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Energy loss for a highly Meandering open Channel Flow

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Abstract

Flow in meandering channel is quite ubiquitous for natural flow systems such as in rives. Rivers generally follow this pattern for minimization of energy loss. However, several factors such as environmental condition, roughness are responsible for generation of this path for rivers. Selection of proper value of Roughness coefficient is essential for evaluating the actual carrying capacity of Natural channel. An excessive value underestimates the discharge and a low value can over estimates. Suggested values for Manning's n are found tabulated in many standard articles. The resistance to the flow in a river is dependent on a number of flow and surface and geometrical 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 Manning's n .It is seen 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. Experimental investigations concerning the loss of energy of flows for a highly meandering channel for different flow condition, geometry are presented.

Keyword: Meandering channel, sinuosity, manning's coefficient, energy loss, discharge.

Introduction

Natural streams, rivers, and man-made surface drainage channels often found to be sinuous in nature. Improper estimation of discharge due to occurrence of high rainfall and other factors causes extensive damage to nearby properties and, loss of life in many parts of the world. Prediction of the stage or the depth of water for a particular discharge in meandering channels is the vital factor for flood forecasting, flood management and design of hydraulic structures.

Discharge estimation methods currently employed in meandering channel are established on historic hand calculation formulae such as Chezy's, Darcy-Weisbatch or Manning's equation. Already Researchers has provided significant improvements in accepting and calculation of channel discharge which are mainly for straight reaches. This ranges from the acquisition knowledge to analysis of the complex flow mechanisms to the advent of computing tools that enable more sophisticated solution techniques. Natural rivers are meander. 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. Normally roughness coefficients vary significantly in case of meandering channel as compared to straight channel. Therefore the roughness coefficients selected are either arbitrarily or by an intuitive process. The n values for meandering channels needs to be determined by estimating the effects of both geometry factors and sinuosity effects. The study made in this paper is to show the variation in loss of channel energy due to different flow conditions of a highly meandering channel.

Manning's Resistance Factors for Various Channel Surfaces: Distribution of energy in a meandering 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. 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[1-4] have shown that 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.

Due to flow interaction between the main channels, the flow in a highlymeandering section consumes more energy. 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 are discussed. The values of n are determined from the factors that influence the roughness of a channel.

Suggested values for Manning's n are tabulated[5-6]. Roughness characteristics of natural channels are given by patra and kar[2].

However there are large numbers of formulae and procedures available to calculate Manning's n for a river reach, the following four methods are found to be more useful.

The equation for high gradient channels $n = \dfrac{0.32\, S^{0.38}}{R^{0.16}}$ (5)

Where S, R are the channel gradient and hydraulic radius in meters. The equation was developed by Jarrett 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[7].

The equation for natural alluvial channels

$$n = \frac{0.0926 R^{0.17}}{1.16 + 2\log(R/d_{84})} \quad (6)$$

Where R, d_{84} are the hydraulic radius and 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 $R > 30$[8]. i. Visual estimation of n values can be performed at each site using[9] as a guideline. ii. The method for estimation of n by Cowan[10], as modified by Schneider [11] is designed specifically to account for floodplain resistance given as

$$n = (n_b + n_1 + n_2 + n_3 + n_4)\, m \quad (7)$$

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. This equation was verified for wooded floodplains with flow depths from 0.8-1.5 m[10].

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.

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Methodology

Experimental Setup: For carrying out research in meandering channels, experimental setup was built in Fluid mechanics and Hydraulics Laboratory of NIT, Rourkela. A meandering channel having trapezoidal main channel (bottom width 0.33m,depth 0.065m and side slope 1:1and wide rectangular floodplains having total width 3.95m was built inside a steel tilting flume of around 15m length(figure-1) was built inside a steel tilting flume. The bed and wall of channel was made with Perspex sheet (6 to 10 mm thick and having Manning's n value=0.01) cut to designed shape and dimension, glued with chemicals and put in position.

