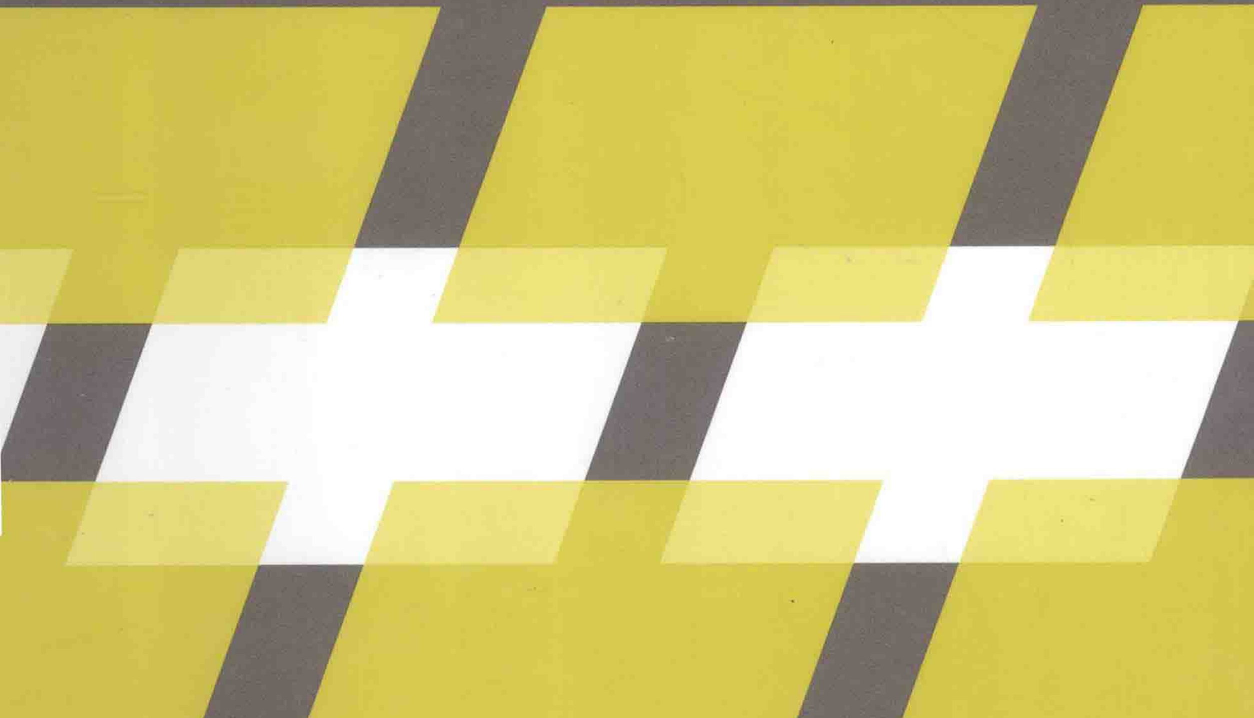
Editor: Liquan Xie

Hydraulic Engineering III



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Hydraulic Engineering III

Editor

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Preface

Hydraulic research is developing beyond traditional civil engineering to satisfy increasing demands in natural hazards, structural safety assessment and also environmental research. In such conditions, this book embraces a variety of research studies presented at the 3rd Technical Conference on Hydraulic Engineering (CHE 2014), 2014 Structural and Civil Engineering Workshop (SCEW 2014) and the 4th Workshop on Environment and Safety Engineering (WESE 2014), held in Hong Kong during December 13–14, 2014. The series of conferences was conceived and organized with the aim to promote technological progress and activities, technical transfer and cooperation, and opportunities for engineers and researchers to maintain and improve scientific and technical competence in the field of hydraulic engineering, environment and safety engineering, and other related fields.

62 technical papers were selected for publication in the proceedings. Each of the papers has been peer reviewed by recognized specialists and revised prior to acceptance for publication. The papers embody a mix of theory and practice, planning and reflection participation, and observation to provide the rich diversity of perspectives represented at the conference. This book review recent advances in scientific theories and modelling technologies that are important for understanding the challenging issues in hydraulic engineering and environment engineering. Some excellent papers were submitted to this book, and some highlights include:

