Ⅱ−39 STUDY ON FLOW RESISTANCE IN MOUNTAIN STREAMS THROUGH AND OVER THE GRAVEL LAYER

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Introduction

Steep slopes, large relative depths and very coarse bed materials often characterize the Mountain Rivers. The nature of flow in such rivers is complicated and needs careful considerations for analysis. Not a unique model has been developed yet to know the flow behaviors and characteristics of these kinds of rivers. Estimation of precise value of flow resistance is one of the crucial items to be investigated. Formulas that have been developed so far are based on their own specific cases and conditions and could not be generalized. Many relations developed for estimation of flow resistance in lowland rivers are not sufficient or even not applicable for Mountain Rivers. Considering the above-mentioned facts estimation of flow resistance for Mountain Rivers still remains the subject of research.

The water surface changes rapidly and locally around the gravel causing more energy losses because of formation of hydraulic jumps, wakes etc behind the gravel and due to this reason velocity profiles of surface flow do not follow the logarithmic-law profile.

Experimental setup

The experiments were conducted on 10-m long 15-cm wide and 30-cm deep experimental flume that could be adjusted into different slopes as per requirement. Angular gravel of uniform sizes was used for different slopes ranging from 1/20 to 1/200. Experiments were conducted for each sizes of gravel separately. Gravels were dumped to a depth of 15 cm over the length of 6 m in experimental flume. Definition sketch is as shown in figure 1.

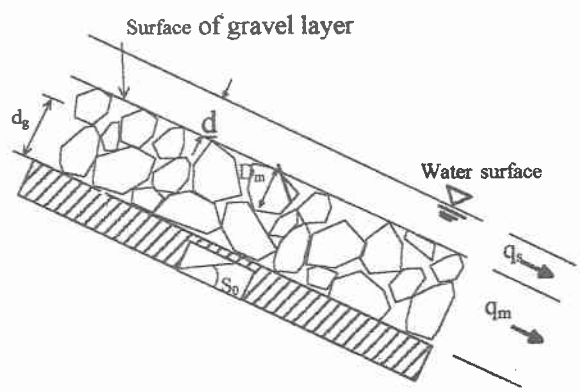

Figure 1 Definition Sketch

Discussion on flow through the gravel layer

Stephenson (1979) proposed an empirical formula for velocity flux V through gravel layer

$V = n_p(Sgd/k')^{1/2}$ ......(1) Where S = slope; g = acceleration due to gravity = 9.80 ms^{-1}; d = representative gravel diameter; n_p = porosity of bed layer materials. The dimensionless friction factor k' is defined as (Stephenson, 1979) $k' = k + 800/R$; Where k = 1 for smooth marbles; 2 for rounded gravel; and 4 for crushed rock and R = Reynolds number defined as $dv/n_p\nu$; ν =kinematic viscosity; $q_t = q_s + q_m$ ....(2)

qm = V.d_g ... (3); q_m = flow discharge per unit width through the gravel and d_g = flow depth from the bottom of gravel as shown in definition sketch. q_t = total discharge per unit width. q_s = flow over the gravel layer per unit width. Porosity measured for angular gravel of sizes 2.5, 3.5 and 4.5 cms is 0.44, 0.45 and 0.42 respectively.

Figure 2 shows a plot of flow depth versus discharges. Solid horizontal line indicates the height of gravel layer in experiment. Having close look into the plot it can be found that for a given discharge depth of flow is higher in milder slopes and rate of increase of discharge is higher in larger size of gravel. It is also could be noticed that flow discharge increases rapidly when the depth of flow exceeds the surface of gravel layer. Figures 3 is a plot of measured discharges (q_m) versus calculated discharges (q_m) through the gravel layer that are obtained from experiment and using Stephenson equation (1). For k = 2 measured and calculated discharges have shown the good agreement than other values of k. Viewing the results from the plot it can be said that if one precisely adopts the value of k Stephenson's equation calculates the discharge through the gravel layer more accurately.

Discussion on flow over the gravel layer

In this study well-known manning roughness coefficient n and Darcy-weisbach friction factor $\sqrt{8/f}$ and logarithmic-law were used with the relation developed by various researchers. $V = 1/n R^{2/3} S^{1/2}$ ... (4);Where R = Hydraulic radius; S = Energy Slopes; V = q_s/d therefore n can be calculated as; $n = d^{5/3}S^{1/2}/q_s$ ..(5); Figure 4 shows a plot of measured n from equation (5) versus relative depth d/D_{84}.