The main channel is a sine generated curve of one and half wave length (λ=3.970m) and preceded and followed by a straight portion jointed with a transitional curved portion in order to have proper flow field developed in the test reach which is at the second bend apex of the central curve. Water was supplied to the flume from an underground sump via an overhead tank by centrifugal pump (15 hp) and recirculate to the sump after flowing through the simple channel and a downstream volumetric tank fitted with closure valves for calibration purpose. Water entered the channel bell mouth section via an upstream rectangular notch specifically built to measure discharge in such a wide laboratory channel. An adjustable vertical gate along with flow straighteners was provided in upstream section sufficiently ahead of rectangular notch to reduce turbulence and velocity of approach in the flow near the notch section. At the downstream end another adjustable tail gate is provided to control the flow depth and maintain a quasi-uniform flow in the channel. A movable bridge was provided across the flume for both span wise and stream wise movements of men and instrument over the channel area so that each location on the plan of meandering channel could be accessed for taking measurements. Figure-1 (A-D) shows photos of some distinct components of experimental set up. The dimensions of the meandering channel were adopted keeping in view the larger research goals of velocity (Width ratio,$\alpha \approx 12$and aspect ratio =5 as seen in natural channels) of varying sinuosity (0-5).However the present case relates to a channel with sinuosity value equal to 4.11.

Point velocities were measured along verticals spread across the main channel as to cover the width of entire cross section. Also at a no. of horizontal layers in each vertical, point velocities were taken. The lateral spacing of grid points over which measurements were taken was kept 4cm inside the main channel and 8cm on the flood plain. Velocity measurements were taken by pitot static tube (outside diameter 4.77mm) and two piezometers fitted inside a transparent fiber block fixed to a wooden board and hung vertically at the edge of flume the ends of which were open to atmosphere at one end and connected to total pressure hole and static hole of pitot tube by long transparent PVC tubes at other ends. Before taking the readings the pitot tube along with the long tubes measuring about 5m were to be properly immersed in water and caution was exercised for complete expulsion of any air bubble present inside the pitot tube or the PVC tube. Even the presence of a small air bubble inside the static limb or total pressure limb could give erroneous readings in piezometers used for recording the pressure.

Table-1
Summary of experimental Results for highly Meander Channel

S. No	Item description	Present Experimental Channels
1	Channel Type	Meandering
2	Flume size	4.0m×15m×0.5m long
3	Geometry of Main channel section	Trapezoidal (side slope 1:1)
4	Nature of surface of bed	smooth and rigid bed
5	Channel width	33cm at bottom and 46 cm at top
6	Bank full depth of channel	6.5cm
7	Bed Slope of the channel	0.0016
8	Sinuosity	4.11

