# CONCEPT OF BED ROUGHNESS BOUNDARY LAYER AND ITS RESULTANT OUTCOMES TO BE APPLIED TO 2D DEPTH-AVERAGED ANALYSIS OF FLOW AND FLUVIAL PROCESS IN STREAMS WITH VEGETATION

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When river management is focusing flood mitigation, water resources utilization and ecosystem conservation, vegetation in riparian area recently is a key and it is represented by fluvial process. Recently 2D depth-average analysis has become popular and powerful, and one expects its applicability to even a stream with vegetation. However, there must be some restriction for application in 2D depth-averaged model for flow with vegetation. In this paper, as for flow with non-submerged vegetation, several points necessary to be modified are theoretically discussed. From the check along the 2D modeling, the friction resistance law should be reasonably considered and the concept of “bed roughness boundary layer” is proposed and formulated against the vegetation density. Based on this concept, the shear flow structure in this layer is discussed and formulated. It brings the reasonable evaluation of the shear stress and subsequently the kinematic eddy viscosity as important parameter for discussion of sediment transport. In addition, vertical profile of suspended sediment concentration is discussed to relate the depth-averaged concentration to the bottom concentration of suspended sediment. By using the results of this paper, we are able to apply the 2D depth-averaged analysis for flow and fluvial process reasonably for flow and fluvial process in a stream with variable density of vegetation.

## 1 INTRODUCTION

River is a key of human activity in river basin. Spatial variation of flow discharge is related to flood and water resources management and various landscapes created by fluvial process is related to river ecosystem. In rivers, flow is mainly governed by river morphology and it drives sediment transport. Sediment transport causes various fluvial processes and changes the boundary condition of flow. When we are interested in ecosystem, various morphology provides places of vegetation invasion and growth, and they provides habitat to various organisms. As mentioned above, the interaction among flow, sediment transport, river morphology and vegetation is essential characteristics of a river, and its management is a key in river management aiming flood mitigation, water resources management and ecosystem conservation. Recently 2D depth-averaged numerical analysis becomes very familiar and it provides much information in river management, however, inadequate treatments for flow in vegetated area often brings inaccurate conclusions of the analysis.

In this paper, several issues along the scheme of 2D depth-averaged analysis are focused on and discussed to derive reasonable alternatives for flow with vegetation.

## 2 BED ROUGHNESS BOUNDARY LAYER IN FLOW WITH NON-SUBMERGED VEGETATION

### 2.1 Bed Roughness Boundary Layer and Velocity Distribution

In the characteristic of flow with non-submerged vegetation is represented by the velocity balancing form drag and longitudinal component of the gravity constant along the depth, $U_v$, and it is expressed by the following equation.

$$U_v = \sqrt{\frac{2gI_e}{C_D \lambda D}} \tag{1}$$

where $I_e$=energy gradient of flow. In fact there is a thin layer near the bed governed by the bed roughness (Figure 1). The authors investigated the data measured in the laboratory flume by Liu *et al*. [1], and the thickness of bed roughness boundary layer was formulated as follows (Jeon *et al*. [2]).

$$\frac{\theta_v}{h} = \frac{0.008}{0.008 + \lambda Dh} \tag{2}$$

where $\theta_v$=bed roughness boundary thickness; and $h$=depth. Figure 2 depicts Equation (2) with the data obtained from the experiments by Liu *et al*. [1], and $\theta_v$ approaches to the depth $h$ (similar to the flow without vegetation) when the parameter related to vegetation density ($\lambda Dh$) becomes smaller.

