423.0	103.0	1298.0	94.0	197.0	1721.0	54.93	0.0189	2.79	35.24	0.063
Series-VIII	2	103537	30.7	94	535.8	105.4	1350.8	94.0	199.4	1886.6	54.88	0.0199	2.65	33.84	0.068
Smooth	3	108583	31.6	94	620.4	107.2	1390.4	94.0	201.2	2010.8	54.00	0.0210	2.51	32.40	0.074

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

Sellin et al. (1993), Pang (1998), and Willetts and Hardwick (1993) had 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.

The variation of Manning's *n* with depth of flow for the types of channels investigated show a divergent trend (Fig. 2). For the type-I, series-I channel there is a decrease in the value of *n* from run No. 1 to run No. 3 (Fig. 2a). This indicates that the simple meander channel of series - I consume less energy as the depth of flow increases. When the channel overtops and spreads its water to the adjoining floodplain (series-II), a sudden increase in the value of *n* can be noticed. This is mainly due to the increased resistance to flow in the compound section resulting from the interaction of flow between main channel and floodplain. The values of *n* decrease from run No. 1 to run No.2 (Fig. 2a). This is mainly due to the gradual completion of the process of flow interaction between the two depths of flow in the over bank flow situation. At further increase in depth of flow in the floodplain, the results show an increase in the value of *n*. The increase in the value of *n* from run No.2 to run No.3 is due to the reversal of flow interaction. At this depth the floodplain supplies momentum to the main channel.

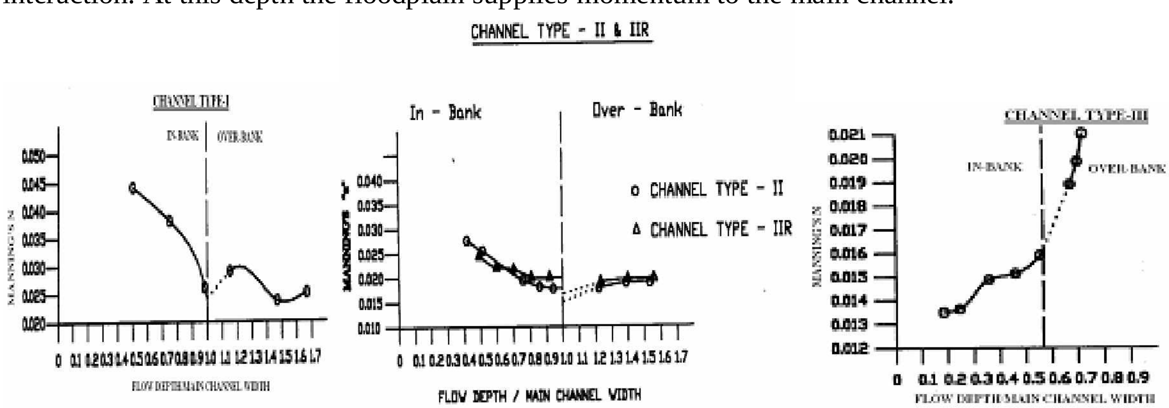


Fig.2 Variation of Manning's *n* with depth of flow from in bank to over bank conditions

For simple meander channel of type-II, series-III (Fig.2b), there is a gradual decrease in the value of *n* with increase in depth of flow from run No.1 to run No. 3. As the flow overtops the main channel and spreads to the floodplain, there is further decrease in the value of *n* from run No. 3, series III to run No.1, series IV. There after the value of Manning's *n* gradually increases to attain a steady state. The variation of Manning's *n* for channel type-II and IIR are nearly similar.

The value of Manning's *n* for the type III channel exhibit an increasing trend (Fig. 2c). For the simple meander channel flow, the increase in Manning's *n* is mainly due to the increase in strength of secondary flow induced by curvature resulting in higher loss of energy. Unlike the previous channels, the geometry and slope of this channel causes an additional loss of energy which continues for the depths of flows investigated. The increase in the value of Manning's *n* from run No. 1 to run No. 3 in the over-bank flow is mainly due to a greater energy loss resulting from the flow interaction between the channel and the floodplain flows for the ranges of depths investigated.

The above discussion indicates that 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.

