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LARGE SCALE ROUGHNESS

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ABSTRACT

Large scale roughness and intermediate scale roughness depend upon $\frac{d}{D_{50}}$ and $\frac{d}{D_{84}}$ where D_{50} = the size of the median axis which is bigger than or equal to 50% of median axis. Similarly D_{84} = The size of the median axis which is bigger than or equal to 84% of median axis. For large scale roughness $\frac{d}{D_{50}}$ <2 and $\frac{d}{D_{84}}$ <1.2 and for intermediate scale roughness 2< $\frac{d}{D_{50}}$ <7.5 and 1.2 < $\frac{d}{D_{84}}$ <4.

Subject Headings: Boulders, channels, Drag, Flow resistance, Flumes

KEYWORDS: Open Channel Flow, Flow Resistance, Friction Factor

INTRODUCTION

Since size of 2.0 inch roughness material is more i.e. D_{50} is more hence $\frac{d}{D_{50}}$ is lesser than 0.75 inch roughness bed. Since velocity of flow is more for 0.75 inch roughness bed and chezy's resistance factor depends upon velocity of flow and roughness is more effective in high velocity of flow hence chezy's resistance factor C is more for 0.75 inch roughness bed.

Experimental Setup & Procedures: Data were obtained for 0.75 inch and 2.0 inch roughness bed.

Flume: The flume is open and 1.168 m wide and 9.54 m long. Each roughness bed was constructed by smearing masonite boards with fiberglass resin. The boards were then screwed to the bed of the flume.

Experimental Procedure: For each bed, five to seven flows were measured for three different slopes (2, 5 and 8%). At each flow, depth was gaged at a single cross section, so that mean flow and channel properties could be calculated. In flow with large scale roughness, the cross-sectional area of flow is significantly affected by the projections of the elements into the flow.

Roughness depends upon $\frac{d}{D_{50}}$ and $\frac{d}{D_{84}}$. For large scale roughness $\frac{d}{D_{50}}$ <2 and $\frac{d}{D_{84}}$ <1.2 where d is the mean depth of flow and D_{50} = the size of the median axis which is bigger than or equal to 50% of median axis. Similarly

D_{84} = The size of the median axis which is bigger than or equal to 84% of median axis. Similarly for Intermediate Scale roughness $2 < \frac{d}{D_{50}} < 7.5$ and $1.2 < \frac{d}{D_{84}} < 4$.

Table 1: Flume Data for 0.75 Inch Roughness Bed

Sl. No. (1)	Channel Slope (2)	Discharge in Cubic Meters per Second (3)	Mean Velocity in Meters per Second (4)	Mean Depth d in Meters (5)
1	0.02	0.00580	0.222	0.0223
2	0.02	0.01181	0.348	0.0290
3	0.02	0.02482	0.484	0.0439
4	0.02	0.04047	0.586	0.0591
5	0.02	0.05348	0.656	0.0698
6	0.05	0.00381	0.230	0.0141
7	0.05	0.00843	0.363	0.0199
8	0.05	0.02037	0.583	0.0299
9	0.05	0.03333	0.782	0.0365
10	0.05	0.04586	0.904	0.0434
11	0.05	0.05460	0.979	0.0477
12	0.08	0.00207	0.186	0.0095
13	0.08	0.00631	0.380	0.0142
14	0.08	0.01007	0.430	0.0200
15	0.08	0.02825	0.807	0.0299
16	0.08	0.04518	1.032	0.0375
17	0.08	0.04879	1.064	0.0392