The authors investigated the vertical distribution of velocity $u(z)$ inside the bed roughness boundary layer according to the data measured by Liu *et al*. [1], and it was clarified that $u(z)$ follows a logarithmic law subjected to the bed roughness in this layer, while it shows a constant velocity $U_v$ expressed by Equation (1) in the outside of this layer. Thus, the velocity distribution of flow with non-submerged vegetation is written as follows:

$$\frac{u(z)}{u_*} = \frac{1}{\kappa}\ln\left(\frac{z}{k_s}\right) + B_s(R_{e*}) \quad (z < \theta_v); \quad u(z) = U_v \quad (\theta_v < z < h) \tag{3}$$

where $z$=vertical distance from the bed; $k_s$=equivalent sand roughness, $B_s(Re_*)$=function of roughness Reynolds number $Re_*=u_* k_s/\nu$; $h$=depth; and $\nu$=kinematic viscosity. Log law in the bed roughness boundary layer is certificated with sufficient reliability in spite of limited number of the measured data by Liu *et al*. [1], for each run by using the defect law expression as shown in Figure 3 (Jeon, *et al*. [2]).

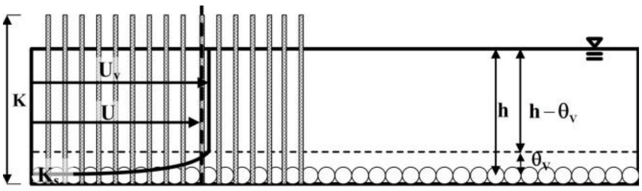


Figure 1. Bed roughness boundary layer for flow with vegetation

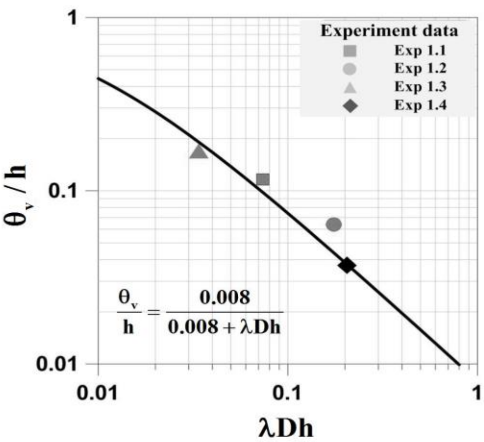


Figure 2. Relation between $\theta_v/h$ and $\lambda Dh$

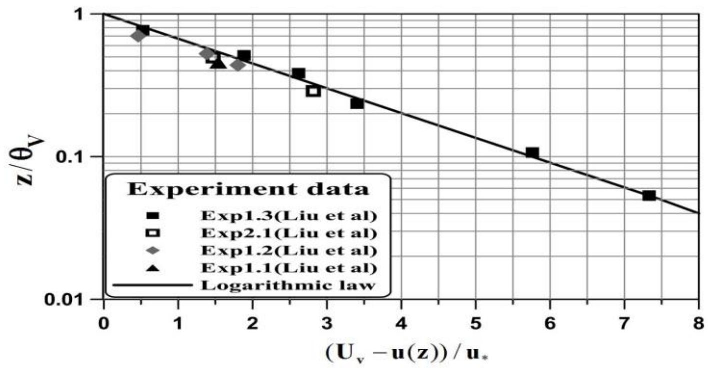


Figure 3. Defect law expression of velocity distribution in bed roughness boundary layer (Jeon, *et al*. [2])

### 2.2 Points to be modified in 2D Depth-averaged Scheme for Flow with Vegetation

When the flow with submerged vegetation by taking account of the bed roughness boundary layer, the followings should be investigated for more reasonable treatments (see Figure 4):

First of all, form drag should be added in flow with vegetation, and taking into account this term can provide a first approximation of flow with vegetation (Tsujimoto. [3]), and most studies have followed on this line. However, not only the addition of form drag, but also some other parts in the governing equations should be modified. The friction resistance law represented by $c_f$ should be modified for flow with vegetation to relate the depth-averaged flow and the shear velocity $u_*$, which is the key to discuss the kinematic eddy viscosity $\nu_t$, bed load transport rate and entrainment rate of suspended sediment. Under shallow water approximation which is applicable in 2D analysis, horizontal diffusivity (represented by the subscript $h$) is subjected to the kinematic eddy viscosity caused by bed roughness (vertical diffusivity). Furthermore, the turbulent diffusion coefficient of suspended sediment $\varepsilon_s$ is related to the kinematic eddy viscosity $\nu_t$ by using the turbulent Schmidt number. In case of suspended sediment, 2D analysis describes the behavior of the depth-averaged concentration of suspended sediment $C$, while the fluvial process is subjected to the bottom concentration $c_b$. In order to know the ratio of the bottom concentration to the depth-averaged one, the vertical profile of suspended sediment should be known in the flow with vegetation and it must be subjected to the bed roughness boundary layer.