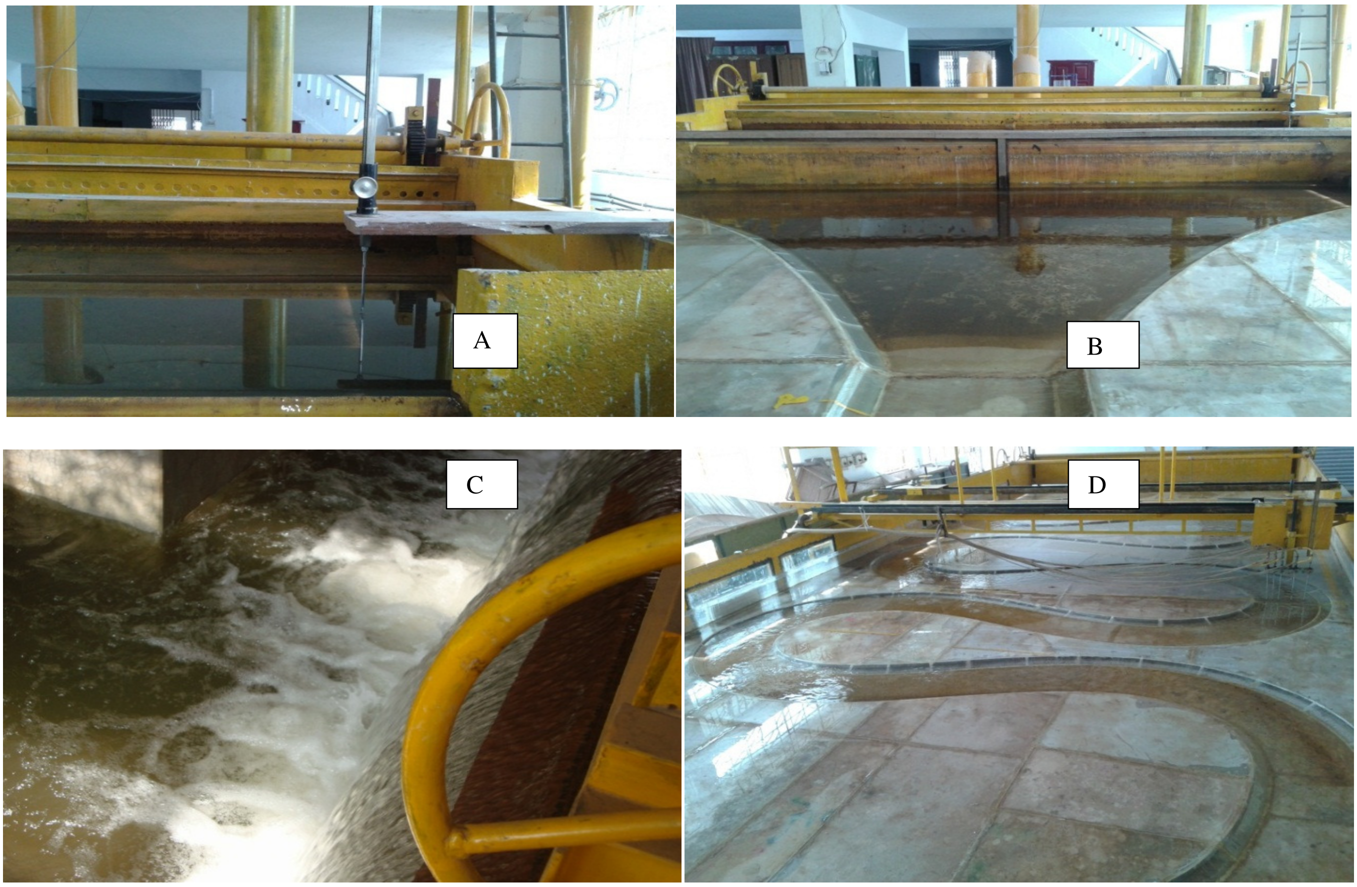

Figure-1
(A-D)Top to bottom: (A) Inlet section showing adjustable gate, notch, bell mouth etc.(B)point gauge present above the water surface(C)Channel looking towardsU/S showing the test section, (D)D/S volumetric tank

Results and Discussion

A major area of uncertainty in a river channel analysis is the accuracy in predicting the discharge carrying capability of river. The discharge calculation for channel is based mainly on refined one dimensional analysis using the conventional Manning's, Chezy's or Darcy-Weischbach equation given as

$$V = \frac{1}{n} R^{2/3} S_e^{1/2} \quad (4)$$

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, and n = Manning's roughness coefficient

Chezy's equation is written as $$V = C\sqrt{RS_e} \quad (5)$$

And Darcy-Weishbatch equation is given as

$$V = \left(\frac{8g}{f}\right)\sqrt{RS_e} \quad (6)$$

where C the Chezy's roughness coefficient, f the Darcy-Weischbach roughness coefficient, and g gravitational acceleration.

