BED LOAD TRANSPORTATION IN STREAMS WITH RIGID VEGETATION

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INTRODUCTION

An experimental study is presented to investigate bed load transportation criteria in channel bed with rigid vegetation. Several experimental runs are conducted for uniform flow with different discharges, different channel slopes, two types of sand particle size, and different vegetation densities. Bed load discharges are measured for all cases by using a sand trap. A relation between bed load discharge and tractive shear stress is figured. The effect of vegetation density on bed load transport is well explained. A new expression considering vegetation density is presented for the determination of bed load discharge.

EXPERIMENTAL PROCEDURES

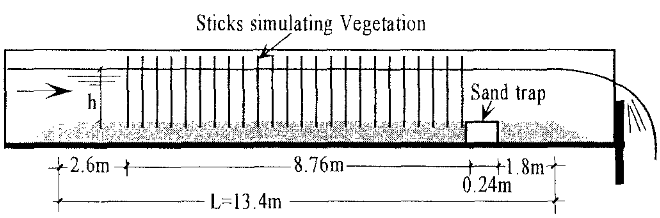

Fig.1 Typical sketch simulating vegetation in a flume.

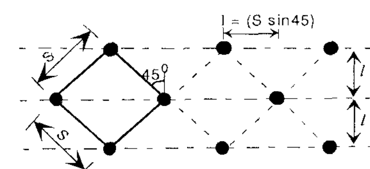

Fig. 2 Arrangement of sticks simulating vegetation.

Table 1 Conditions for uniform flow experiments.

Run	λ	I_0	Q (cm³/s)
d_{50} =0.0987(cm), σ_g =1.144			
1	0.016785	0.023514	4486
2			6734
3			12462
4		0.02	4269
5			6664
6			9551
7			12021
8			15851
9		0.030833	9208
10	0.0077996	0.00993	12564
11		0.012429	6187
12			12872
13		0.016533	10348
14			16342
15	0.0041963	0.009811	9379
16		0.014302	12976
17		0.008364	6664
18			8385
19			12061
d_{50} =0.0701(cm), σ_g =1.467			
20	0.016785	0.0198	3855
21			6762
22			10348
23			14041
24		0.028169	11961
25	0.0077996	0.011053	4269
26			6254
27			9074
28			11627
29			14260
30		0.014269	10623
31	0.0041963	0.008235	5604
32			7608
33			11280
34			13673
35		0.0125	11090

The experiments are conducted on a tilting rectangular flume in the Hydraulics Laboratory at Saga University. The flume could be set at any slope between 0% and 3.33%. The flume has 0.4 m steel bottom width and Plexiglas walls of 20 m length and 0.4 m height. The disturbances due to the inlet transition are eliminated through the use of sheets of thick woven filters. At the flume end, there are two steel gates; one is a watertight vertical sliding gate to preserve the water in the flume to a certain level before starting, the other is a tilting steel gate, which is used to adjust the water level during experiments. Figure 1 shows the schematic diagram of the flume. The bed material was selected as uniform natural quartz sand with grain diameters, d_{50} of 0.0987 and 0.0701 cm, respectively. The sand was spread on the flume bottom over a length of 13.4 m forming a depth of 6 cm mobile bed. Rigid vegetation was simulated by woody cylindrical bamboo sticks with diameter D of 0.31 cm. The sticks tips were plunged into the sand bed in staggered shape for distance of 8.76 m. The sticks were organized in three different spacing S; 2.12, 3.11, and 4.24 cm, respectively, as shown in Fig. 2. At the end of vegetation zone, a sand trap box was placed in the flume. The experimental conditions and observations made are given in Table 1, where $\lambda = \pi D^2 / 4S^2$ is the vegetation density, σ_g is the standard deviation, I_0 is the bed slope, and Q is the flow discharge. In each run, uniform flow condition was reached by controlling the slope, discharge and water depth, simultaneously. Water level was measured at the side-wall of the flume. The movable sand grains were allowed to fall into the sand trap box for a certain time. Then, the collected sand particles were sucked by siphonic action and discharged into a specimen jar.

