ESTIMATION OF BED LOAD TRANSPORT RATE THROUGH EMERGENT VEGETATION

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Introduction

The growth of diverse and heterogeneous combination of herbs and shrubs plays an important role in determining water, sediment, nutrient and pollutant transport. Vegetation is a key factor in the interrelated system of flow, sediment transport and geomorphology in streams and rivers. The vegetation and hydraulics determine channel form by controlling the movement, trapping and storing of sediments. Effects of vegetation on flow characteristics are significant and cause difficulties in hydraulic designs. It has been generally identified that vegetation increases flow resistance, changes backwater profiles and thereby modifies sediment transport processes. The existing mathematical formulations to quantify bed load transport rates in channels without vegetation are not capable of predicting transport rates for channels with vegetation. Therefore, it is very essential to have studies on the bed load transport process in channels in the presence of vegetation. The sediment transport processes may be different depending on the type vegetation, whether they are submerged or emergent and rigid or flexible stems.

This research study investigates the effect of rigid, emergent vegetation on bed load transport in open channels through laboratory experiments. A series of experiments were conducted using a laboratory open channel with different types of vegetation patterns to measure bed load transport rates.

Experimental Procedure

The bed load transport through emergent vegetation was studied by carrying out a series of laboratory experiments. Very coarse sand to medium size gravel was used on the channel bed and metal cylindrical rods with representative diameters were used in the experiments for rigid emergent vegetation.

The experiments were carried out in 10m long, 0.4 m wide, 0.5 m deep rectangular re-circulating tilting flume in the Hydraulic laboratory of the Faculty of Engineering, University of Peradeniya (Figure 1). A 1.5 m long stretch of the channel located at a distance of 4.5 m from the channel entrance was selected as the test section.

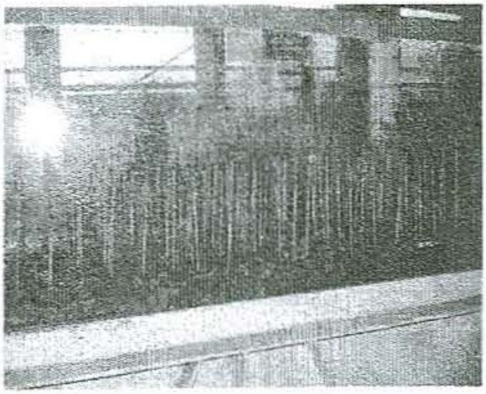

Figure 1: Experimental set-up

The channel was adjusted to a required slope and the sediment was placed in the test section then flow was passed over the channel bed. The transported sediments were collected into a sediment trap located at the end of the channel. The weight of the sediments accumulated in the trap was measured continuously using a load cell coupled with a multi meter. The sediment feeder was used to supply the material at the upstream end of the channel at a constant rate to maintain the sediment equilibrium.

The test was repeated for a combination of four different discharges and three different slopes. The same process was repeated for five different vegetation arrangements and each arrangement was tested for a combination of four different discharges and three bed slopes. The vegetation arrangements used in the tests are shown in Figure 2 and parameters of each arrangement are given in Table 1. Cylindrical metal rods were used to represent vegetation and hence, the vegetation is considered to be rigid and emergent.

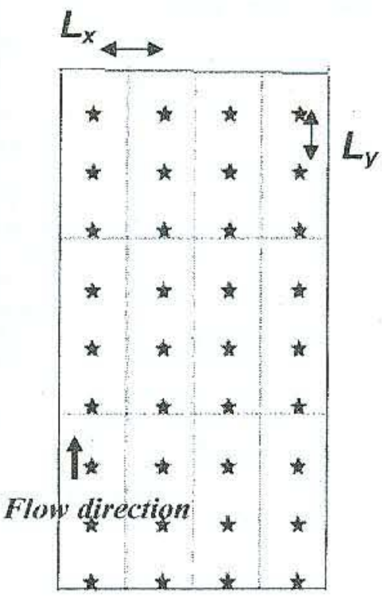

Figure 2: Vegetation arrangement

Data Analysis

The fundamental relationship derived for bed load transport rate (q_b) in steady, uniform flow is given as (Einstein, 1942);

$$\pi_{qb} = f(X_1, X_2, X_3, X_4) \quad \text{.................. (1)}$$

where, $\pi_{qb} = \dfrac{q_b}{\rho u_*^3}$; $X_1 = \dfrac{u_* d}{\nu}$;

$$X_3 = \frac{h}{d} ; \quad X_4 = \frac{\rho_s}{\rho} \quad \text{...................... (2)}$$

and ρ = density of water ρ_s= particle density, ν= kinematic viscosity of water, γ_s= submerged specific weight of sediments, d= median diameter of sediment, h= water depth and u_* = shear velocity.