It is explained that the Manning's roughness coefficient not only denotes the characteristics of channel roughness but also influences the energy loss of the flow[4,12,13]. For sinuous channels the values of n become large indicating that the energy loss is more for such channels. The experimental results for Manning's n with depth of flow for simple meander channels are plotted in figure-2. 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 figure is that steeper channels consume more energy than the flatter channels. The detailed calculation of roughness coefficients are tabulated in table.2.

Variation of Manning's n with Depth of Flow: The experimental results for Manning's n with depth of flow for the present highly meandering channels investigated are plotted in figure - 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 highly meander channel consumes more energy as the depth of flow increases. So, with increase in aspect ratio Manning's n decreases. Manning's n also varies with aspect ratio for different depth.

Table-2
Details of Hydraulic parameters of the experimental runs

Depth of flow in cm	Length in cm	Discharge in cm3	Area in cm2	Perimeter	Slope	n	C	f
1.33	339	1486.977723	64.57143562	34.88090404	0.00165	0.012344	41.79417	0.044929
2.43	339	2128.867653	121.7565752	36.43653896	0.00165	0.024102	23.61874	0.140684
2.5	339	2197.170363	125.5114537	36.53553391	0.00165	0.024521	23.32247	0.144281
3.53	339	3462.357524	182.3641117	37.99217388	0.00165	0.028258	21.39873	0.171389
3.55	339	3542.564608	183.4977453	38.02045815	0.00165	0.027891	21.69993	0.166664
4	339	4205.808126	209.3036072	38.65685425	0.00165	0.028932	21.32435	0.172587
4.55	339	5361.43142	241.6219227	39.43467171	0.00165	0.028452	22.13571	0.160167
4.9	339	5830.202203	262.6336007	39.92964646	0.00165	0.029816	21.37391	0.171787
5	339	6214.536252	268.7005769	40.07106781	0.00165	0.028989	22.05461	0.161347
5.4	339	7210.42185	293.2513243	40.63675324	0.00165	0.028636	22.60155	0.153632
5.6	339	7622.385406	305.6964036	40.91959595	0.00165	0.028897	22.52678	0.154654

