Modelling of Bed Roughness with variations in Flow Parameters

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Abstract - *Estimation of open channel bed roughness is a topic of continued interest. Many research works have been done on open channel bed resistance. Depending upon the bed conditions of the open channel, Mannings' roughness coefficient, velocity of flow, depth of flow, Froude's number and other flow parameters varies. In this study the modeling of the effect of flow parameters on the estimation of bed roughness for various bed condition has been proposed.*

***Key Words*: Mannings' roughness co-efficient, velocity of flow, depth of flow, Froude's number and bed roughness.**

1.INTRODUCTION

The flow in open channel is governed by various forces, component of gravity due to bed slope, inertia force, surface tension, viscous force and force of resistance due to friction, shear-opposing gravity component due to surface roughness. The resistance due to bed roughness plays an important role in open channel flow. The flow parameters, that are the depth of flow, flow velocity, Froude's number etc. varies with the variation of bed roughness in open channel flow. The various equations governing the open channel flow resistance are:

Chezy's formula

$$V = C\sqrt{Rs} \qquad [1]$$

Manning's formula

$$V = \frac{1}{n}R^{2/3}s^{1/2} \qquad [2]$$

Where C and n are known as Chezy's and Manning's coefficients respectively and their values for different surfaces with different roughnesses are determined by experiments. Although both are coefficients they are not dimensionless. From equations [1] and [2] the dimensions of C and n are obtained to be $L^{1/2}T^{-1}$ and $^{L-1/3}T$ respectively.

Out of the two roughness coefficients, Manning's n is popular and widely used by investigators. This n mainly depends on surface roughness and factors like vegetation cover, cross-section a irregularity, channel silting, scouring, obstruction and stage or depth of flow.

Another resistance coefficient is Darcy's coefficient of friction which is dimensionless. The equation is obtained to be

$$V = \sqrt{\frac{8g}{f}}\sqrt{Rs} \qquad [3]$$

Where V is velocity of flow, g is acceleration due to gravity and f is Darcy's coefficient of friction.

The three coefficients C, n and f can be related by the equation:

$$C = \frac{1}{n}R^{1/6} = \sqrt{\frac{8g}{f}} \qquad [4]$$

Equation [4] gives the relationship among C, n and f in open channel.

2. METHODOLOGY

Zhou, J., and Zeng, C., (2009) proposed a hybrid LES-RANS model which combines the large eddy simulation (LES) model with the Reynolds-averaged Navier-Stokes (RANS) model to accurately predict the mean flow and turbulence characteristics of open channel T-diversion flows [14].
Huthoff, F., et.al., (2012) studied two cases of flows in natural vegetated water-ways, case 1: fixed point flow measurements in a Green river and case 2: vessel borne flow measurements along a cross-section with flood plains in the river Rhine to investigate the bed roughness properties and to compare these to predictions from the vegetation roughness model proposed by Huthoff *et al* [8].
Gao, G., et.al., (2011) investigated the effect of vegetation on the flow structure, and acquired accurate velocity profiles with the help of three dimensional model, using two layer mixing length model [4].
Hamimed, A., et.al., (2013) investigated the influence density and placement of emergent vegetation on flow resistance, water depth and velocity profile [7].

Folorunso, O.P., (2015) measured and quantified the hydraulic resistance of an open channel with grass and gravel bed placed alternately in the form of checkerboard configuration [3].
Ramesh, R., et.al. (2000) proposed a new approach in order to estimate roughness coefficients in a channel system for flow into a non-linear optimization model by directly embedding the finite-difference approximations of the governing equations as equality constraints.
Dash Saine S, et.al., (2013) presented experimental investigations concerning the loss of energy of flows for a highly meandering channel for different flow condition, geometry [11].
Rhee, D.S., et.al., (2007) used three Korean natural vegetations Zoysia matrella (Korean zoysia), Pennisetum alopecuroides (L.) Spreng. (Korean native vegetation) and Phragmites communis Trin. (Korean reed) in flume tests to see the effect of vegetation in the channel on flow resistance.
Kahrizeh, H.G., et al., (2015) obtained effective dimensionless parameters using dimension equation. N= f (sf, R/ks ,Re*,Fr), where sf, y / ks, Re *, Fr are dimensionless parameters [12].