The movement of bed load is a process taking place very near to the bed and hence, the direct influence of h on bed load transport rate is small and hence, the term X_3 can be neglected. As we are interested in estimating the transport rates as bulk quantities and not as individual grain basis, so that ρ_s will not play a major role here and hence, the term X_4 can be omitted. If flow is turbulent and also for coarse sediments in the channel bed, the term X_1 becomes very large which will have no influence to the sediment transport phenomenon. Therefore, Eq. (1) is simplified to the following;

$$\pi_{qb} = f(X_2) \quad \text{.................. .....(3)}$$

Table 1: Details of vegetation arrangement (N_a = vegetation density)

Parameter	Vegetation arrangements				
	1	2	3	4	5
L_x (mm)	40	40	80	80	120
L_y (mm)	40	80	40	160	40
N_a (Veg/m^2)	625	312	312	116	208

The variation of π_{qb} with X_2 for the experimental runs carried out with vegetation arrangement 1 is shown in Figure 3. The experimental data points appear to be highly scattered. In addition, several existing bed load transport formulae were also used for the comparison of predicted and measured transport rates and the results found to be not satisfactory. Therefore, it can be noted that the bed load transport rate has been severely affected by the presence of vegetation, limiting the applicability of available empirical formula for estimating bed load transport rates when the vegetation is present on the channel bed.

To improve the prediction of bed load transport rates in open channels with vegetation, the parameters related to vegetation patterns such as, L_x, L_y, N_a, and D, are also to be considered in the analysis. Therefore, the non dimensional bed load transport rate π_{qb} can be re-written as;

$$\pi_{qb} = f(X_1, X_2, X_3, X_4, X_5) \quad \text{............(4)}$$

where, $X_5 = (L_x / L_y) * (1/ N_a D^2)^2$ .... (5)

where, D- diameter of vegetation, L_x- spacing between the vegetation in perpendicular to flow direction, L_y- spacing between the vegetation in parallel to flow direction, N_a- density of vegetation (number of vegetation/ area).

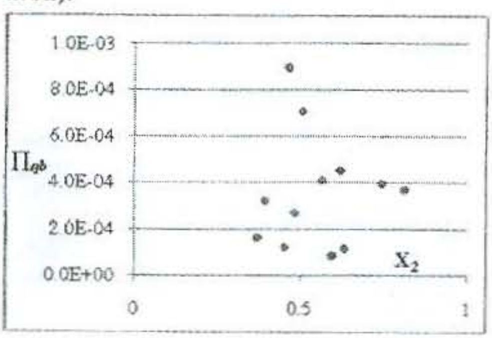

Figure 3: π_{qb} Vs X_2 for vegetation arrangement 1

Neglecting the terms X_1, X_3 and X_4 as in the previous case, the Eq. (4) can be simplified to the following;

$$\pi_{qb} = f(X_2, X_5) \quad \text{.................... (6)}$$

Figure 4 indicates the variation of π_{qb} with X_5/X_2 for different vegetation arrangements. According to this graph, it can be noted that the correlation between π_{qb} and X_5/X_2 appears to be good for the experimental data gathered during this study except one case which could be due to experimental errors. The proposed formulation could be tested further against many laboratory data collected by widening the range of experimental conditions.

Conclusions and Recommendations

A series of laboratory tests were carried out to investigate the effect of vegetation on bed load transport in open channels under steady, uniform flows. The results indicate that the bed load transport rates are highly affected by the presence of vegetation and are difficult to estimate using currently available methods. A new dimensionless parameter related to vegetation pattern was incorporated into the fundamental relationship of sediment transport as a modification when the vegetation is present on the channel bed. According to the analysis, the variations of π_{qb} with X_5/X_2 appears to give very encouraging results indicating a possibility of analyzing bed load transport phenomenon in open channels with vegetation. However, the number of test cases used in the analysis is not sufficient to recommend the proposed method for general usage. This requires more experimental data covering a wide range of sediment gradations, water discharges, channel slopes and vegetation patterns. In addition, it is also recommended to use field data for the verification of the proposed method.

Figure 4: π_{qb} Vs X_5/X_2 for vegetation arrangements

References

Einstein, H. A. (1942). Formulas for the Transportation of Bed-Load, ASCE, Pp.107, 561-597.