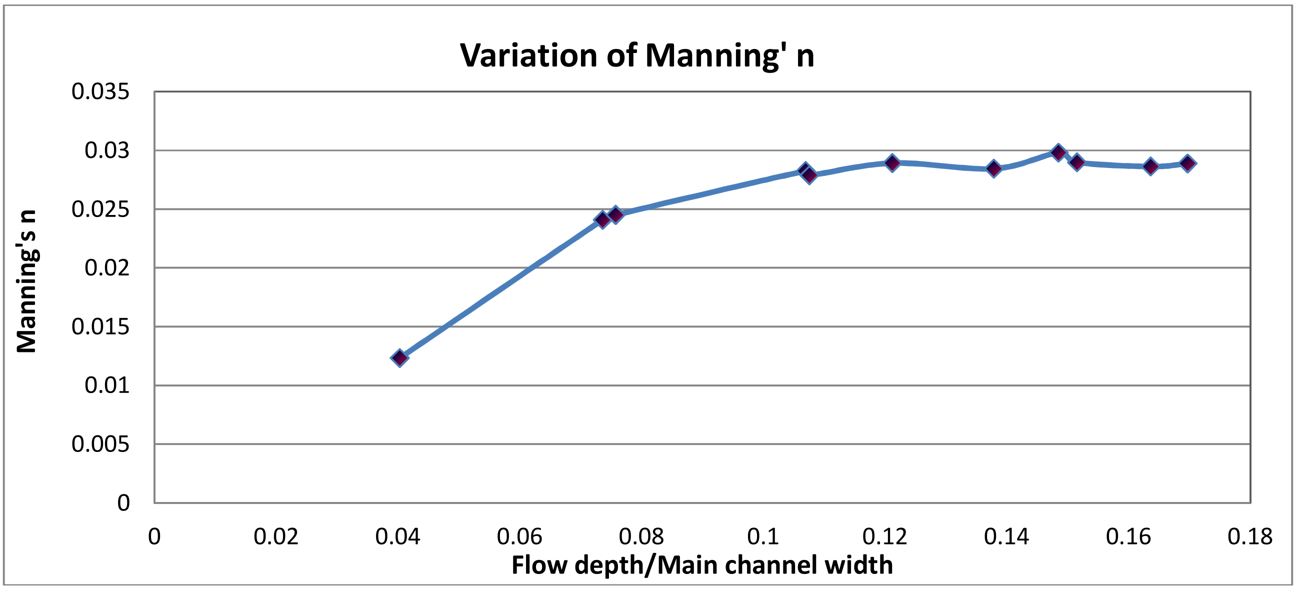

Figure-2
(Variation of Manning's n with Depth of Flow)

Variation of Chezy`sC with Depth of Flow in Open Channel: The variation of Chezy's C with depth of flow for the highly meandering channels investigated for different depth of flows is shown in figure-3. It can be seen from the figure that the meandering channels, exhibits a steady decrease in the value of C with depth of flow. Chezy's C is found to be constant at higher depth of flow. So it can be suggested that the Chezy's formula can be applicable to predict stage-discharge relationship more correctly as compared to other formulas mainly for highly meandering channels at higher depths of flow only.

Variation of Darcy-Weisbachf with Depth of Flow in Open Channel: The variations of friction factor f with depth of flow for the present meandering channels are shown in figure -3. The behavioral trend of friction factor f is also increasing with flow depth. From the figure-4 it is seen that the roughness coefficients n and f are behaving in similar manner because, the relationship between the coefficients with hydraulic radius (R) can be expressed as $f = \frac{8g}{R^{1/3}} n^2$.

Here it can be suggested that the Darcy-weisbach formula can also be applicable to predict stage-discharge relationship more correctly as compared to Manning's formulas mainly for highly meandering channels at higher depths of flow only. The behavior may change for other slope conditions. The authors are now further processing to see the behavioral trends of the roughness coefficients of a highly meandering channel due to higher and lower slopes.

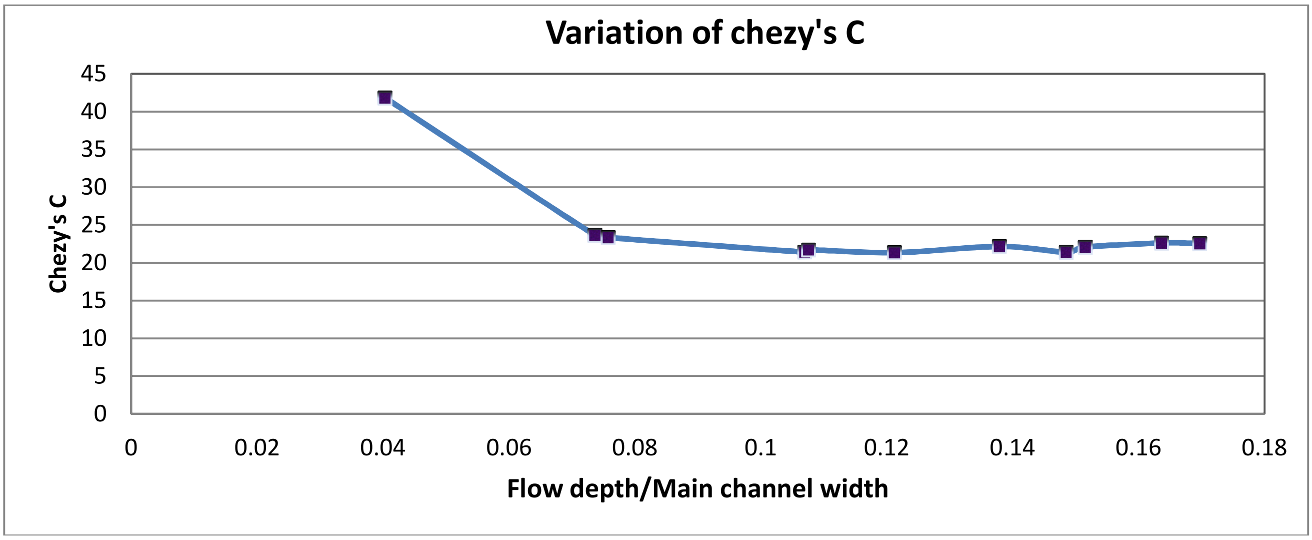

Figure-3
(Variation of Chezy'sC with Depth of Flow)