Table 2: Flume Data for 0.75 Inch Roughness Bed D_{50}=0.013m, D_{84}=0.0193m

Sl. No. (1)	$\frac{d}{D_{50}}$ (2)	$\frac{d}{D_{84}}$ (3)	Depth d' of Bed Datum in Meters (4)	Relative Roughness Area $\frac{Aw}{Wd'}$ (5)	Function of Effective Roughness Concentration b (6)
1	1.715	1.155	0.0282	0.2081	0.397
2	2.231	1.503	0.0349	0.1696	0.480
3	3.377	2.275	0.0495	0.1146	0.660
4	4.546	3.062	0.0642	0.0801	0.846
5	5.369	3.617	0.0746	0.0641	0.975
6	1.085	0.731	0.0204	0.3052	0.269
7	1.531	1.031	0.0262	0.2411	0.349
8	2.300	1.549	0.0360	0.1709	0.482
9	2.808	1.891	0.0426	0.1433	0.560
10	3.338	2.249	0.0491	0.1156	0.655
11	3.669	2.472	0.0536	0.1090	0.693
12	0.731	0.492	0.0159	0.4031	0.189
13	1.092	0.736	0.0211	0.3253	0.255
14	1.538	1.036	0.0258	0.2222	0.370
15	2.300	1.549	0.0363	0.1742	0.477
16	2.885	1.943	0.0435	0.1382	0.575
17	3.015	2.031	0.0450	0.1285	0.605

Table 3: Flume Data for 0.75 Inch Roughness Bed

Sl. No. (1)	Hydraulic Radius R= $\frac{A}{P} = \frac{Wd}{W+2d}$ (2)	Chezy's Resistance Factor c (3)	Manning's Roughness Coefficient n (4)
1	0.021	10.832	0.071
2	0.028	14.706	0.055
3	0.040	17.112	0.050
4	0.054	17.758	0.051
5	0.063	18.481	0.050
6	0.013	9.021	0.078
7	0.019	11.777	0.065
8	0.029	15.310	0.053
9	0.035	18.693	0.045
10	0.041	19.966	0.043
11	0.044	20.872	0.042
12	0.009	6.932	0.096
13	0.014	11.355	0.063
14	0.019	11.029	0.069
15	0.029	16.754	0.049
16	0.035	19.503	0.043
17	0.037	19.557	0.043

Table 4: Flume Data for 0.75 Inch Roughness Bed. S_{50}=0.008 m

Sl. No. (1)	Relative Submergence $\frac{d}{S_{50}}$ (2)
1	2.790
2	3.626
3	5.482
4	7.383
5	8.728
6	1.768
7	2.484
8	3.736
9	4.557
10	5.428
11	5.965
12	1.190
13	1.776
14	2.505
15	3.743
16	4.682
17	4.905

Table 5: Flume Data for 2.0 Inch Roughness Bed

Sl. No. (1)	Channel Slope (2)	Discharge in Cubic Meters per Second (3)	Mean Velocity in Meters per Second (4)	Mean Depth d in Meters (5)
1	0.02	0.00329	0.100	0.0282
2	0.02	0.00837	0.189	0.0378
3	0.02	0.01158	0.227	0.0436
4	0.02	0.02541	0.377	0.0578
5	0.02	0.04047	0.519	0.0668
6	0.02	0.04949	0.601	0.0705
7	0.05	0.00329	0.132	0.0213
8	0.05	0.00713	0.214	0.0285
9	0.05	0.01413	0.337	0.0359
10	0.05	0.02068	0.431	0.0411
11	0.05	0.02941	0.542	0.0465
12	0.05	0.04368	0.643	0.0582
13	0.08	0.00247	0.162	0.0130
14	0.08	0.00565	0.205	0.0236
15	0.08	0.01077	0.313	0.0295
16	0.08	0.02187	0.515	0.0363
17	0.08	0.03249	0.637	0.0437
18	0.08	0.03724	0.712	0.0488

Table 6: Flume Data for 2.0 Inch Roughness Bed

Sl. No. (1)	Hydraulic Radius R= $\frac{Wd}{W+2d}$ (2)	Depth d' of Bed Datum in Meters (3)	Relative Roughness Area $\frac{Aw}{Wd'}$ (4)	Function of Effective Roughness Concentration b (5)
1	0.027	0.0505	0.4413	0.220
2	0.036	0.0611	0.3814	0.281
3	0.041	0.0665	0.3443	0.324
4	0.053	0.0795	0.2735	0.431
5	0.060	0.0892	0.2511	0.483
6	0.063	0.0947	0.2553	0.486
7	0.021	0.0442	0.5179	0.164
8	0.027	0.0513	0.4450	0.218
9	0.034	0.0575	0.3750	0.282
10	0.038	0.0633	0.3508	0.313
11	0.043	0.0688	0.3252	0.348
12	0.053	0.0788	0.2617	0.447
13	0.013	0.0411	0.6842	0.084
14	0.023	0.0505	0.5330	0.161
15	0.028	0.0551	0.4646	0.208
16	0.034	0.0659	0.4483	0231
17	0.041	0.0747	0.4155	0.267
18	0.041	0.0701	0.3615	0.312