3. EXPERIMENTAL SET-UP

The experiment was performed in a 6m long and 0.3m wide rectangular glass flume with metal bed at Water Resource laboratory in Assam down town University, Guwahati. Different bed conditions were made artificially, using grass carpet and coconut coir mat for rough bed condition and PVC material and original metallic bed for smooth bed condition. The flow depths were measured and various flow parameters were calculated.

Fig-1: Rectangular channel of 6m length, 0.3m width and 0.46m depth.

Fig-2: Figure showing the upstream of the channel.

Fig-3: Figure showing the downstream of the channel.

Five cases were studied for different bed conditions. The cases are tabulated below.

Table-1: Different cases of bed conditions of the channel

Number of Cases	Bed condition of the Channel
Case A	Original bed material
Case B	PVC
Case C	Grass carpet
Case D	Coconut coir mat
Case E	Coconut coir mat with stone

4. MATHEMATICAL MODELLING OF BED ROUGHNESS

The mathematical modelling of bed roughness with respect to variation of flow parameters for different bed conditions are presented. The spreadsheet calculations were performed in order to obtain the values of Mannings's roughness coefficient and other flow parameters. Relation of Mannings' roughness coefficient with depth of flow, and Froude's number are obtained using regression equations and graphical analysis.

4.1. Variation of Mannings' roughness coefficient (n) with depth of flow (y)

4.1.1. For original bed of the channel

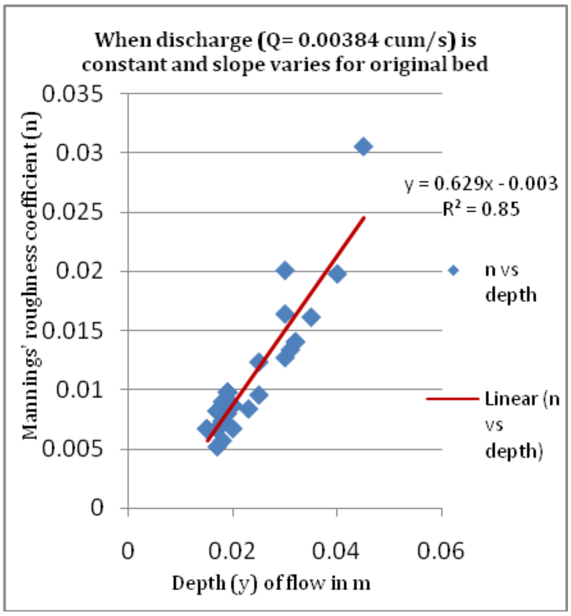

Chart-1: Variation of Mannings' n with depth (y) of flow for original bed.

The variation of Mannings' n with depth of flow for original bed condition is shown in the above figure. The discharge is kept constant at Q= 0.00384 cum/s and the slope of the channel varies as s_1= 1:100, s_2= 1:150 and s_3= 1:250. The value of linear regression coefficient is obtained as 0.85.

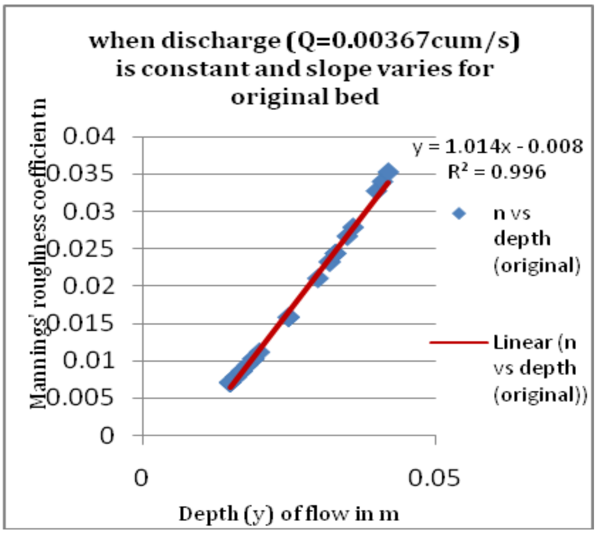

Chart-2: Variation of Mannings' n with depth (y) of flow for original bed.

The variation of Mannings' n with depth of flow for original bed condition is shown in the above figure. The discharge is kept constant at Q= 0.00367 cum/s and the slope of the channel varies as s_1= 1:100, s_2= 1:150 and s_3= 1:250. The value of linear regression coefficient is obtained as 0.996.