Variation of Chezy's *C* with Depth of Flow

The variation of Chezy's *C* with depth of flow for the three types of channels investigated is shown in Fig. 3. It can be seen from the figure that the simple meander channel of type-I, exhibits a continuous increase in the value of *C* with depth of flow. A sudden decrease in the value of *C* can be noticed when the flow spills over to the floodplains (Fig. 3a). As the depth of flow in the floodplain increases, the value of *C* also increases and tries to attain a steady state.

For the type-II channel when the flow is confined to meander section only (series II), a gradual increase in the value of *C* can be noticed from run No -1 to run No.5 (Fig. 3b). Unlike the previous channel, the change in the value of *C* is not sudden when the water spills over to the floodplain. The channel is expected to give a steady value of *C* at still higher depths of flow in the floodplain. It can be seen that the parameter *C* for the channel type - II and II R are similar.

Channel type - III shows a gradual decrease in the value of Chezy's *C* from run No. 1 to run No. 5 in series VII, when the flow is confined to simple meander channel only (Fig. 3c). 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.

It seems that the geometry of channel of types - I, II and II R and their higher bed slope with respect to type-III channel are in a position to balance the additional loss of energy induced by curvature. That is why type-I, II and II R channels show a continuous increase in the value of *C* with depth, both for in-bank and over-bank flow situations.

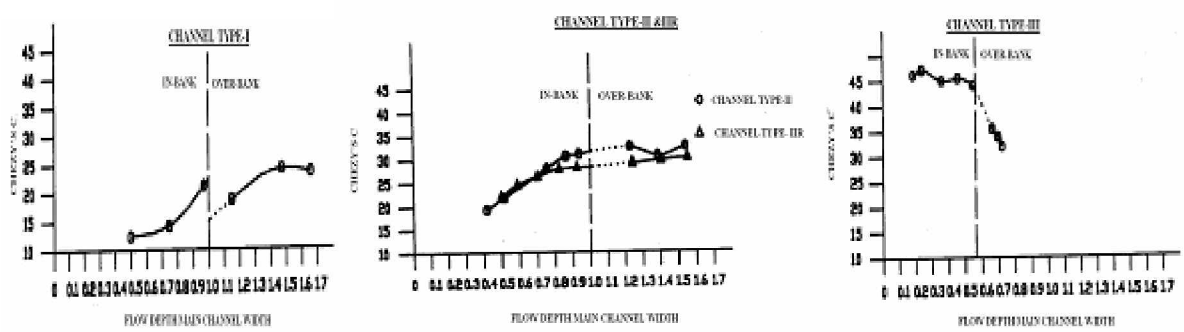


Fig.3 Variation of Chezy's *C* with depth of flow from in bank to over bank conditions

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

The variation of friction term *f* with depth of flow for the channel types I, II, IIR and III is shown in Fig.4. The behavioral trend of friction factor *f* is nearly similar to that of the variation of Manning's *n*.

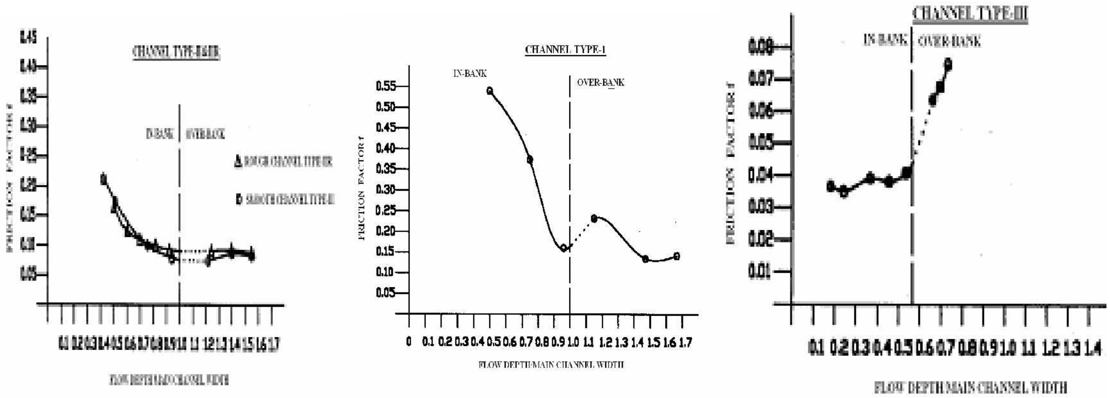


Fig.4 Variation of Darcy-Weisbach Factor *f* with depth of flow from in bank to over bank flow