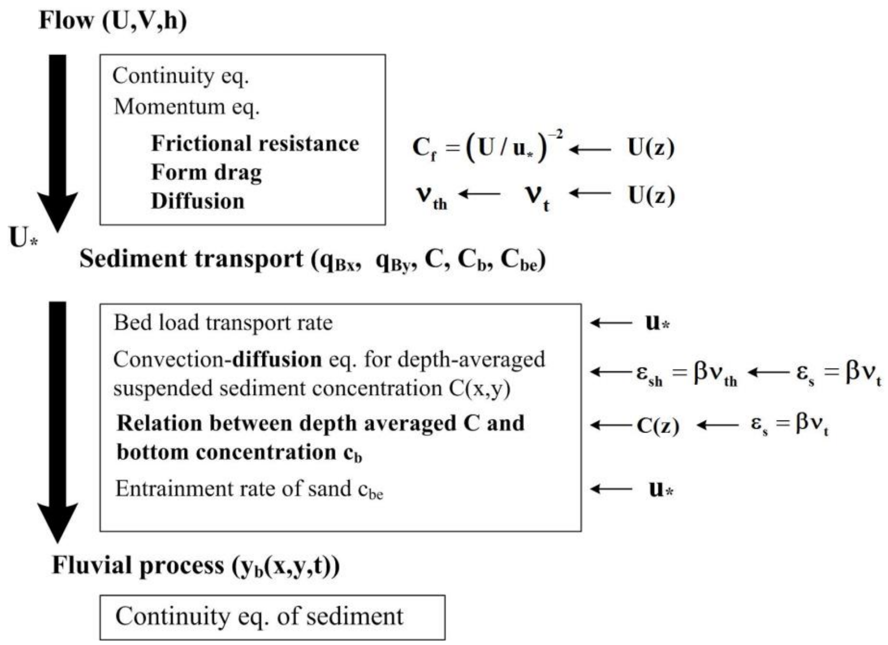


Figure 4. Necessary modifications in 2D depth-averaged scheme for flow with vegetation

## 3 CONCLUSIONS

When river management is focusing flood mitigation, water resources and ecosystem conservation, vegetation in riparian area is a key and it is represented by fluvial process. Recently 2D depth-averaged analysis has become familiar and powerful, and one expects its applicability to a stream with vegetation. However, there must be some restriction for application in 2D analysis for flow with vegetation. As for flow with non-submerged vegetation, several points necessary to be modified are theoretically discussed. In flow with vegetation, taking account for drag term due to vegetation is a principal key but it is not necessary sufficient by it alone.

From the check along the 2D modeling, the friction resistance law should be reasonably considered and the concept of "bed roughness boundary layer" has been proposed and formulated against the vegetation density. Based on this concept, the shear flow structure in this layer has been discussed and formulated. It has brought the reasonable evaluation of the shear stress and subsequently the kinematic eddy viscosity as important parameter for discussion of sediment transport. In addition, vertical profile of suspended sediment concentration has been discussed to relate the depth-averaged concentration to the bottom concentration of suspended sediment which is a key when fluvial process is discussed.

In this paper, formulas to modify parameters necessary for flow with vegetation have been analytically derived which are presented as functions of the vegetation density, and some of them are depicted in graphs. Resultantly we are able to apply the 2D depth-averaged analysis reasonably to flow and fluvial process in a stream with various density of vegetation.

## 4 ACKNOWLEDGMENTS

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