Table 7: Flume Data for 2.0 Inch Roughness Bed. D_{50} = 0.043 m, D_{84} = 0.047m

Sl. No. (1)	$\frac{d}{D_{50}}$ (2)	$\frac{d}{D_{84}}$ (3)	Manning's Roughness Coefficient n (4)	Chezy's Resistance Coefficient C (5)
1	0.656	0.600	0.186	4.303
2	0.879	0.804	0.120	7.044
3	1.014	0.928	0.109	7.927
4	1.344	1.230	0.078	11.579
5	1.553	1.421	0.061	14.892
6	1.640	1.500	0.055	16.931
7	0.495	0.453	0.190	4.074
8	0.633	0.606	0.139	5.824
9	0.835	0.764	0.103	8.173
10	0.956	0.874	0.087	9.888
11	1.081	0.989	0.075	11.689
12	1.353	1.238	0.073	12.491
13	0.302	0.277	0.141	5.023
14	0.549	0.502	0.164	4.779
15	0.686	0.628	0.123	6.613
16	0.844	0.772	0.085	9.875
17	1.016	0.930	0.078	11.123
18	1.042	0.953	0.070	12.432

Table 8: Flume Data for 2.0 Inch Roughness Bed. S_{50}=0.02975 m

Sl. No. (1)	Relative Submergence $\frac{d}{S_{50}}$ (2)
1	0.947
2	1.269
3	1.463
4	1.938
5	2.241
6	2.367
7	0.715
8	0.956
9	1.206
10	1.379
11	1.559
12	1.952
13	0.436
14	0.792
15	0.989
16	1.219
17	1.466
19	1.502

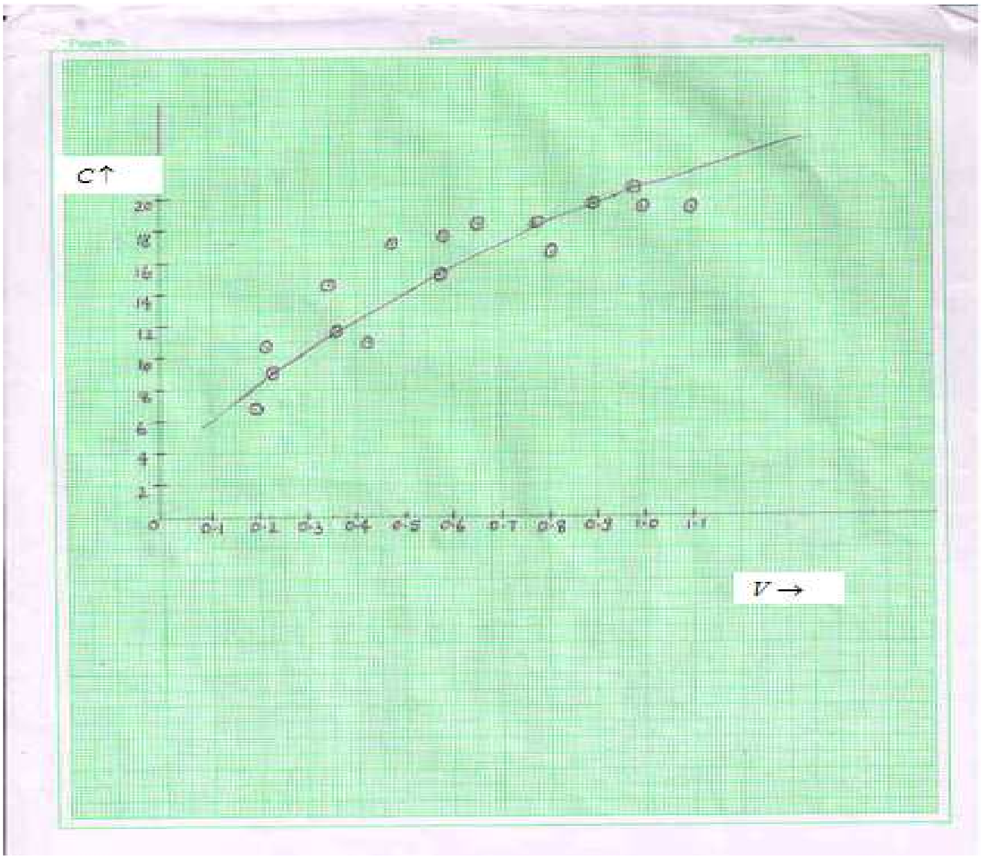

Figure 1: Variation of Parameter Chezy's Resistance Coefficient with Parameter Mean Velocity of Flow V for 0.75 Inch Roughness Bed