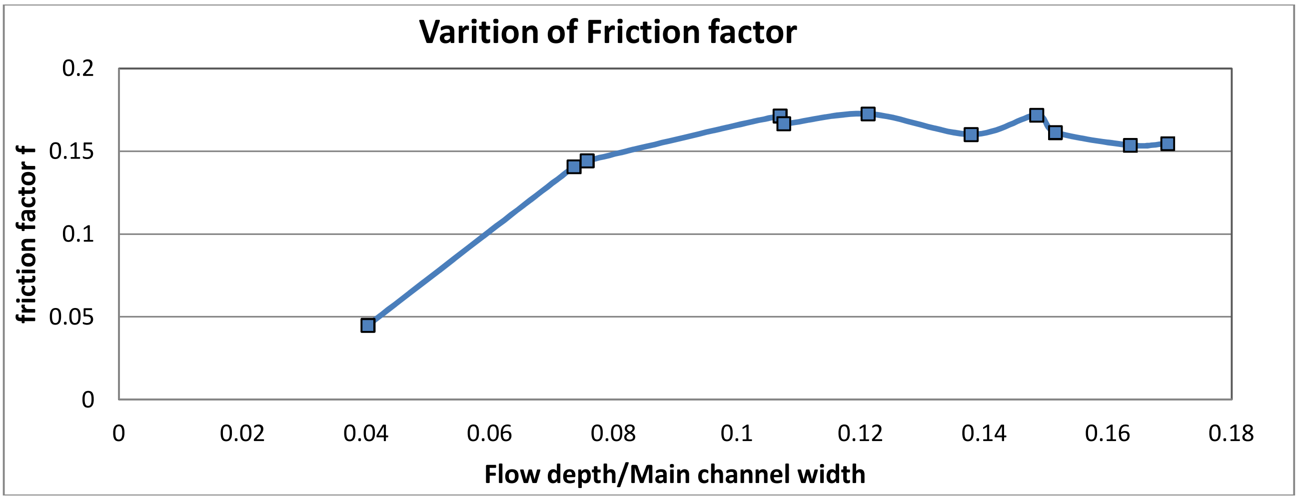

Figure-4
(Variation of Friction factor f with Depth of Flow)

Conclusion

Experiments are carried out to examine the effect of channel sinuosity, and cross section geometry and flow depths on the prediction of roughness coefficients in a highly meandering channel (Sr = 4.11). Based on analysis and discussions of the experimental investigations certain conclusions can be drawn.

The conclusions from the present work are as discussed below: i. The flow resistance in terms of Manning's n, Chezy'sC and Darcy-Weisbach friction factors f changes with flow depth for a meandering channel. The resistance coefficient not only denotes the roughness characteristics of a channel but also the energy loss of the flow. The assumption of an average value of flow resistance coefficient in terms of Manning's n for all depths of flow results in significant errors in discharge estimation. ii. The Manning's n, Chezy's C and Darcy-Weisbach friction factors f are found to very significantly for low aspect ratio. The variation is less for higher depth of flow. iii. The variation of Chezy's C and Darcy-Weisbach friction factors f are found to be less as compared to Manning's n for the present highly sinuous meandering channel. iv. It is recommended that for lowere flow depths proper model to establish the relationship of roughness coefficients are required for a meandering channel. However for higher depth of flow of a highly meandering channel, Chezy's and Darcy-Weisbach formulas can be applied directly to estimate the stage-discharge relationships directly.

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