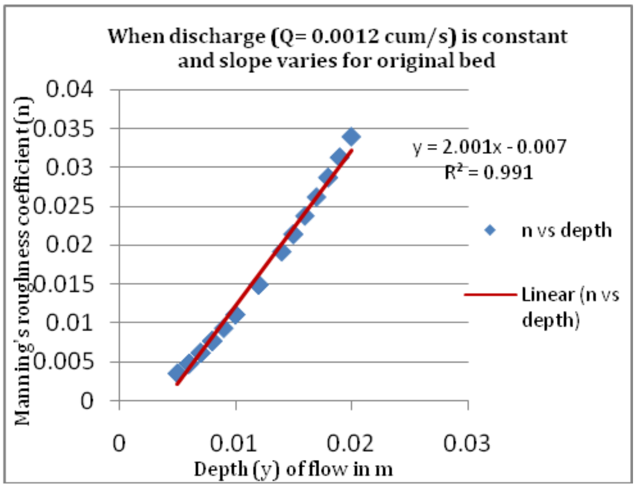

Chart-3: Variation of Mannings' n with depth (y) of flow for original bed.

The variation of Mannings' n with depth of flow for original bed condition is shown in the above figure. The discharge is kept constant at Q= 0.0012 cum/s and the slope of the channel varies as s_1= 1:100, s_2= 1:150 and s_3= 1:250. The value of linear regression coefficient is obtained as 0.991.

4.1.2. For PVC bed material

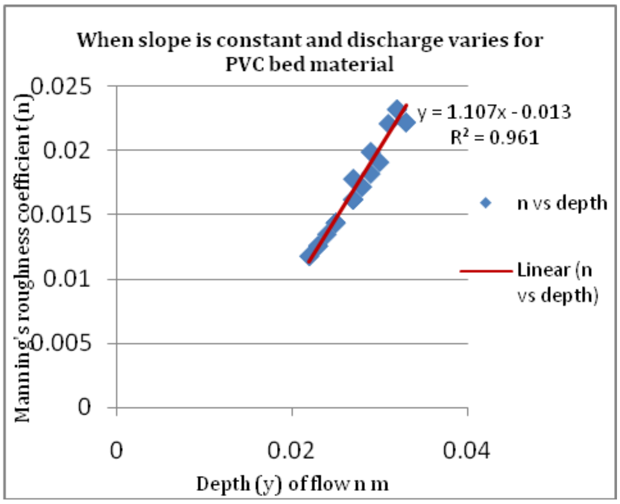

Chart-4: Variation of Mannings' n with depth (y) of flow for pvc as bed material.

The variation of Mannings' n with depth of flow for PVC as bed material is shown in the above figure. The slope of the channel is kept constant and the discharge to the channel varies as Q_1= 0.0338 cum/s, Q_2= 0.00295 cum/s and Q_3= 0.0025 cum/s. The value of linear regression coefficient is obtained as 0.961.

4.1.3. For grass carpet as bed material

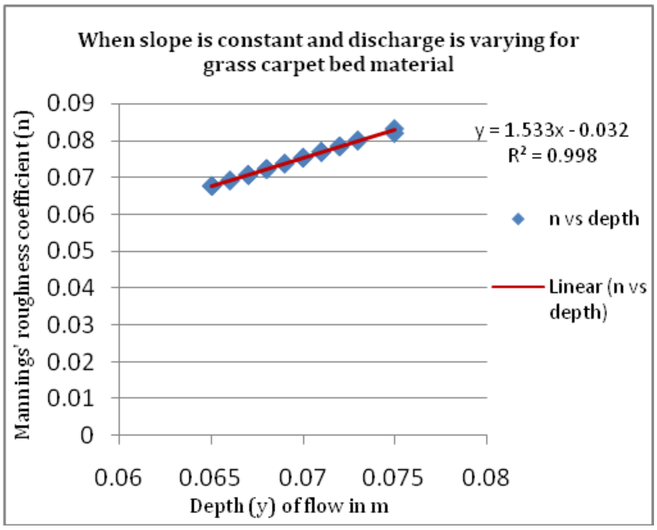

Chart-5: Variation of Mannings' n with depth (y) of flow for grass carpet as bed material.