- river engineering and sediment transport, e.g. unsteady open-channel flow over rough bed, sparse planted open channel flow, bed load deposition in vegetated area of a stream, flows with non-submerged vegetation in depth-averaged 2D scheme, seabed sediment at Leizhou Bay of Guangdong (china), sand ridges in Liaodong Bay in northern Bohai Sea.
- waterway engineering, e.g. measures for the waterway of middle Yangtze river, deep-water channel regulation at the lower reach of the Yangtze river.
- flood control, irrigation and drainage, e.g. levee breach process by overflow, rain adaptative landscape in Fujian coastal cities of China, "99.6" Meiyu front rainstorm in China, fractal dimension in the evolution of drainage networks, decadal wind velocity in Henan province of China, hydrological responses of the upper reaches of Yangtze river to climate change.
- hydraulic structures, e.g. thin-plate rectangular weir, wall-jets for hydraulic engineering applications, pier base of hydroturbine with ring beam and columns.
- geotechnical aspects, e.g. slope stability analysis by the improved simplified Bishop's method considering the difference of inter-slice shearing force, instability of composite subgrade in a railway project under construction.
- safety analysis in engineering, e.g. earthquake response of self-anchored suspension bridges, seismic response of PC continuous box-girder bridge with corrugated steel webs, risk of accident investigation and correlation analysis of the foundation pit, key construction technologies for long-span aqueduct with reinforced concrete box arch, fire detection in the condition of low air pressure, risk assessment of domino effect in LPG tank area.
- water resources and water treatment, e.g. index system of water resources allocation, evaporation duct prediction models, characteristics of a heavy rain event in Guilin (china), diatomaceous earth precoat filtration for drinking water treatment, effect of Sanosil on removing algae.
- environmental fluid dynamics, e.g. measured wave in Andaman Sea (Myanmar), particulate organic matter (POM) with sediment at vegetated area in rivers.

- waste management and environmental protection, e.g. environment risk research on Yongjiang river basin in Guangxi province (China), risk assessment of heavy metals in the sediments of Jiulong river estuary in Fujian province (China).
- pollution and control, e.g. adsorption of cu^{2+} from aqueous solution by aminated ephedra waste.
- modelling technology in hydraulic engineering, e.g. mathematical model for closure of a cofferdam in Caofeidian Harbour (China), elementary physical model to study the monogranular cohesive materials, Hoek–Brown disturbance factor for analyzing an axisymmetrical cavern.
- mechanics in engineering, e.g. mesoscopic mechanics theory for concrete in hydraulic engineering, mechanical structure system of straight arch with two articulations by break point.
- numerical software and applications, e.g. tidal current modeling of the yacht marinas of double happiness island in Xiamen (China) by Mike21 series of FM module, shoreline change on Beidaihe New District Coast (China) by model-GENESIS based on one-line theory, construction safety of Beijing subway.
- civil engineering, e.g. reinforced concrete beam by high titanium blast furnace slag, connection design of concrete-filled twin steel tubes column, blind bolted end-plate connection on structural square hollow section.
- sedimentary records and climate environment evolution, e.g. Qinghai lake (China).
- other aspects, e.g. early warning system for groundwater hazard in coal mine, heat storage of solar-ground concrete pile, temperature characteristics for concrete box girder, comprehensive evaluation of cracking characteristics of box girder high performance concretes, land use changes in the coastal cities in China.

At the very time we would like to express our deep gratitude to all authors, reviewers for their excellent work, and Léon Bijnsdorp, Lukas Goosen and other editors from Taylor & Francis Group for their wonderful work.

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The 3rd technical conference on hydraulic engineering

The 4th workshop on environment and safety engineering

2014 structural and civil engineering workshop

The 3rd technical conference on hydraulic engineering

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Bed roughness boundary layer and bed load deposition in vegetated area of a stream

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ABSTRACT: Depth-averaged analysis of flow and sediment transport has become familiar and powerful means in river management. When it is applied to a stream with vegetation, form drag due to vegetation is taken into account, but the change of frictional resistance law is not properly treated. Though the flow with non-submerged vegetation, the velocity is constant except only the thin layer near the bed where the shear flow appears due to bed roughness to govern the frictional resistance law. In this paper, the bed roughness boundary layer is investigated for reasonable estimation of shear velocity and subsequently bed load transport process.