With the general observation of the graph it can be said that for smaller relative depths the n values is higher for each diameter striking the large area of protruding gravel and eddy currents setup behind the larger of gravel. This may be the results of increased turbulence or resulting from the velocity of water gravel. As per experiment results, with the increase of relative depths n value decreases and tends to be constant when the relative depth is higher than 1.5. Barring some cases n value increases as the slope of channel increases.
Regarding the Darcy-weisbach friction factor the following empirical equations (6) and (7) have been proposed by Hey (1979) defining the resistance for turbulent flow in straight channels with fixed rough boundaries of uniform materials and by Bathurst (1985) for bed slopes ranging from 0.004 to 0.04 respectively. $\sqrt{8/f} = 5.74\log(aR/D)$...(6); where 'a' is the coefficient depends on cross sectional shape of channel and is varies from 11.1 to 13.46; $D = 3.5\ D_{84}$; D_{84} = size of which 84% of bed material finer than that. $\sqrt{8/f} = 5.62\log(d/D_{84}) + 4$..........(7) ; Figure 5 shows the plot of relationship between measured friction factor and relative depths. In the same plot Bathurst, Hey and Logarithmic laws of flow resistance have been plotted. From the plot it can be seen that for steeper slopes Bathurst and Hey equations are in good agreement with the measured value of experiment. However, for the milder slope and higher relative depths measured value tends to follow the Logarithmic law.

Conclusion

Stephenson's equation can be used to calculate the flow through the gravel layer by selecting the precise value of K (=2) in the Mountain Rivers. As per the Manning n, it is higher for smaller relative depths and tends to be constant for relative depths higher than 1.5. It shows that Manning equation can be used for the mountain river for the relative depths higher than 1.5. Bathurst and Hey equations can be used for steep slope channel (>1/100) but for mild slope channel Logarithmic law is more accurate to evaluate the flow resistance. These conclusions have been made based on the experimental data obtained from flume test so that for the further verification data from real rivers are needed.

References: 1) Stephenson, D (1979): Rockfill in hydraulic engineering. Elsevier, Amsterdam, the Netherlands, 2) Btharust, J.C. (1994): At-A-Site mountain river flow resistance variation, Poc. Hydr. Engrg.,94 ASCE, Reston,VA., pp.652-656.

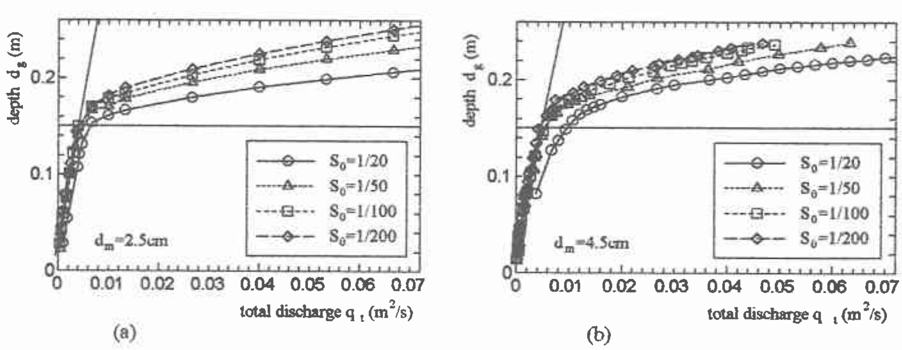

Figure 2. Relationship between flow depth and Discharge

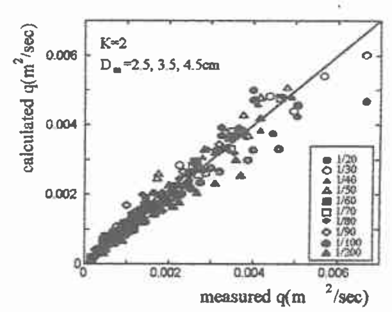

Figure 3. Measured and Calculated Discharge through gravel layer

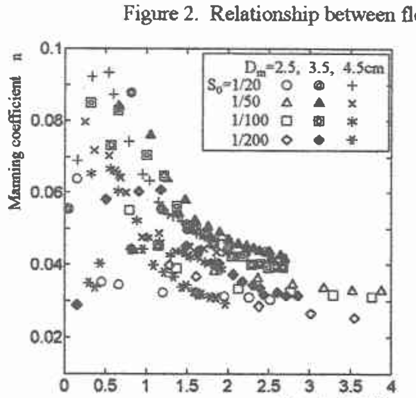

Figure 4. Manning n versus Relative depth

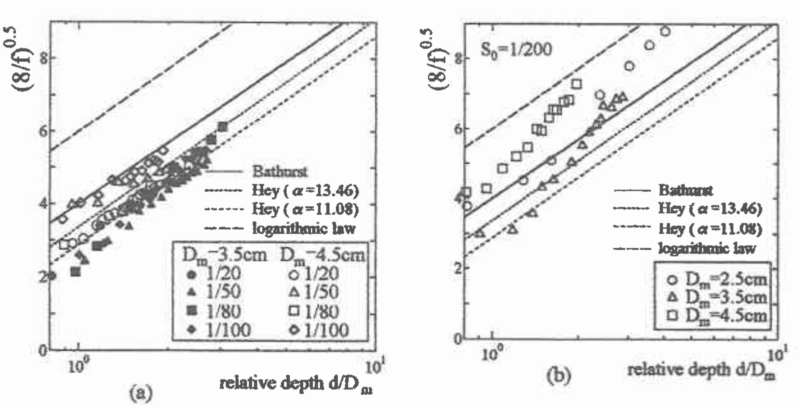

Figure 5. Measured Darcy friction factor $\sqrt{8/f}$ versus Relative depth