The variation of Mannings' n with depth of flow for grass carpet as bed material is shown in the above figure. The slope of the channel is kept constant and the discharge to the channel varies as Q_1= 0.0338 cum/s, Q_2= 0.00295 cum/s and Q_3= 0.0025 cum/s. The value of linear regression coefficient is obtained as 0.961.

4.1.4. For coconut coir mat as bed material

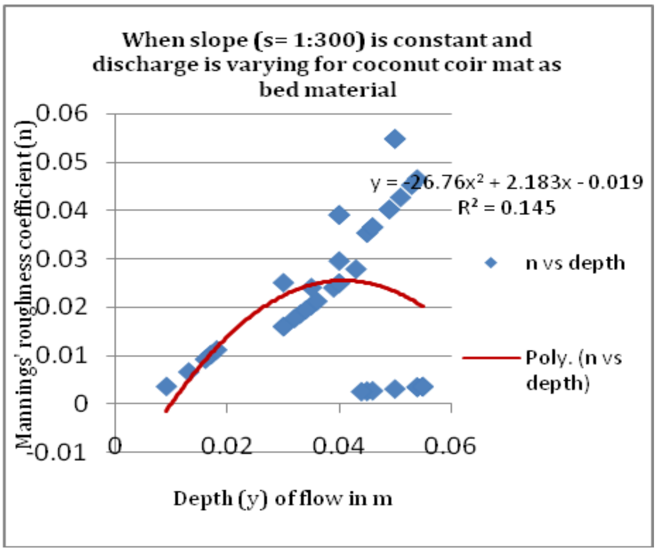

Chart-6: Variation of Mannings' n with depth (y) of flow for coconut coir mat as bed material.

The variation of Mannings' n with depth of flow for coconut coir mat as bed material is shown in the above figure. The slope of the channel is kept constant at s= 1:300 and the discharge to the channel varies as Q_1= 0.0039375 cum/s, Q_2= 0.00234 cum/s, Q_3= 0.00277 cum/s and Q_4= 0.00177 cum/s. The value of polynomial regression coefficient is obtained as 0.145.

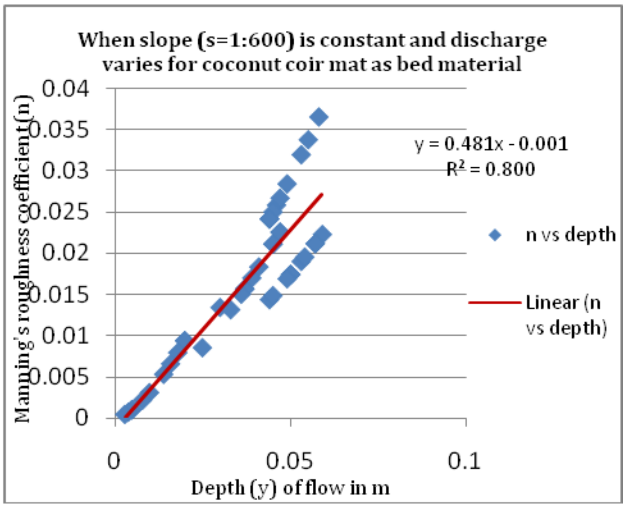

Chart-7: Variation of Mannings' n with depth (y) of flow for coconut coir mat as bed material.

The variation of Mannings' n with depth of flow for coconut coir mat as bed material is shown in the above figure. The slope of the channel is kept constant at s= 1:600 and the discharge to the channel varies as Q_1= 0.0039375 cum/s, Q_2= 0.00234 cum/s, Q_3= 0.00277 cum/s and Q_4= 0.00177 cum/s. The value of linear regression coefficient is obtained as 0.800.

4.1.5. For coconut coir mat and stone as bed material

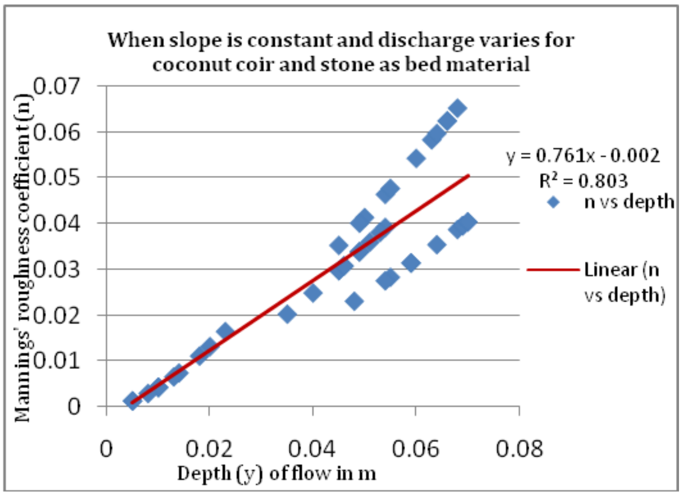

Chart-8: Variation of Mannings' n with depth (y) of flow for coconut coir mat and stone as bed material.

