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Study of Combined Effects of Roughness and Bed Infiltration on Turbulent Channel Flow

Dept. of Civil Engineering , University of Tokyo Member Guangwei Huang
Fellow Nobuyuki Tamai

1. Introduction

Flow over a rough and porous surface occurs in diverse engineering applications. For instance, in bed-type river intake, the knowledge of flow structure over the suction zone is very essential for accurate determination of the boundary shear stress, which is closely related to bedload transport. Experimental studies regarding the effects of surface suction on turbulent channel flow are rather limited, and the numerical studies of this kind are even scarce. The paper by Prino (1995) was probably the first numerical study of suction effects on open channel flow. However, the effect of a rough porous surface has not been dealt with so far. This situation might be attributed to the fact that in spite of the advances made in recent years to calculate very complex turbulent flows, little progress has been made in the modeling of flow near rough surfaces. With few exceptions, surface roughness is treated by the so-called wall-function method in which numerical solution of the flow near the surface is avoided altogether by assuming the classical log-law of the wall. Nevertheless, from the eco-engineering point of view, velocity, turbulence over a rough porous bed are very important environmental factors which must be treated more accurately.

In this paper, the combined effects of bed roughness and bed suction on channel flow are numerically investigated by making use of the k-ω model, which, according to our tests and recent studies by other researchers, is well capable of describing all flow features up to the surface. With different suction rates, the flow alterations over a rough surface are computed and compared with the case of a smooth porous surface. Of particular interest is the response of velocity and turbulent kinetic energy to the coexistence of bed suction and bed roughness.

2. Turbulence model

The k-ω model proposed by Wilcox is given below:

$$\frac{\partial k}{\partial t}+U_j\frac{\partial k}{\partial x_j}=\frac{\partial}{x_j}[(\nu+\sigma^*\nu_t)\frac{\partial k}{\partial x_j}]-\overline{u_iu_j}\frac{\partial U_i}{\partial x_j}-\beta^* k\omega$$

$$\frac{\partial \omega}{\partial t}+U_j\frac{\partial \omega}{\partial x_j}=\frac{\partial}{x_j}[(\nu+\sigma\nu_t)\frac{\partial \omega}{\partial x_j}]+\alpha\frac{\omega}{k}(-\overline{u_iu_j}\frac{\partial U_i}{\partial x_j})-\beta\omega^2$$

$$-\overline{u_iu_j}=\nu_t(\frac{\partial U_i}{\partial x_j}+\frac{\partial U_i}{\partial x_j}) \quad ; \quad \nu_t=\frac{k}{\omega}$$

where k the turbulent kinetic energy, ω the specific dissipation rate, and
$\alpha=5/9, \beta=3/40, \beta^*=0.09, \sigma=\sigma^*=0.5$

Bed roughness, Bed suction, k-ω model

7-3-1, Hongo, Bunkyo-ku, Tokyo, 113, Japan, Tel: 03-3812-2111×6139, Fax: 03-5689-7217

A key advantage of the k-ω formulation over other two-equation models is the fact that ω-oriented equations possess solutions in which the value of ω may be arbitrarily specified at the surface. This provides a natural way to incorporate effects of surface roughness through surface boundary conditions. For sȧndgrain roughness, is was shown by Wilcox that the boundary condition for the specific dissipation rate ω can be written as following:

$$\omega = \frac{u_\tau^2}{\nu} S_R, \quad at \quad y = 0$$

$$S_R = \begin{cases} (50 / k_s^+)^2 & k_s^+ < 25 \\ 100 / k_s^+ & 25 \le k_s^+ \le 400 \end{cases}$$

where k_s^+ is the roughness Reynolds number. The momentum and continuity equations, coupled with the k-ω model are solved by finite volume method on a non-uniform grid. which is essential for accurate numerical integration up to the surface.

3. Case Study

Figure 1 shows the computed velocity profiles for both smooth and rough surface (k_s^+=100) with the non-dimensional suction velocity Vs=0.05. The velocity profiles over smooth and rough surface without bed suction are also plotted in the same figure for the purpose of comparison.

It is clearly seen that approximately above y+=100, the velocity is apparently decreased even at a relatively low suction rate, and that the suction effects are more profound over smooth surface than that over the rough surface. Figure 2 shows the variation of turbulent kinetic energy with increasing suction rate over the rough surface. The non-dimensional turbulent kinetic energy (k/u_τ^2) is reduced with increasing suction rate.

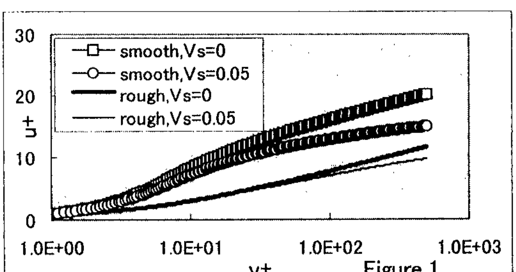

Figure 1

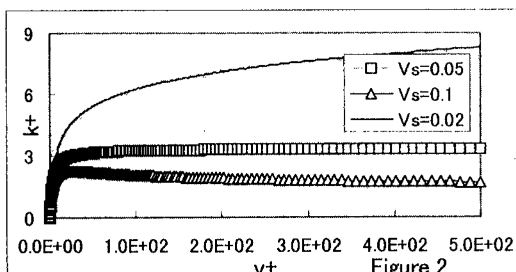

Figure 2

4. Conclusion

The flow is affected considerably even by rather low suction rate, and the degree of flow modification depends to a large extent on surface dynamic attribute. The present study is just the first step toward understanding of the combined effects of bed roughness and bed suction, so that further study is needed.

References

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