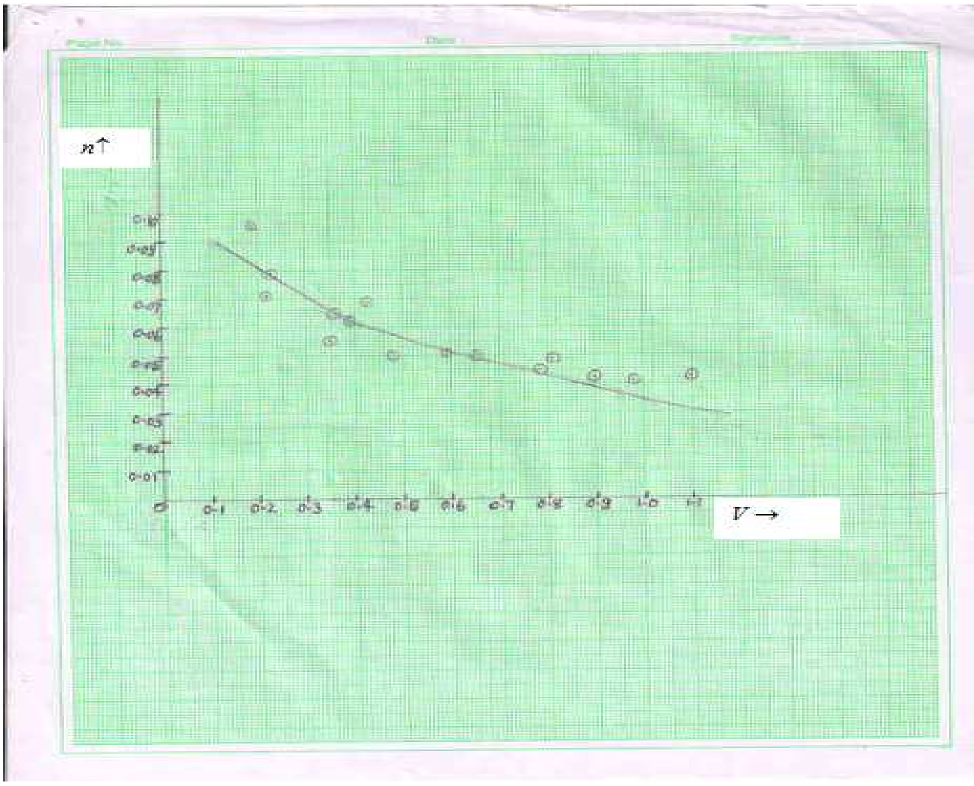

Figure 2: Variation of Parameter Manning's Roughness Coefficient with Parameter Mean Velocity of Flow for 0.75 Inch Roughness Bed