The variation of Mannings' n with depth of flow for coconut coir mat as bed material is shown in the above figure. The slope of the channel is kept constant and the discharge to the channel varies as Q_1= 0.0039375 cum/s, Q_2= 0.00234 cum/s, Q_3= 0.00277 cum/s and Q_4= 0.00177 cum/s. The value of linear regression coefficient is obtained as 0.803.

4.2. Variation of Mannings' roughness coefficient (n) with Froude's number (F)

4.2.1. For original bed of the channel

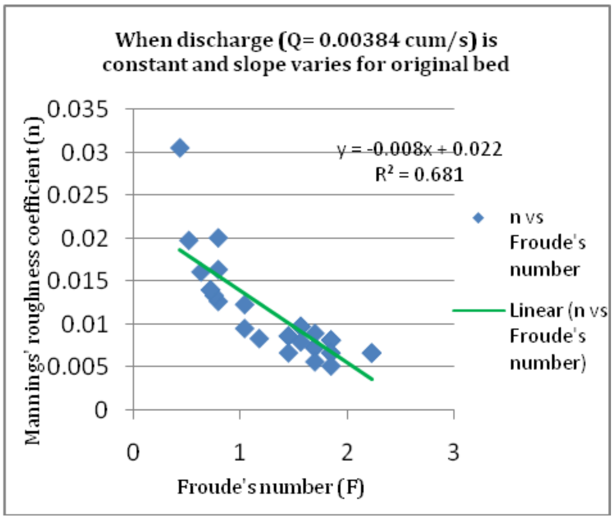

Chart-9: Variation of Mannings' n with Froude's number (F) for original bed.

The variation of Mannings' n with Froude's number for original bed condition is shown in the above figure. The discharge is kept constant at Q= 0.00384 cum/s and the slope of the channel varies as s_1= 1:100, s_2= 1:150 and s_3= 1:250. The value of linear regression coefficient is obtained as 0.681.

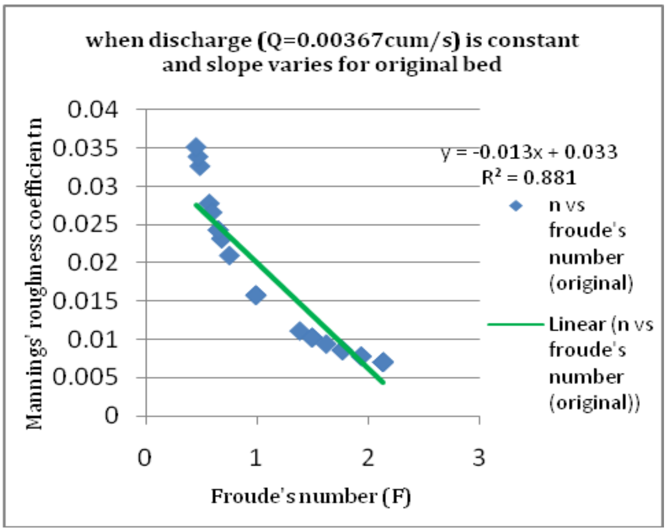

Chart-10: Variation of Mannings' n with Froude's number (F) for original bed.

The variation of Mannings' n with Froude's number for original bed condition is shown in the above figure. The discharge is kept constant at Q= 0.00367 cum/s and the slope of the channel varies as s_1= 1:100, s_2= 1:150 and s_3= 1:250. The value of linear regression coefficient is obtained as 0.881.