1 INTRODUCTION

Flood mitigation and ecosystem conservation are simultaneously required in recent river management, and understanding and analysis of flow and river morphology in a stream with vegetation have become important topics in river hydraulics. Recently, the depth averaged 2-dimensional model has become familiar with the analysis of river morphology. The drag coefficient is the key in determining the drag related with vegetation and also to understand the vertical distribution of the velocity. The applicability is fine and sometimes it is available to describe the outline of fluvial process there (Tsujimoto 1999). In depth averaged model, the resistance law to relate the depth averaged velocity U to the shear velocity u^* for uniform flow is introduced. If the logarithmic law (Eq. 1) is applied as velocity profile $u(z)$, Keulegan's equation obtained by integration the velocity profile along the depth is employed.

$$\frac{u}{u^*} = \frac{1}{\kappa}\ln\left(\frac{z}{k_s}\right) + B_s(R_{e*}) \quad \frac{U}{u^*} = \frac{1}{\kappa}\ln\left(\frac{h}{k_s}\right) + B_s(R_{e*}) - \frac{1}{\kappa} \tag{1}$$

where κ = Karman's constant; h = depth; k_s = equivalent sand roughness, $B_s(Re^*)$ = function of roughness Reynolds number $Re^* = u^*k_s/\nu$; and ν = kinematic viscosity.

In vegetated area, form drag is predominant and velocity profile is uniform along the depth only except the thin layer near the bed where the boundary layer is developed to bring a shear flow (see Fig. 1).

In the conventional depth analysis for streams with vegetation, form drag for vegetation is introduced in addition to the bed friction treated as similarly as that in non-vegetated area. However, depending on the velocity profile shown in (Fig. 1), a proper resistance law should be applied in vegetated area. As shown later, the resistance law is not sensitive for the calculation of depth and depth-averaged flow, but it brings underestimation of the shear velocity and subsequently it may not bring a reasonable analysis of sediment transport and subsequent fluvial process. In this paper, we discuss the bed roughness boundary layer in vegetated area and deduce a reasonable relation between U and u_* in vegetated area to proceed to an analysis of sediment transport.

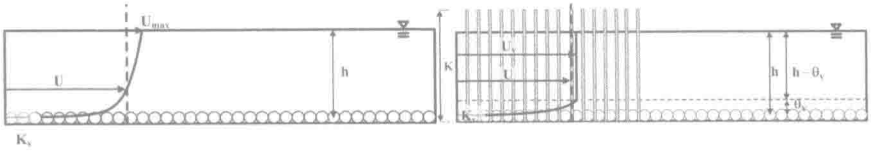

Figure 1. Vertical distribution of velocity in vegetated area.

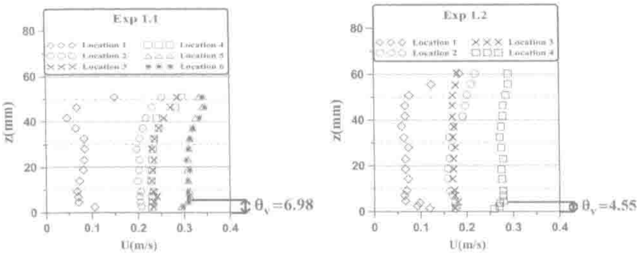

Figure 2. Velocity profile in vegetated area measured by Liu et al.

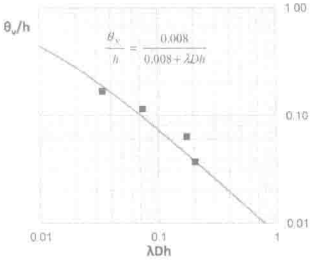

Figure 3. Relation between θ_v/h and λDh.

2 BED ROUGHNESS BOUNDARY LAYER IN VEGETATED AREA

2.1 *Bed roughness boundary layer thickness in vegetated area*

Figure 2 shows elaborate measurement of vertical distribution in vegetated area by (Liu et al. 2008), where group of piles arranged staggered pattern was utilized as non-submerged vegetation; D = diameter; λ = number density of piles; h = depth; U_v = characteristic velocity in vegetated area: and θ_v = bed roughness boundary layer thickness. The characteristic velocity in vegetated area is given as follows by equating the gravity component and the form drag, where g = gravitational acceleration; I_e = energy gradient, and C_D = drag coefficient.

$$U_v = \left[2gI_e/\lambda DC_D\right]^{\frac{1}{2}} \tag{2}$$

The bed roughness boundary layer thickness is subjected to the characteristics of vegetation and dimensional analysis propose the relation between θ_v/h and λDh. By considering θ_v may decrease with the vegetation density and tends to the flow depth with sufficiently disperse density, the following relation is proposed as a favorable formula to estimate the bed roughness boundary layer thickness (see Fig. 3).

$$\frac{\theta_v}{h} = \frac{0.008}{0.008 + \lambda Dh} \tag{3}$$

2.2 *Velocity distribution in bed roughness boundary layer in vegetated area*

Velocity distribution in bed roughness boundary layer is investigated, and logarithmic law is expected to be applied.

