Relationship for Thrust and Thickness of Stone Pitching Along Side of River

Dr. Birendra Kumar Singh
Civil Engineering Department, Birla Institute of Technology, Mesra, Ranchi-835215 (Jharkhand), India

***Abstract*:-As discharge of flow increases in river, the thickness of stone pitching alongside of bank of river increases. The thickness of stone pitching provided alongside of river obtained from lateral thrust taking mean velocity of flow into account provides more thickness of stone pitching alongside of the river compared to the lateral thrust obtained from mean depth of flow. The equations for lateral thrust taking into account the velocity of flow and depth of flow with thickness of stone pitching provided alongside of the river are derived.**

***Keywords* - Lateral thrust; Mean Velocity of flow; Thickness of stone pitching; Mean depth of flow; Flume.**

I. INTRODUCTION

The relationship between the lateral thrust and thickness of stone pitching alongside river is analyzed. The thickness of stone pitching obtained from lateral thrust taking mean velocity of flow into account is determined. It is compared with the thickness of stone pitching obtained from the lateral thrust taking mean depth of flow into account.

II. EXPERIMENTAL SETUP & PROCEDURES

Data were obtained for 0.75-inch roughness bed.

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

Experimental Procedure - 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.

III. RESULTS AND ANALYSIS

Corresponding to average value of mean velocity of flow from 0.75-inch roughness bed i.e.

V = 0.590 m/sec, Q_m = 0.04047 m^3/sec, Q_p =7798 m^3/sec using

$$\frac{Q_m}{Q_p} = \frac{1}{n^{2.5}}$$ Where Q_m= Discharge

of flow for model i.e. laboratory channel & Q_p= Discharge of flow for prototype i.e. for river and n = scale factor = 130 for river.

Corresponding to Q_m=0.04047m_3/sec, dm = Mean depth of flow for channel = 0.0591m and d_p = Mean depth of flow for river found from $\frac{d_m}{d_p} = \frac{1}{n} = \frac{1}{130}$

i.e. d_p = 7.683 meter. Now Q_p = W d_pV_p where W = width of river = 21 m (assumed). Hence

Vp=48.33 m/sec. Hence lateral thrust = $\frac{wV_p^{\ 2}}{2g}$ where w = Unit wt. of water = 10 KN/m^3, g = Acceleration due to gravity = 9.81m/sec^2.

Hence, lateral thrust = 1191 KN/m^2. Now thickness of stone pitching provided alongside of the river t = 0.06 $Q_p^{1/3}$ = 0.06 $(7798)^{0.333}$ = 1.186 meter.

Hence corresponding to 1191 KN/m^2 of lateral thrust 1.186 meter thickness of stone pitching alongside of river can be provided.

Relationship for lateral thrust & thickness of stone pitching alongside of river is

$$\frac{\frac{wV_P^{\ 2}}{2g}}{\left(\frac{wV_P^{\ 2}}{2g}\right)_{\max}} = 0.864\left(\frac{t}{t_{\max}}\right)^{4.783}$$

$\frac{wV_p^{\ 2}}{2g}$= Average value of parameters taken from 0.75 inch roughness bed and converted into prototype similarly $\left(\frac{wV_P^{\ 2}}{2g}\right)_{\max}$ = Max^m value of lateral thrust t= thickness of stone pitching provided alongside of river.

t_{max}= Maximum thickness of stone pitching corresponding to maximum lateral thrust.

For Q_m = 0.04586 m^3/sec using $\frac{Q_m}{Q_p} = \frac{1}{n^{2.5}} = \frac{1}{(130)^{2.5}}$

Qp = 8837 m^3/sec corresponding to Q_m = 0.04586 m^3/sec. Mean depth of flow for channel dm = 0.0434m. Now using $\frac{d_m}{d_p} = \frac{1}{130}$ where n = scale factor = 130 . The depth of flow for river d_p= 5.642m. Now Q_p= Wd_pV_p where W = width of river = 21m (Assumed) V_p=74.585 m/sec.

Now lateral thrust = $\frac{wV_p^{\,2}}{2g}$ = 2835.33 KN/m^2. Maximum value of Q_m = 0.05460 m^3/sec using $\frac{Q_m}{Q_p} = \frac{1}{(130)^{2.5}}$ and corresponding to Q_m=0.05460 m^3/sec. d_m = 0.0477m hence $\frac{d_m}{d_p} = \frac{1}{130}$ $\therefore d_p$=6.201 metre and Q_p =10521 m3/sec and Q_p= Wd_pV_p where W = width of river = 21m.

Hence, V_p= 81 m/sec and maximum value of lateral thrust $\left(\frac{W_v P^2}{2g}\right)_{max}$ = 3344KN/m^2 and corresponding thickness of stone pitching alongside of river = 0.06 $(10521)^{0.333}$ = 1.311 meter.