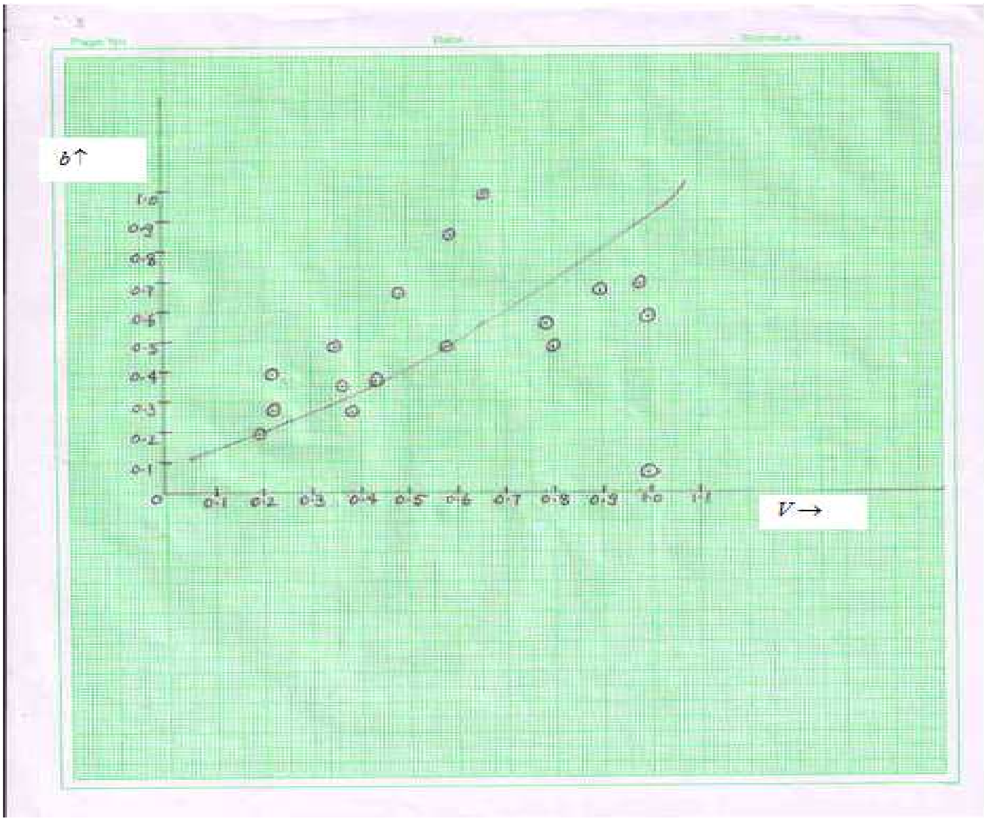

Figure 3: Variation of Parameter Function of Effective Roughness Concentration with Parameter Mean Velocity of Flow for 0.75 Inch Roughness Bed

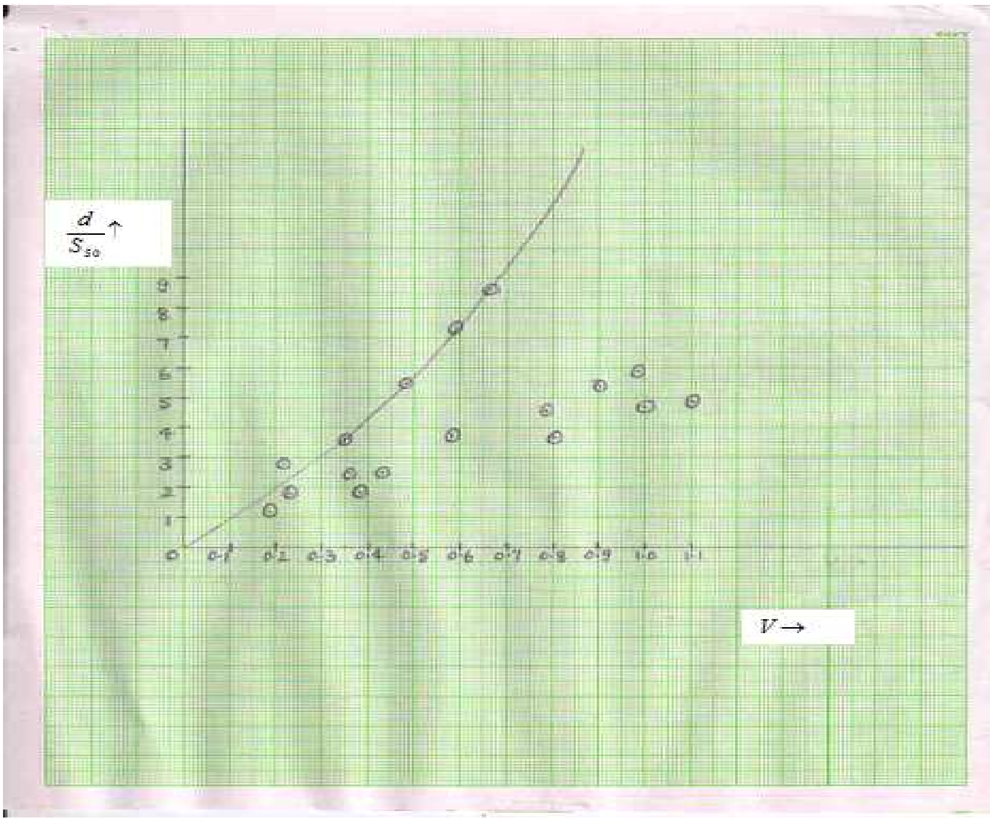

Figure 4: Variation of Parameter Relative Submergence with Parameter Mean Velocity of Flow for 0.75 Inch Roughness Bed