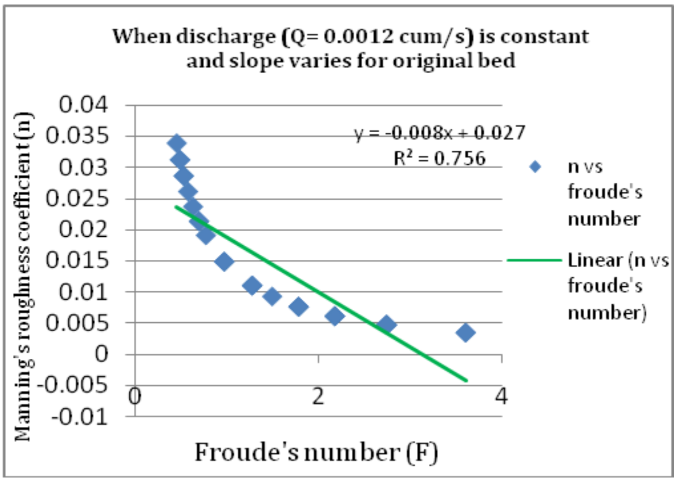

Chart-11: Variation of Mannings' n with Froude's number (F) for original bed.

The variation of Mannings' n with Froude's number for original bed condition is shown in the above figure. The discharge is kept constant at Q= 0.0012 cum/s and the slope of the channel varies as s_1= 1:100, s_2= 1:150 and s_3= 1:250. The value of linear regression coefficient is obtained as 0.756.

4.2.2. For PVC bed material

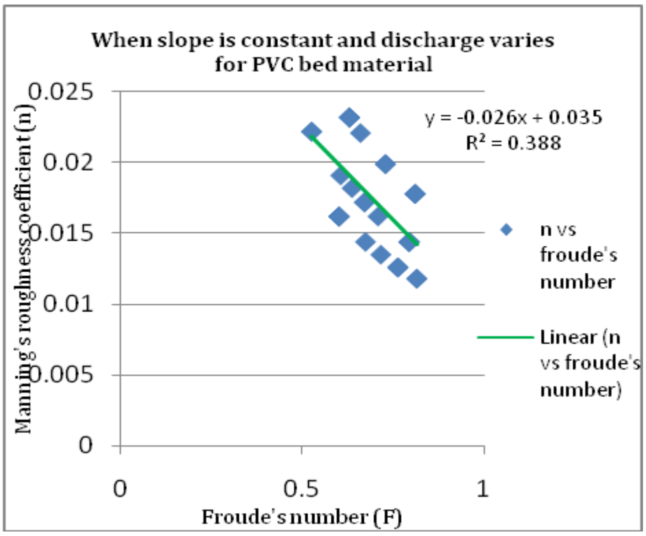

Chart-12: Variation of Mannings' n with Froude's number (F) for pvc as bed material.

The variation of Mannings' n with Froude's number (F) for PVC as bed material is shown in the above figure. The slope of the channel is kept constant and the discharge to the channel varies as Q_1= 0.0338 cum/s, Q_2= 0.00295 cum/s and Q_3= 0.0025 cum/s. The value of linear regression coefficient is obtained as 0.388.

4.2.3. For grass carpet as bed material

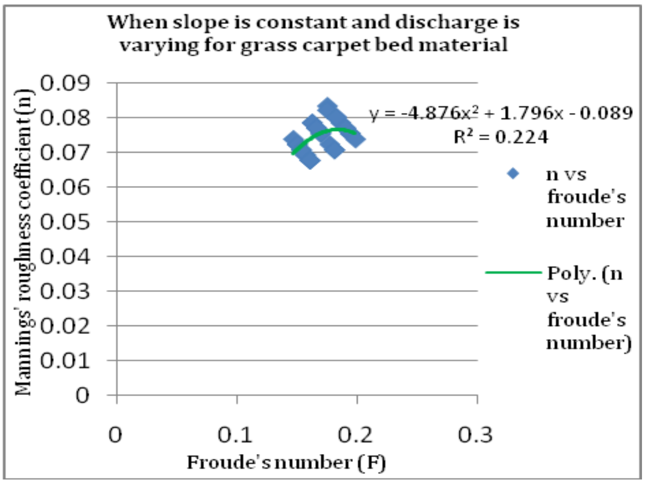

Chart-13: Variation of Mannings' n with Froude's number (F) for grass carpet as bed material.