CALCULATION OF TRACTIVE SHEAR STRESS

The motion of sand particles is under the interaction of two opposing groups of forces: the hydrodynamic applied forces, and the resistance force that is associated with the submerged weight. The existence of vegetation in the bottom significantly reduces the applied forces because of the drag resistance. In the same time, it increases the resistance because of suppressing the turbulent motion. The force balance equation may be represented by

$$\rho g h I_e = \rho u_{*e}^2 + \frac{1}{2}\rho U^2 C_D D h \frac{1}{S^2} \tag{1}$$

where ρ is the water density, h is the water depth, I_e is the energy slope at the same cross-section, and U is the mean velocity of flow. The coefficient C_D is the drag coefficient for a cylindrical body, which may be obtained from the well-known curve that relating drag coefficient C_D with the Reynolds number $R_e = UD/\nu$, where ν denotes the fluid kinematic viscosity. Based on the measured data of experiments, the total dimensionless shear stress, $\Psi = u_*^2 / sgd_{50}$, is calculated, where $u_* = \sqrt{ghI_e}$, g is the gravitational acceleration, $s = 1.65$ is the specific gravity of particles. The effective dimensionless shear stress for grain roughness, $\Psi_e = u_{*e}^2 / sgd_{50}$, is obtained by using Eq. 1, where u_{*e} is the shear velocity referring to grains.

BED LOAD DISCHARGE

When tractive shear stress in the bottom of channels exceeds the critical stress, the movement of sediment particles and bed load discharge take place. In the experiments, the collected samples from sand trap are analyzed and sediment discharge values are presented in the well-known dimensionless form $\Phi = q_b / \sqrt{sgd_{50}^{\,3}}$, where q_b is the bed load discharge per unit width. The corresponding values of tractive shear stress Ψ_e are calculated from Eq. 1. The critical shear stress, Ψ_c is calculated for each case by using an expression from another series of experiments, see Watanabe, et al. (the previous paper in this proceeding). This expression is giving a relation between the critical shear stress $\Psi_c = u_{*c}^2 / sgd$ and the Reynolds number for particles $R_{e*} = u_{*c}\, d / \nu$ considering the vegetation density parameter λ.

$$\Psi_c = e^{c\lambda^{0.75}} \left[\frac{0.106}{R_{e*}} + 0.055 \left(1 - e^{-0.16\sqrt{R_{e*}}} \right) \right] \tag{2}$$

where c is a coefficient in the range of (30 ~ 50), with average of 42.

A relation between sediment discharge Φ and the expression ($\Psi_e - \Psi_c$) with vegetation density parameter, λ is shown in Fig. 3. In the same graph the results are compared with the curve simulation the equation of Meyer-Peter et al. (1). In the figure, despite of experimental data scatter, it is clear that the increase of shear stress causes increase in sediment discharge value, same as Meyer-peter curve. For the same value of shear stress, the bed discharge in vegetated channel is less than in channel without vegetation. Also, for channels with high density of vegetation, it needs a higher tractive shear stress than the low density of vegetation to get the same sediment discharge. A modified expression for Meyer-Peter formula considering both the vegetation density and the critical shear stress calculated by Eq. 2, is presented in the following form

$$\Phi = 8\, e^{-450\,\lambda} (\Psi_e - \Psi_c)^{3/2} \tag{3}$$

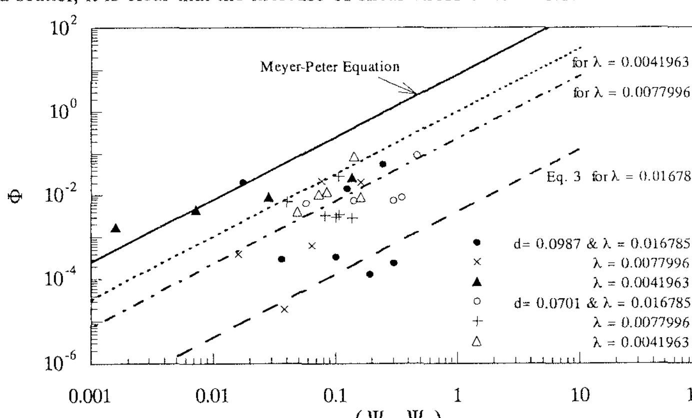

Fig. 3 Effect of vegetation density on bed load function

CONCLUSION

Bed load discharge values in vegetated channels are not the same as the values of non-vegetated channel. A relation between sediment discharge and tractive shear stress is well clarified. The effect of vegetation density on bed load quantity is illustrated. A comparison with Meyer-Peter formula of bed load discharge is done. A Modified expression for calculating sediment discharge considering vegetation density is presented. More data are needed to verify this expression.

REFERENCES

1. Yang, C. T., *Sediment Transport;Theory and Practice*, The McGraw-Hill Co., 1996.