RESULTS AND ANALYSIS

0.75 Inch Roughness Bed

Average Values

$\frac{d}{D_{50}}$ = 2.561

C = 15.274

n = 0.057

b = 0.520

$\frac{d}{S_{50}}$ = 4.162

2.0 Inch Roughness Bed

$\frac{d}{D_{50}}$ = 0.939

Chezy's resistance factor C = 9.153

Manning's roughness coefficient n = 0.108

Function of effective roughness concentration b = 0.292

Relative submergence $\frac{d}{S_{50}}$ = 1.355

Since size of 2.0 inch roughness material is more i.e. D_{50} is more hence $\frac{d}{D_{50}}$ is lesser than 0.75 inch roughness bed. More size of the roughness material provides more roughness hence there is 2.727 times more roughness for 2.0 inch roughness bed as compared to 0.75 inch roughness bed with respect to $\frac{d}{D_{50}}$. Since D_{50} is more for 2.0 inch roughness bed hence $\frac{d}{D_{50}}$ is lesser for 2.0 inch roughness bed. Since velocity of flow is more for 0.75 inch roughness bed & chezy's resistance factor depends upon velocity of flow since roughness is more effective is high velocity of flow hence C is more for 0.75 inch roughness bed. There is 1.668 times more C for 0.75 inch roughness bed as compared to 2.0 inch roughness bed.

Since Manning's roughness coefficient is lesser for high velocity of flow hence there is 1.895 times lesser Manning's roughness coefficient for 0.75 inch roughness bed as compared to 2.0 inch roughness bed.

Since velocity of flow is more for 0.75 inch roughness bed and roughness is more effective is high velocity of flow to get more wetted frontal cross sectional area hence there is 1.781 times more b for 0.75 inch roughness bed as compared to 2.0 inch roughness bed. There is 0.0142 m depth of water over 0.75 inch size of roughness material whereas there is 0.011 m is unsubmerged for 2.0 inch roughness bed and function of effective roughness concentration depends upon wetted frontal cross sectional area hence b is more for 0.75 inch roughness bed as compared to 2.0 inch roughness bed.

Since velocity of flow is more for 0.75 inch roughness bed as roughness is more effective in high velocity of flow to get more submergence hence relative submergence is more for 0.75 inch roughness bed as compared to 2.0 inch roughness bed hence there is 3.072 times more relative submergence for 0.75 inch roughness bed as compared to 2.0 inch roughness bed.

Since b depends upon wetted frontal cross sectional area and relative submergence depends upon the submergence factor since submergence is more as compared to wetted frontal cross sectional area hence this is more increase in relative submergence as compared to function of effective roughness concentration.

0.75 Inch Roughness Bed

Relationship for $\frac{d}{D_{50}}$ with C, n, b and $\frac{d}{S_{50}}$

$$\frac{d}{D_{50}} = 0.491\,(C)^{0.998} - 0.898\left(\frac{d}{S_{50}}\right)^{1.114} - 0.930(n)^{1.075} - 0.927(b)^{1.079} \tag{1}$$

Relationship for C with n, b and $\frac{d}{S_{50}}$

$$C = 3.222\left(\frac{d}{S_{50}}\right)^{1.114} - 0.927\,(b)^{1.079} - 0.930(n)^{1.075} \tag{2}$$

Relationship for n with C, b and $\frac{d}{S_{50}}$

$$n = 1.002\,(c)^{0.998}\, x\; 0.592\,(b)^{1.079} - 0.898\left(\frac{d}{S_{50}}\right)^{1.114} \tag{3}$$

Another form of equation n

$$n = 1.002\,(c)^{0.998}\, x\; 0.021\,(b)^{1.079} - \frac{0.927(b)^{1.079}}{0.898\left(\frac{d}{S_{50}}\right)^{1.114}} \tag{4}$$

