CRITICAL SHEAR STRESS IN STREAMS WITH RIGID VEGETATION

M. Watanabe[1], T. Mouri[2], H. M. Nagy[3], and K. Watanabe[4]
[1]Student, Dept. of Civil Engineering, Saga University, Student Member.
[2]GraduateStudent, Graduate school of Engineering, Saga University, Student Member.
[3]Associate Prof., Dept. of Civil Engineering, Saga University.
[4]Professor, Dept. of Civil Engineering, Saga University, Member.

INTRODUCTION

The incipient motion of sediments in the bottom of open channels covered by non-submerged rigid vegetation is investigated through an experimental study of non-uniform and uniform flow, respectively. The threshold movement of particles is observed at a specific section wherein the flow characteristics are measured. The Shields diagram for incipient motion is modified for streams with vegetation. The effect of vegetation density on critical shear stress is illustrated.

EXPERIMENTAL PROCEDURES

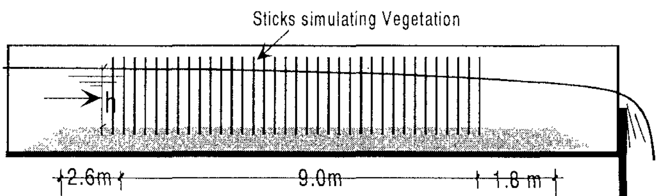

Fig.1 Typical sketch simulating vegetation in a flume.

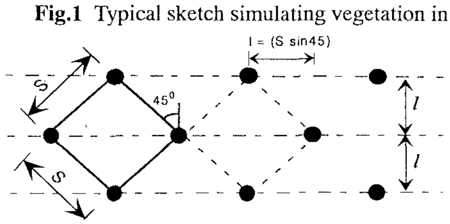

Fig. 2 Arrangement of sticks simulating vegetation.

A flume measuring 20 x 0.4 m and having depth of 0.4 m was used for conducting the experiments in the Hydraulics Laboratory, Saga University. The flume was allowed to be tilted for different slopes. At the tail end, water level was adjusted by vertical sliding gate. Two groups of experiments were conducted: non-uniform and uniform flow experiments, respectively. **Figure 1** shows a typical sketch of the experimental flume for non-uniform flow condition. In non-uniform flow group, sand bed material was uniform with particle diameter d_{50} of 0.1291, 0.0987, and 0.0701 cm, respectively. In the uniform flow group, only 0.0987 cm of sand particle diameter was used. In each run the sand bed was evened out. The length of sand bed was 13.4 m, as shown in the figure. The vegetation elements were simulated by vertical rigid cylinders of bamboo sticks with diameter D of 0.31 cm and height of 25 cm over an area of 0.4 x 9.0 m in spanwise and streamwise, respectively. The sticks were arranged in staggered shape on the sand bed. **Figure 2** shows the arrangement of sticks. The spacing S is taken equal to 2.12, 3.11 and 4.24 cm, respectively. The flow was allowed to pass with several discharges, Q. The discharge was measured by using calibrated V-notch located before the inlet of the experimental flume. Water levels along the channel were measured at the side-wall of the flume. The threshold motion of sand particles was visualized, and its location as well as the associated water depth were recorded. The experimental conditions and observations made are given in **Table 1**, where, $\lambda = \pi D^2 / 4S^2$ is the vegetation density, I_0 is the bed slope, and σ_g is the particle size geometric standard deviation.

Table.1 Experimental conditions

	λ	I_0	Q (cm^3/s)
Non-uniform flow			
d_{50} =0.1291(cm), σ_g = 1.259			
1			9551
2	0.016785	0.01	12361
3			15617
4			9551
5	0.0077996	0.0067	12361
6			12976
7			9551
8	0.0041963	0.005	12361
9			12979
d_{50} =0.0987(cm), σ_g = 1.144			
10			8791
11	0.016785	0.01	10078
12			11862
13			9040
14	0.0077996	0.005	9379
15			10808
16			8546
17	0.0041963	0.0025	10168
18			10996
d_{50} =0.0701(cm), σ_g = 1.467			
19			8385
20	0.016785	0.01	9551
21			10996
22			8385
23	0.0077996	0.005	9208
24			9551
25			7608
26	0.0041963	0.0025	8385
27			8627
Uniform flow			
d_{50} =0.0987(cm), σ_g = 1.144			
28			5175
29	0.016785	0.016471	8709
30			12061
31			3956
32	0.0077996	0.009933	7913
33			12564
34			15157
35		0.004878	6664
36			4323
37			6947
38	0.0041963	0.006444	8546
39			10168
40			11764