Variation of Energy ($\sqrt{S_f}/n$) with Depth of Flow

To understand the energy loss that are due to more potent flow exchange mechanism in meander channel floodplain geometry, the stage-discharge data are analysed using the standard resistance equations and the single channel method. Sellin, Ervine and Willetts (1993) observed that for smooth floodplains the flow resistance coefficient of Manning's *n*, when plotted against the relative depths of flow in the channel, showed a sharp change in the *n* values, particularly when the channel is highly sinuous. Pang (1998) had also reported that Manning's roughness coefficient not only denotes the characteristics of channel roughness, but also the influence of the energy loss of flow. The larger the value of *n*, the more is the energy loss in the flow. Willetts and Hardwick (1993) studied four types of sinuous channels having the same cross section and reported that the value of Manning's *n* for a 8 mm depth of water over the floodplain could vary from 0.01 (for their straight channel) to 0.018 for the channel with sinuosity of 2.06. The variation of *n* for a floodplain water depth of 40 mm ranged from 0.0026 (for straight channel) to 0.0199 for the same channel section with sinuosity of 2.06. For highly sinuous channels the values of *n* becomes large indicating that the energy loss is more for such channels.

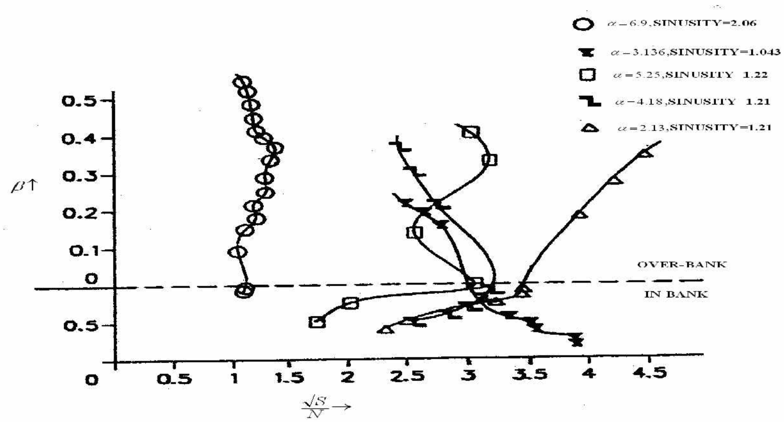


Fig.5 Variation of $\sqrt{S_f}/n$ with Relative Depth of flow β from In-bank to Over-bank conditions

In the present meandering channels, the values of $\sqrt{S_f}/n$, where S_f is the channel slope when plotted against the relative depths (Fig.5) shows a divergent trend. For wider floodplain channels, that is, channel types-I and III, there is a decrease in the values of $\sqrt{S_f}/n$ after the immediate bank full depth. For the type-I channel, the decrease is more rapid than the type-III channel. The results of energy loss from a higher sinuous trapezoidal channel data (sinuosity = 2.06) of Willetts and Hardwick (1993), plotted in the same figure shows a trend similar to the variation of $\sqrt{S_f}/n$ for channels of types I and III. The narrow floodplain (type-II) channel shows a continuous increase in the values of $\sqrt{S_f}/n$ from in-bank flow to over-bank flow as the depths of flow in the channel increases.

Variation of Manning's *n* for over-bank flows Using divided Channel Method

At just over bank flow condition there is an abrupt change in the prevailing hydraulic condition of a channel section leading to an abrupt change in the roughness coefficients of a channel. At over bank flow the mean velocity in the main channel section and that in the floodplain are different. The channel section becomes compound and the flow structure for such section is characterized by large shear layers generated due to the difference of velocity between the main channel and floodplain flow. Under such a condition, Knight et al. (1989) have shown that there is a large difference in the Manning's *n* between the main channel and floodplain to that when the channel is composite. For the River Severn the reported variation of *n* between levels 53.0 m and 61.0 m is shown in Fig. 6.