$$\frac{u(z)}{u*} = \frac{1}{\kappa}\ln\left(\frac{z}{k_s}\right) + B_s(R_{e*})\,(z < \theta_v) \tag{4}$$

Though the number of the data is small for each run, the shear velocity in the vegetated area, $u*$, is evaluated by fitting the logarithmic law for each run, then the data of the all

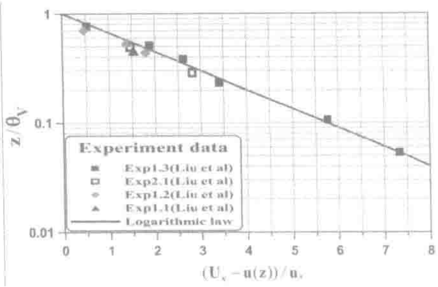

Figure 4. Defect law expression of velocity distribution in bed roughness boundary layer.

runs are plotted in the defect law expression in (Fig. 4). Defect law expression is written as follows.

$$\frac{U_v - u(z)}{u*} = -\frac{1}{\kappa}\ln\left(\frac{z}{\theta_v}\right)(z < \theta_v) \qquad (5)$$

According to this figure, it is recognized that the velocity profile follows the logarithmic law though the number of the measured data for each run is very few.

2.3 *Resistance law in vegetated area*

In order to obtain the resistance law to be applied to the vegetated area, velocity distribution is integrated from the bottom to the free surface as follows:

$$\frac{U}{u*} = \frac{(h-\theta_v)}{h}\frac{U_v}{u*} + \frac{\theta_v}{h}\left[\frac{1}{\kappa}\ln\left(\frac{\theta_v}{k_s}\right) + B_s(R_{e*}) - \frac{1}{\kappa}\right] \qquad (6)$$

In vegetated area, the shear velocity to govern sediment transport is evaluated by using equation 6 from the obtained depth-averaged velocity in horizontal 2D flow analysis, and it is applied to evaluate bed load transport rate, entrainment flux of suspended sediment and so on.

3 FLUME EXPERIMENT AND CERTIFICATION OF MODEL IMPROVEMENT

3.1 *Laboratory experiment*

To observe the sediment transport in the vegetation area during flood stage. In the laboratory experiment, a model vegetation made by a group of cylinders made of bamboo arranged in staggered pattern ($D = 0.25$ mm, $\lambda = 0.25/\text{cm}^2$) was set in the interval of 5.0 m in a flume 20 m long and 0.5 m wide with the constant slope. The bed slope was rigid.

Firstly, the flow measurements (U and h) were conducted along the centerline of the flume (Obana et al. 2012). Then, sand ($d = 0.5$ cm, $\sigma/\rho = 2.65$; d = diameter, σ, ρ = mass density of sand and water) was fed at 1.0 m upstream of the vegetated area with constant volume along the width. The supplied sediment rate was 0.047 cm^2/s. After 20 min of sediment supply, water is stopped and then deposition of sand in the vegetation area was measured along the centerline in the vegetated zone.

3.2 *Simulation of depth-averaged flow and comparison with flume experiment*

The measured data and the results of 2D depth averaged model longitudinal changes of depth and depth-averaged velocity are compared in figure 6. The calculation was conducted

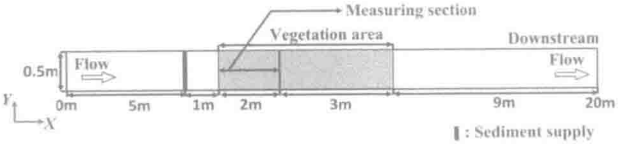

Figure 5. Experimental Flume.

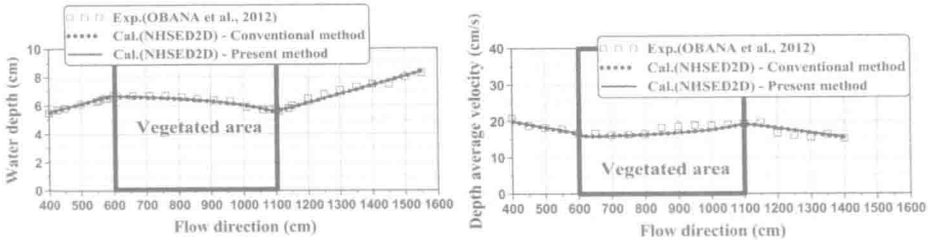

Figure 6. Comparison between measured and calculated results of depth and depth-averaged velocity.

by using a program developed for horizontal 2D depth averaged flow where the bed friction and the form drag due to vegetation are taken into account by the following equation.