Now using the equation of thrust and thickness of stone pitching i.e.

$$\frac{\frac{wV_P^{\,2}}{2g}}{\left(\frac{wV_P^{\,2}}{2g}\right)_{max}} = 0.864\left(\frac{t}{t_{max}}\right)^{4.783} \quad - \quad (1)$$

$$\frac{2835.33}{3344} = 0.864\left(\frac{t}{1.311}\right)^{4.783}$$

Hence, thickness of stone pitching provided along side of river t = 1.306 metre. For lateral thrust of 2835.33 KN/m^2 rock of bearing capacity of 3300 KN/m^2 can be used along bank of river.

Also using the formula :=

t=0.06 $Q_p^{1/3}$ = 0.06 $(8837)^{0.333}$ = 1.237 meter≈ 1.306 meter

Hence, equation (1) is the required equation for lateral thrust and thickness of stone pitching provided along of the river bank.

Average value of mean depth of flow d_m= 0.0333m & corresponding d_p= 4.329 m from

$\frac{d_m}{d_p} = \frac{1}{n} = \frac{1}{130}$ where d_m = mean depth of flow for channel, d_p = mean depth of flow for prototype & n = scale factor = 130 taken for river.

Lateral thrust in terms of depth of flow = $\frac{wh^2}{2}$ where w = Unit weight of water and h = depth of flow = d_p. Hence lateral thrust = $\frac{10(4.329)^2}{2}$ =93.7KN/m^2.

Hence, sand silt bags are provided along bank of river which has bearing capacity of 150 KN/m^2. Corresponding to d_m=0.0333m, Q_m= 0.02037m^3/sec and Q_p = 3925 m^3/sec since $\frac{Q_m}{Q_p} = \frac{1}{n^{2.5}}$ where Q_m= Discharge of flow for channel and Q_p= Discharge of flow for river or prototype and n = scale factor = 130 taken for river.

Hence, thickness of sand bag = 0.06 $(3925)^{0.333}$ = 0.94 meter = 94cm and the required equation for lateral thrust & thickness of stone pitching provided along bank of river is

$$\frac{\frac{wh^2}{2}}{\left(\frac{wh^2}{2}\right)_{max}} = 1.09\left(\frac{t}{t_{max}}\right)^{4.823} \quad - \quad (2)$$

Where $\frac{wh^2}{2}$ = Lateral thrust obtained from average value of d_m and $\left(\frac{wh^2}{2}\right)_{max}$ = Lateral thrust corresponds to maximum value of mean depth of flow for channel & hence maximum value of mean depth of flow for river. Similarly, t = thickness of stone pitching provided along bank of river for average value of lateral thrust and t_{max} = maximum value of thickness of stone pitching provided along bank of river.

For any value of mean depth of flow for channel for 0.75-inch roughness bed dm= 0.0439 m,d_p = 5.707m. Hence lateral thrust = $\frac{10x(5.707)^2}{2}$ = 162.85KN/m_2 and maximum value of lateral thrust is obtained corresponding to maximum value of mean depth of flow for channel d_m=0.0698 m, d_p =9.074 m hence maximum value of lateral thrust $\frac{10x(9.074)^2}{2}$ = 411.69KN/m^2.Corresponding to d_m= 0.0698 m, Q_m= 0.05348 m^3/sec hence Q_p= 10305m^3/sec.

Using $\frac{Q_m}{Q_p}=\frac{1}{n^{2.5}}=\frac{1}{(130)^{2.5}}$, maximum value of thickness of stone pitching = 0.06 x $(10305)^{0.333}$ = 1.301 meter.

Hence from equation (2), t = 1.075 meter. Corresponding to d_m= 0.0439 meter, Q_m=0.02482m^3/sec, Q_p=4783m^3/sec using $\frac{Q_m}{Q_p}=\frac{1}{n^{2.5}}=\frac{1}{(130)^{2.5}}$. Hence thickness of stone pitching alongside of river t = 0.06$(4783)^{0.333}$ = 1.008 meter≈ 1.075 meter.

IV. CONCLUSIONS

The thickness of stone pitching provided alongside of river obtained from lateral thrust taking mean velocity of flow into account provides more thickness of stone pitching alongside of the river as compared to the lateral thrust obtained from mean depth of flow. The thickness of stone pitching obtained using equations (1) and (2) provide the results which is same as that of stone pitching obtained from the equation t = 0.06 $(Q_p)^{1/3}$.