Relationship for and $\frac{d}{S_{50}}$ with C, n and b

$$\frac{d}{S_{50}} = 0.307\,(C)^{0.998} - 0.927(b)^{1.079} - 0.930(n)^{1.075} \quad (5)$$

Relationship for b with C, $\frac{d}{S_{50}}$ and n

$$b = 0.327\,(C)^{0.998} - 898\left(\frac{d}{S_{50}}\right)^{1.114} - 0.930(n)^{1.075} \quad (6)$$

Relationship for C with $\frac{d}{D_{50}}$, n, b and $\frac{d}{S_{50}}$

$$C = 3.744\left(\frac{d}{S_{50}}\right)^{1.114} - 0.930(n)^{1.075} - 0.927(b)^{1.079} - 0.898\left(\frac{d}{D_{50}}\right)^{1.113} \quad (7)$$

Relationship for $\frac{d}{S_{50}}$ with n, b and $\frac{d}{D_{50}}$

$$\frac{d}{S_{50}} = 1.637\left(\frac{d}{D_{50}}\right)^{1.113} - 0.927(b)^{1.079} - 0.930(n)^{1.075} \quad (8)$$

Relationship for $\frac{d}{D_{50}}$ with b, n and $\frac{d}{S_{50}}$

$$\frac{d}{D_{50}} = 0.625\left(\frac{d}{S_{50}}\right)^{1.114} - 0.927(b)^{1.079} - 0.930(n)^{1.075} \quad (9)$$

Relationship for b with n, $\frac{d}{S_{50}}$ and $\frac{d}{D_{50}}$

$$b = 0.638\left(\frac{d}{S_{50}}\right)^{1.114} - 0.898\left(\frac{d}{D_{50}}\right)^{1.113} - 0.930(n)^{1.075} \quad (10)$$

Relationship for n with $\frac{d}{S_{50}}$, $\frac{d}{D_{50}}$ and b

$$n = 0.628\left(\frac{d}{S_{50}}\right)^{1.114} - 0.898\left(\frac{d}{D_{50}}\right)^{1.113} - 0.927(b)^{1.079} \quad (11)$$

Relationship for n with $\frac{d}{D_{50}}$, C, b and $\frac{d}{S_{50}}$

$$n = 0.492(C)^{0.998} - 0.898\left(\frac{d}{S_{50}}\right)^{1.114} - 0.927(b)^{1.079} - 0.898\left(\frac{d}{D_{50}}\right)^{1.113} \quad (12)$$

Relationship for C with $\frac{d}{S_{50}}$, b and $\frac{d}{D_{50}}$

$$C = 3.736\left(\frac{d}{S_{50}}\right)^{1.114} - 0.898\left(\frac{d}{D_{50}}\right)^{1.113} - 0.927(b)^{1.079} \quad (13)$$

Relationship for $\frac{d}{S_{50}}$ with b, $\frac{d}{D_{50}}$ and C

$$\frac{d}{S_{50}} = 0.473(C)^{0.998} - 0.927(b)^{1.079} - 0.898\left(\frac{d}{D_{50}}\right)^{1.113} \quad (14)$$

Relationship for b with $\frac{d}{S_{50}}$, $\frac{d}{D_{50}}$ and C

$$b = 0.492(C)^{0.998} - 0.898\left(\frac{d}{S_{50}}\right)^{1.114} - 0.898\left(\frac{d}{D_{50}}\right)^{1.113} \quad (15)$$

Relationship for $\frac{d}{D_{50}}$ with $\frac{d}{S_{50}}$, b and C

$$\frac{d}{D_{50}} = 0.488(C)^{0.998} - 0.898\left(\frac{d}{S_{50}}\right)^{1.114} - 0.927(b)^{1.079} \quad (16)$$