$$\tau_x = \rho C_f U\sqrt{U^2+V^2}, \quad \tau_y = \rho C_f \lambda V\sqrt{U^2+V^2} \tag{7}$$

$$F_x = \frac{1}{2}C_D \lambda U\sqrt{U^2+V^2}, \quad F_y = \frac{1}{2}C_D \lambda V\sqrt{U^2+V^2} \tag{8}$$

where U,V = longitudinal and lateral component of depth-averaged velocity, C_f = friction coefficient defined as $(U/u^*)^2$. In the conventional way, Keulegan's equation (Eq. 1) is employed to both non-vegetated and vegetated areas. While, when the present method is applied, equation 5 is employed in the vegetated area. As shown in figure 6, Conventional way and present way give good agreements between experimental data and calculated data about depth-averaged velocity and water depth. Figure 7 shows the shear velocity may be appreciably underestimated if the conventional way is employed.

3.3 *Bed load transport and deposition in vegetated area*

Bed load transport can be described by the formula proposed by (Ashida & Michiue 1972), and written as follows.

$$q_{B^*} \equiv \frac{q_B}{\sqrt{(\sigma/\rho-1)gd^3}} = 17\tau^{*3/2}\left(1-\frac{\tau^*_c}{\tau^*}\right)\left(1-\sqrt{\frac{\tau^*_c}{\tau^*}}\right) \tag{9}$$

where q_B, q_{B^*} = bed load transport rate; $\tau^* = u^{*2}/[(\sigma/\rho-1)gd]$ = Shields number; and τ^*_c = dimensionless critical tractive force. If bed load transport formula by (Ashida & Michiue 1972) is applied, the supplied sediment in the present experiment is around equivalent in the upstream of the vegetated area but excessive in the vegetated zone. Thus, bed load sediment deposit just upstream of the vegetated area and the upstream part of the vegetated area.

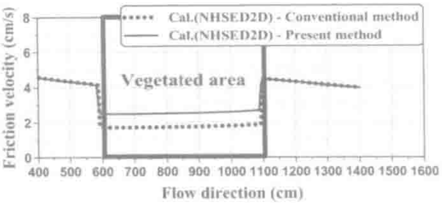

Figure 7. Calculated results on shear velocity.

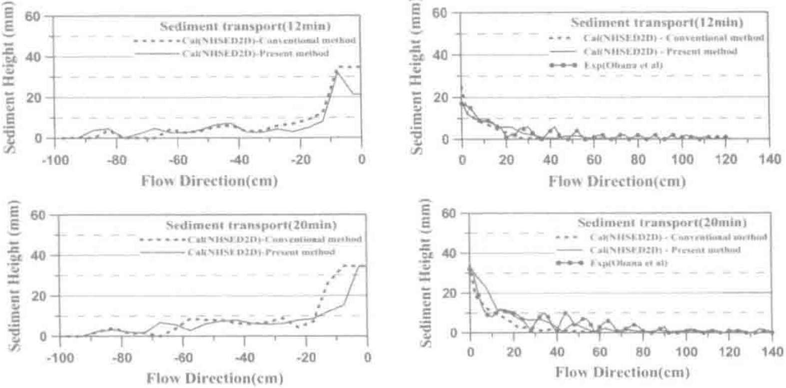

Figure 8. Deposition profile of bed load sediment.

In figure 8, longitudinal profile of bed load deposition with time is depicted with the measured profile in the vegetated area after 12 min. and 20 min. As for the deposition of bed load in the upstream of the vegetated zone, we did not carried the measurement in the flume experiments.

As for the calculated results, those employed the conventional resistance law and the presently proposed one for the vegetated area are compared with the measured data. The present model can describe the deposition profile with steeper downstream slope with faster migration because of the higher value of the shear stress and it shows better conformity with the experimental result. Thus it is concluded that introduction of the present proposal of the resistance law based on the concept of bed roughness boundary layer in vegetated area.

4 CONCLUSION

Recently, 2D horizontal depth-averaged flow model becomes familiar to be recognized as powerful means of stream with vegetation by adding the form drag of vegetation. Though it is expected to apply fluvial process of streams with vegetation, the shear stress may be underestimated and fluvial process may not be properly described. In this study, we focused on the bed roughness boundary layer in the vegetated area to deduce the resistance law in the vegetated area.

The modification of the resistance law by introducing the bed roughness boundary layer brings less changes in flow calculation represented by depth and depth-averaged velocity but significant correction of shear velocity and subsequently sediment transport. The proposed modification will affect other aspects in fluvial processes, which will be clarified successively.

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