V. APPENDIX 1 - OBSERVATIONS TABLES

Table 1: Flume data for 0.75-inch roughness bed

Sl. No. (1)	Channel Slope (2)	Discharge in cubic meters per second (3)	Mean depth d in meters (4)	Mean velocity in meters per second (5)	Depth d' of bed datum in meters (6)
1.	0.02	0.00580	0.0223	0.222	0.0282
2.	0.02	0.01181	0.0290	0.348	0.0349
3.	0.02	0.02482	0.0439	0.484	0.0495
4.	0.02	0.04047	0.0591	0.586	0.0642
5.	0.02	0.05348	0.0698	0.656	0.0746
6.	0.05	0.00381	0.0141	0.230	0.0204
7.	0.05	0.00843	0.0199	0.363	0.0262
8.	0.05	0.02037	0.0299	0.583	0.0360
9.	0.05	0.03333	0.0365	0.782	0.0426
10.	0.05	0.04586	0.0434	0.904	0.0491
11.	0.05	0.05460	0.0477	0.979	0.0536
12.	0.08	0.00207	0.0095	0.186	0.0159
13.	0.08	0.00631	0.0142	0.380	0.0211
14.	0.08	0.01007	0.0200	0.430	0.0258
15.	0.08	0.02825	0.0299	0.807	0.0363
16.	0.08	0.04518	0.0375	1.032	0.0435
17.	0.08	0.04879	0.0392	1.064	0.0450

Table 2: Flume data for 0.75-inch roughness bed

Sl. No. (1)	Hydraulic radius R (1)
1.	0.021
2.	0.028
3.	0.040
4.	0.054
5.	0.063
6.	0.013
7.	0.019
8.	0.029
9.	0.035
10.	0.041
11.	0.044
12.	0.009
13.	0.014
14.	0.019
15.	0.029
16.	0.035
17.	0.037

VI. APPENDIX 2 - NOTATIONS

The following symbols are used in this paper:-

A = Flow cross sectional area = Wd.

d = Mean depth of flow in meters.

d' = Depth of bed datum in meters.

P = Wetted Perimeter.

Q = Discharge in cubic meters per second.

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

S = Channel slope.

V = Mean velocity of flow in meters per second.

REFERENCES

[1]. A Caroglu, E.R (1972) "Friction factors is solid material systems "J. Hydraulic Div. Am. SOC. Civ. Eng, 98(HY 4),681 – 699

[2]. Alam, A.M.Z. and Kennedy J.F (1969)" Friction factors for flow in sand bed channels "J Hydraulic Div. Am. SOC Civ. Eng 95(HY 6), 1973 – 1992

[3]. Ben Chie Yen F. (January 1.2002) "Open channel flow resistance" Journal of the Hydraulic Engg. Vol 128, No – 1 ASCE, PP,20 – 39

[4]. Bray, D.I. (1979) "Estimating average velocity in gravel bed – rivers "J Hydraulic Div. Am. SOC Civ. Eng. 105 (HY 9), 1103 – 1122

[5]. Bathurst, J.C., Flow Resistance of Large-Scale Roughness," Journal of the Hydraulics Division, ASCE, Vol. 104, No. HY12, Paper 14239, Dec., 1978, pp.1587.