Mathematical Formulation for C

Substituting $\frac{d}{S_{50}}$, n, b, $\frac{d}{D_{50}}$ from equations (8), (9), (10), (11), in equation (7) we get

$$C = 3.744\left\{1.637\left(\frac{d}{D_{50}}\right)^{1.113} - 0.927(b)^{1.079} - 0.0.930(n)^{1.075}\right\}^{1.114}$$

$$-0.930\left\{0.628\left(\frac{d}{S_{50}}\right)^{1.114} - 0.898\left(\frac{d}{D_{50}}\right)^{1.113} - 0.927(b)^{1.079}\right\}^{1.075}$$

$$-0.927\left\{0.638\left(\frac{d}{S_{50}}\right)^{1.114}-0.898\left(\frac{d}{D_{50}}\right)^{1.113}-0.930(n)^{1.075}\right\}^{1.079}$$

$$-0.898\left\{0.625\left(\frac{d}{S_{50}}\right)^{1.114}-0.927(b)^{1.079}-0.0.930(n)^{1.075}\right\}^{1.113}$$

$$=3.744\{4.161\}^{1.114}-0.930\{0.059\}^{1.075}-0.927\{0.523\}^{1.079}-0.898\{2.559\}^{1.113}$$

= 18.328-0.044-0.461-2.555

= 18.328-3.060 = 15.268

= 15.274

Hence equation is satisfied.

Mathematical Formulation for n

Substituting the values of C, $\frac{d}{S_{50}}$, b and $\frac{d}{D_{50}}$ from equations 13, 14, 15 and 16 in equation 12 we will have

$$n=0.492\left\{3.736\left(\frac{d}{S_{50}}\right)^{1.114}-0.898\left(\frac{d}{D_{50}}\right)^{1.113}-0.927(b)^{1.079}\right\}^{0.998}$$

$$-0.898\left\{0.473(C)^{0.998}-0.927(b)^{1.079}-0.898\left(\frac{d}{D_{50}}\right)^{1.113}\right\}^{1.114}$$

$$-0.927\left\{0.492(C)^{0.998}-0.898\left(\frac{d}{S_{50}}\right)^{1.114}-0.898\left(\frac{d}{D_{50}}\right)^{1.113}\right\}^{1.079}$$

$$-0.898\left\{0.488(C)^{0.998}-0.898\left(\frac{d}{S_{50}}\right)^{1.114}-0.927(b)^{1.079}\right\}^{1.113}$$

Hence

$$n=0.492\{15.278\}^{0.998}-0.898\{4.169\}^{1.114}-0.927\{0.519\}^{1.079}-0.898\{2.558\}^{1.113}$$

= 7.476-4.405-0.457-2.554=7.416

= $0.060 \approx 0.057$

CONCLUSIONS

There is 2.727 times more roughness for 2.0 inch roughness bed as compared to 0.75 inch roughness bed with respect to $\frac{d}{D_{50}}$. There is 1.668 times more chezy's resistance coefficient for 0.75 inch roughness bed as compared to 2.0 inch roughness bed. There is 1.895 times lesser Manning's roughness coefficient for 0.75 inch roughness bed. There is 1.781 times more function of effective roughness concentration for 0.75 inch roughness bed as compared to 2.0 inch roughness bed. There is 3.072 times more relative submergence for 0.75 inch roughness bed as compared to 2.0 inch roughness bed.

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APPENDICES - NOTATION

The following symbols are used in this paper

$\frac{A_w}{Wd'}$ = Relative roughness area.

A_w = Wetted roughness-cross sectional area.

A = Flow cross sectional area = Wd.

b = Function of effective roughness concentration.

C = Chezy's resistance coefficient.

d = Mean depth of flow in meters

d' = Depth of bed datum in meters.

D_{50} = The size of median axis which is bigger than or equal to 50% of median axis.

D_{84} = The size of median axis which is bigger than or equal to 84% of median axis.

$\frac{d}{S_{50}}$ = Relative submergence

n = Manning's roughness coefficient

P = Wetted Perimeter

Q = Discharge in cubic meters per second

R = Hydraulic radius = $\frac{A}{p} = \frac{Wd}{W+2d}$

P = Wetted Perimeter

S_{50} = The size of the short axis which is bigger than or equal to 50% of short axis.

S = Channel slope

V = Mean velocity of flow in meters per second.

W = Width of the channel = 1.168m

Formula Used

$A + A_w = Wd'$

$$\frac{A_w}{Wd'} = \left(\frac{w}{d}\right)^{-b}$$

$$V = \frac{1.49}{n} R^{2/3} S^{1/2}$$

$$V = C\sqrt{RS}$$