It can be seen from Fig. 6 that the floodplain values of *n* decreases with depth of flow, attains a minimum value, and then increases gradually to attain the composite value of the compound channel. On the other hand, the *n* values of main channel increases with depth of flow over main channel above the bank full stage, attains a maximum value, and then decreases gradually to attain the composite value of the compound channel. The authors want to show that this diverse behaviour of *n* should be considered, while computing discharge in the main channel and floodplain of a compound channel using 'divided channel method' else there may be errors between the actual and the computed values of discharge rate in the compound section.

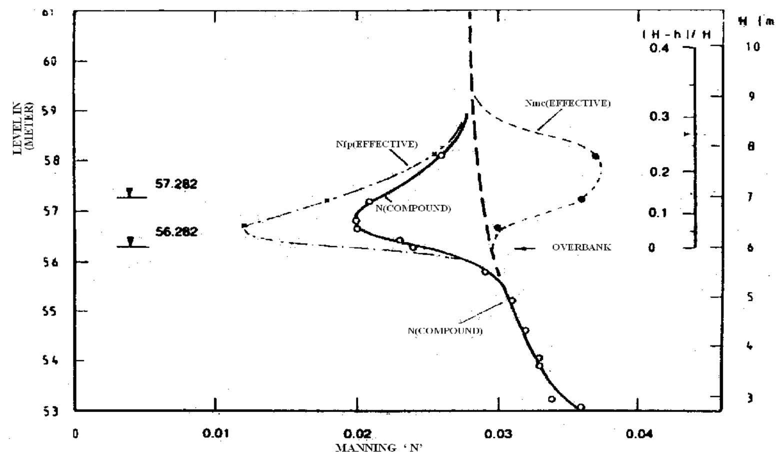


Fig.6 Variation of Manning's *n* for over-bank flow at Montfoprd, River Severn (after Knight et al. 1989)

A similar plot for the Type I of the experimental channel showing the variation of Manning's *n* with depth of flow for the main channel and floodplain of the compound section (Fig. 7). The behaviour of *n* for the main channel and floodplain to that when the channel is composite to a single section are similar to that of the Fig. 6. Using a horizontal interface plane, the values of *n* are found to be more close (Fig. 7a) to the composite value of the compound section than using a vertical plane of separation (Fig. 7b) of the compound channel.

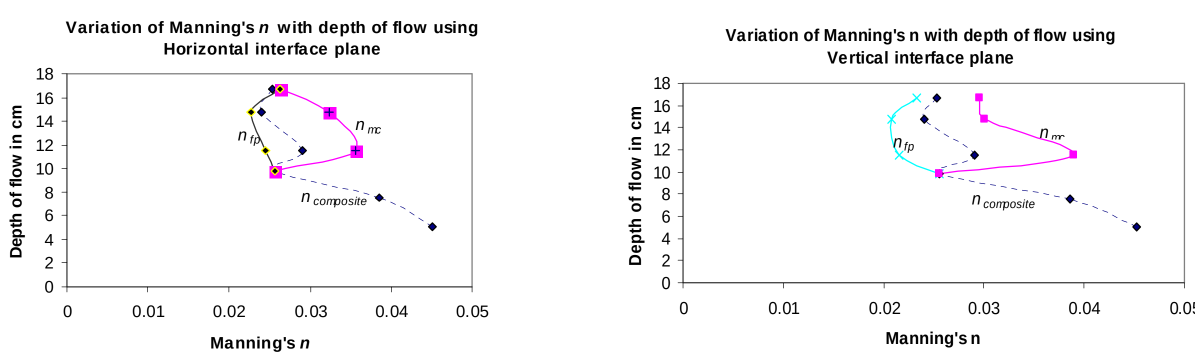


Fig.7 Manning's *n* for over-bank flow showing its variation in the main channel/floodplain to that when the channel is composite

CONCLUSIONS

The following conclusions are drawn from the above discussions

1. 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*.
2. 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.
3. 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*.
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.
5. No trend in the energy loss parameter $\sqrt{S_f}/n$ could be established for the five types of channels investigated when plotted for their values ranging from in bank to over bank flows.
6. 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.
7. 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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