[6]. Bathurst, J.C., Li, R-M., and Simsons, D.B., Hydraulics of Mountains Rivers, Report No CER78-79JCB-RML-DBS55, Civil Engineering Department, Colorado State University, Fort Collins, Colo., 1979.
[7]. Bathurst, J.C., "Flow Resistance in Boulder-Bed Streams," 22-28, 1980. University East Anglia/Institute Hydrology/Colorado State University International Workshop on Engineering Problems in the Management of Gravel Bed Rivers, held atGregyong, Newtown, Wales, U.K. (Proceedings to be Published by John Wiley and Sons, Inc., New York, N.Y.)
[8]. Charlton, F.G., Brown, P.M., and Benson, R.W., "The Hydraulic Geometry of Some Gravel Rivers in Britain." Report No. ITI80. Hydraulics Research Station Wallingford, U.K., July 1978.
[9]. Day, T., "The channel Geometry of Mountain Streams." Mountains Geomorydlogy Olav Slaymaker and H.J. McPherson, eds, Tantalus Research Ltd., B.C., 1972, pp. 141-149.
[10]. Day, T.T., discussion of "Resistance Equation for Alluvial-Channel Flow," by D.E. Burkham and D.R. Dawdy, Journal of the Hydraulics Division, ASCE, Vol. 103, No. HY5. Proc. Paper 12896, May, 1977, pp. 582-584.
[11]. Dey S, Raikar R.V. (2007) "Characteristic of loose rough boundary streams at near threshold" Journal of Hydraulic Engg. ASCE 133(3), 288-304
[12]. Flammer, G.H., Tullis,J. Mason, E.S., "Free Surface Velocity Gradient Flow Past Hemisphere," Journal of the Hydraulics Division, ASCE, Vol. 96, No.HY7, Proc Paper 7418, July, 1970, pp.1485-1502.
[13]. Golubtsov, V.V., "Hydraulic Resistance and Formula for Computing the Average Flow Velocity of Mountain Rivers," Soviet Hydrology: Selected Papers, American Geophysical Union, No. 5, 1969, pp. 500-511.
[14]. Griffiths, G.A. (1981) "Flow resistance in course gravel bed rivers "J. Hydraulic Div. An soc. Civ. Eng. 107 (HY – 7), 899 – 918
[15]. Hartung, F., and Scheuerlein. H., "Macroturbulent Flow in Steep Open Channels with High Natural Roughness," Proceedings of the Twelfih Congress of the International Association for Hydraulic Research, Fort Collins, Colo., Vol, 1, Sept., 1967, pp, 1-8.
[16]. Herbich, J.B., and Shulits, S., "Large-Scale Roughness in Open Channel Flow," Journal of the Hydraulics Division, ASCE, Vol. 90, No. HY6, Proc. Paper 4105, Nov., 1964, pp, 203-230.
[17]. Hey, R.D., "Flow Resistance in Gravel-Bed Rivers," Journal of the Hydraulics Division, ASCE, Vol. 105, No. HY4, Proc. Paper 14500, Apr., 1979, pp, 365-379.
[18]. Hey R.D (1979) "Flow resistance in gravel bed rivers "J Hydraulic Div Am SOC CIV Eng, 105 (HY – 4), 365 – 379.
[19]. Johansson, C.E., "Orientation of Pebbles in Running Water," Geografiska Anneler, Vol. 45, Stockholan, Sweden, 1963, pp,85-112.
[20]. Judd, H.E., and Peterson, D.F.., "Hydraulics of Large Bed Element Channels," Report No. PRWG 17-6, Utah Water Research Laboratory, Utah State University, Logan, Utah, 1969.
[21]. James C. Bathurst (December 1981) "Resistance Equation for Large Scale Roughness "Journal of the Hydraulics Division, ASCE, Vol 107 NOHY-12, pp 1593-1613.
[22]. James C. Batharst (December 1981) "Resistance Equation for Large Scale Roughness" Journal of the Hydraulics Division, American Society of Civil Engineers, Vol. 107 NO HY 12, PP 1593-1613.
[23]. James C. Bathurst (December 1978) " Flow resistance of large-scale roughness "Journal of the Hydraulic Division Vol 104NO12PP1587-1603
[24]. J. Aberle and G.M. Smart (2003) "The influence of roughness structures on flow resistance on steep slopes", Journal of Hydraulic Research Vol 41, Issue 3, Available online 01 Feb 2010,259-269
[25]. Kellerhals, R., "Runoff Routing Through Steep Natural Streams," Journal of the Hydraulics Division, ASCE, Vol. 96, No. HY11, Proc. Paper 7666, Nov., 1970, pp,2201-2217.
[26]. LI, R-M., Simons, D.B., Ward, T.J., and Steele, K.S., "Phase 1 Report: Hydraulic Model Study of Flow Control Structures," Report No. CER77-78RML-DBS-TJW, KSS15, Department of Civil Engineering, Colorado State University, Fort Collins, Colo., Nov.,1977.
[27]. Lovera, F. and kennedy J.F (1969) "Friction factors for flat – bed flows in sand channel" J Hydraulic Div, Am. Soc. CivEng 95 (HY 4) 1227 – 1234.
[28]. Miller, J.P., "High Mountain Streams: Effects of Geology on Channel Characteristics and Bed Material," Memoir No. 4, State Bureau of Mines and Mineral Resources, New Mexico Institute of Mining and Technology, Socorro, N.M., 1958.
[29]. Peterson, D.F., and Mohanty, P.K., "Flume Studies of Flow in Steep, Rough Channels," Journal of the Hydraulics Division, ASCE, Vol. 86, HY9, Proc. Paper 2653, Nov., 1960, pp,55-76.
[30]. Petryk, S. and shen, H.W (1971) "Direct measurement of shear stream in a flume, "JHydraulic Div. Am. SOC. Civ. Eng. 97(HY – 6), 883 – 887
[31]. Thompson, S.M. and Campbell, P.L. (1979) "Hydraulics of a large channel paved with boulders" J. Hydraulics Research, 17(4), 341-354
[32]. Van RiJn, L.C. (1982), "Equivalent roughness of alluvial bed" J Hydraulics Div, Am, SOC.Civ.Eng. 108 (HY10), 1215-1218
[33]. Whiting P.J; and Dietrich W.E. (1990) "Boundary Shear Stress and roughness over mobile alluvial beds" J Hydraulic Engg 116(12), 1495-01511