The variation of Mannings' n with Froude's number (F) for grass carpet as bed material is shown in the above figure. The slope of the channel is kept constant and the discharge to the channel varies as Q_1= 0.0338 cum/s, Q_2= 0.00295 cum/s and Q_3= 0.0025 cum/s. The value of polynomial regression coefficient is obtained as 0.224.

4.2.4. For coconut coir mat as bed material

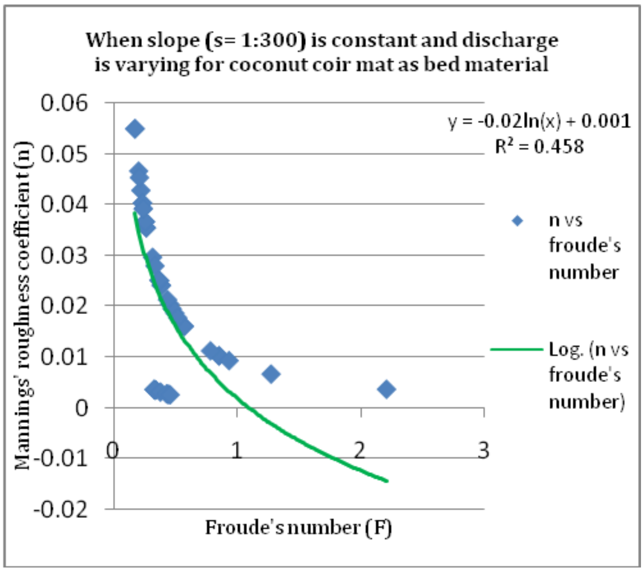

Chart-14: Variation of Mannings' n with Froude's number (F) for coconut coir mat as bed material.

The variation of Mannings' n with Froude's number (F) for coconut coir mat as bed material is shown in the above figure. The slope of the channel is kept constant at s= 1:300 and the discharge to the channel varies as Q_1= 0.0039375 cum/s, Q_2= 0.00234 cum/s, Q_3= 0.00277 cum/s and Q_4= 0.00177 cum/s. The value of logarithmic regression coefficient is obtained as0.458.

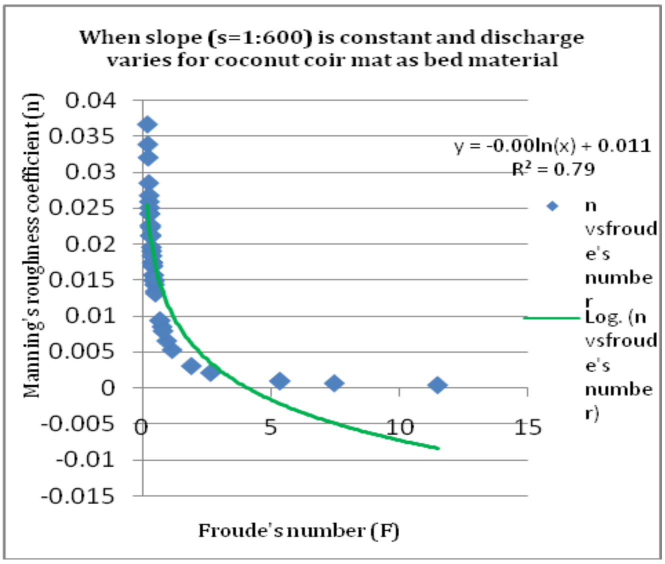

Chart-15: Variation of Mannings' n with Froude's number (F) for coconut coir mat as bed material.

The variation of Mannings' n with Froude's number (F) for coconut coir mat as bed material is shown in the above figure. The slope of the channel is kept constant at s= 1:600 and the discharge to the channel varies as Q_1= 0.0039375 cum/s, Q_2= 0.00234 cum/s, Q_3= 0.00277 cum/s and Q_4= 0.00177 cum/s. The value of logarithmic regression coefficient is obtained as 0.79.