TRACTIVE SHEAR STRESS

In a flowing stream, the motion of sand particles is under the interaction of two opposing groups of forces: the hydrodynamics 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 near bed as will be shown in the following section. The fundamental force balance equation may be represented by

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

where ρ is the clear 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 cylindrical bodies, 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, the total dimensionless shear stress, $\Psi = u_*^2 / sgd_{50}$, is calculated, where $u_* = \sqrt{ghI_e}$, g is the gravitational acceleration, and $s = 1.65$ is the specific gravity of particles. The shear stress for grain roughness, $\Psi_e = u_{*e}^2 / sgd_{50}$, is obtained by using Eq. 1,where u_{*e} is the particles shear velocity.

CRITICAL SHEAR STRESS

General scour is the most important criterion when investigating sediment transport problems. In vegetated streams, general scour may be found in compound with the local scour around the reeds of the plants, which is out of the scope of this study. One important factor affecting on the threshold movement is the turbulence level near the stream bottom. The existence of vegetation suppresses the turbulence as been illustrated in Nagy, et al. (1999).

In each run, the threshold movement of sand particles is observed at its specific section along the flume. Using the preceding Eq. 1 and the experimental data at that section, the critical shear velocity u_{*c} is calculated. In **Fig. 3**, a relation between the dimensionless critical shear stress parameter $\Psi_c = u_{*c}^2 / sgd_{50}$ and the Reynolds number for particles $R_{e*} = u_{*c} d_{50} / \nu$ is obtained for several flow conditions in both non-uniform and uniform flow experiments and for three types of vegetation density as well. In the figure, the results are compared with the well-known Shields curve for critical shear stress. Both the vegetation density and the Reynolds number for particles have a significant effect on increasing the tractive shear stress. For simplicity in computation, the depicted graph may be presented in a new analytical expression, which is obtained as follows

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

The coefficient c has the range of (30 ~ 50) due to data scatter, and its average value is taken equal to 42.

CONCLUSION

The critical shear stress values in vegetated streams are not the same values of flat bed streams. A relation between critical shear stress and Reynolds number for particles is presented. Increasing vegetation density gives higher values for critical shear stress. A modified Shields diagram for critical shear stress in flumes with rigid vegetation is obtained. For programming and calculations, a suitable expression for critical shear stress is presented.

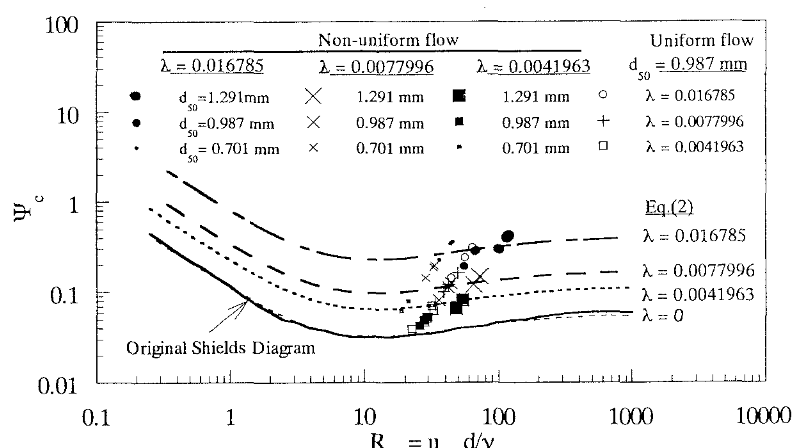

Fig. 3 Modified Shields diagram for critical shear stress in vegetated channel

REFERENCES

1. Nagy, H. and Watanabe, K. (1999): " Tractive Shear Stress in Channels with Rigid Vegetation", Journal of Alexandria Engineering, Alexandria University, Alexandria, Egypt, Vol. 38, No. 6, 1999.