4.2.5. For coconut coir mat and stone as bed material

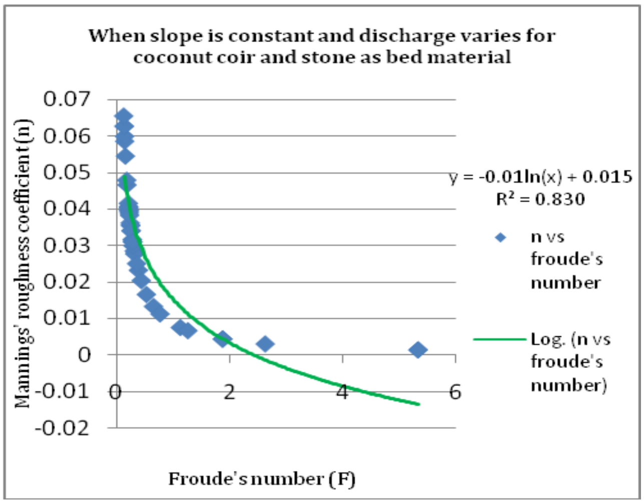

Chart-16: Variation of Mannings' n with Froude's number (F) for coconut coir mat and stone as bed material.

The variation of Mannings' n with Froude's number (F) for coconut coir mat and stone as bed material is shown in the above figure. The slope of the channel is kept constant and the discharge to the channel varies as Q_1= 0.0039375 cum/s, Q_2= 0.00234 cum/s, Q_3= 0.00277 cum/s and Q_4= 0.00177 cum/s. The value of logarithmic regression coefficient is obtained as 0.830.

4.3. Tabulation of the roughness equations

The regression equations for bed roughness with respect to the variation of flow parameters are obtained in the table below.

Table-2: Roughness equations with respect to variation of flow parameters for different channel bed conditions

Sl. No.	Channel bed type	Flow parameters		Roughness equation w.r.t. variation of flow parameters	Value of regression coefficient (R^2)
1	Original bed	Discharge is constant at 0.00384 cum/s and slope varies	a)	$n = 0.629y - 0.003$	0.85
			b)	$n = -0.008F + 0.022$	0.681
		Discharge is constant at 0.00367 cum/s and slope varies	c)	$n = 1.014y - 0.008$	0.996
			d)	$n = -0.013F + 0.033$	0.881
		Discharge is constant at 0.0012 cum/s and slope varies	e)	$n = 2.001y - 0.007$	0.991
			f)	$n = -0.008F + 0.027$	0.756
2	PVC	Slope is constant and discharge varies	a)	$n = 1.107y - 0.013$	0.961
			b)	$n = -0.026F + 0.035$	0.388
3	Grass carpet	Slope is constant and discharge varies	a)	$n = 1.533y - 0.032$	0.998
			b)	$n = -4.876F^2 + 1.796F - 0.089$	0.224
4	Coconut coir mat	Slope is constant at 1:300 and discharge varies	a)	$n = -26.76y^2 + 2.183y - 0.019$	0.145
			b)	$n = -0.02\ln(F) + 0.001$	0.458
		Slope is constant at 1:600 and discharge varies	c)	$n = 0.481y - 0.001$	0.8
			d)	$n = -0.00\ln(F) + 0.011$	0.79
5	Coconut coir mat and stone	Slope is constant and discharge varies	a)	$n = 0.761y - 0.002$	0.803
			b)	$n = -0.01\ln(F) + 0.015$	0.83

The value of regression coefficient R^2 for the equations 2(b), 3(b), 4(a) and 4(b) is extremely less (<0.6), hence these equations are not proposed.

5. CONCLUSION

In the present study an attempt has been made to find the relations between the Mannings' roughness coefficient 'n' and depth of flow (D) and Froude's number (F). It has been observed that the flow parameters vary with the variations of bed roughness in open channel flow. Mannings' roughness coefficient also varies with the variation of open channel bed conditions.

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Dr. Saikia obtained her PhD from Prestigious Institute IIT Guwahati. In her academic career of more than seventeen (17) years she served many institutes as Professor& Head, Deptt. of CE, Regional Institute of Science& Technology, Meghalaya, as an Associate Professor, Deptt. of CE, Royal School of Engineering& Technology, RGI, Guwahati, and as a Lecturer in the Prestigious Institute NIT-Silchar (Previously REC) under MHRD, Govt. of India. Dr. Saikia has authored Eight Civil Engineering text books published by Prentice Hall India. She has published 25 research papers in different international journals; national and international congress and conferences. She presented her research papers in many international conferences such as 15th IASTED International Conference on Applied Simulation and Modeling, Rhodes, Greece; 3rd International Conference of APHW (Asia Pacific hydrology and Water management association) Bangkok, Thailand. She has been invited as Speaker in national conferences. She is the Member of Board of Reviewers of International Journals.

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