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Experimental and Numerical Study of Turbulent Flow in Open Channels with Impermeable and Porous Bed

Evangelos Keramaris[a,*], George Pechlivanidis[b], Dorothea Kasiteropoulou[a], Nikolaos Michalolias[a], Antonios Liakopoulos[a]

[a]*University of Thessaly, Department of Civil Enginnering, Pedion Areos, 38334, Volos, Greece*
[b]*Alexander Technological Educational Institute of Thessaloniki, Department of Civil Engineering T.E., Sinds, 57400, Thessaloniki, Greece*

Abstract

In order to experimentally and numerically investigate turbulent flow in an open channel with porous (vegetated) and impermeable bed 2D Particle Image Velocimetry (PIV) and a Computational Fluid Dynamical (CFD) model were used. PIV is an optical method of flow visualisation that is used to obtain instantaneous velocity measurements on a plane of a flow field. The CFD model is based on the CFX computer package, a high-performance general purpose fluid dynamics program that has been applied to solve wide-ranging fluid flow problems.
In order to validate the results of the numerical model, the CFX based results were compared with experimental data from PIV measurements. The comparison is carried out for two cases: a) impermeable bed and b) porous bed. For the simulation of the porous bed a grass-like of flexible vegetation of 2 cm thickness was used. Vertical distributions of velocities above the impermeable bed and above the vegetation for the porous bed for the same different total depths were evaluated.

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Keywords: Open channel flow; PIV; CFX; Turbulent flow;Velocity distribution;

* Corresponding author. Tel.: +302421074140
E-mail address: ekeramaris@civ.uth.gr

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1. Introduction

Vegetation is one of the more important factors that shape the turbulence in natural open channels, influencing thus the operation of wetlands and the rivers. The existence of aquatic plants has as result the increase of resistance in the flow and the reduction of the mean velocity in comparison with beds without vegetation. The last 20 years a lot of studies (experimental and numerical) have been performed, in order to focus the effect of vegetation in open channels.

As regards the experimental procedure the authors of this study have performed a lot of experiments. In the study of [1] results (experimental and computational) for turbulent flow over and within a porous bed have been presented. The simulation has been achieved with the use of a rods bundle.

In the work of [2] the turbulent flow in open channel with permeable bed is investigated experimentally, with the use of hot film anemometry (TSI cross hot film connected with IFA 100). Measurements of discharge, mean velocity and turbulent characteristics (Reynolds stresses) reveal the effect of the material used (filters, vegetation), ε (porosity) and s'/h (relative porous thickness) on the flow characteristics and the discharge capacity of the channel.

In the study of [3] the characteristics of turbulent flow above porous beds (porous filter and rods bundle) are studied experimentally with the use of hot-film anemometry (TSI cross hot film connected with IFA 100). The experimental results show many differences in both mean and turbulence characteristics between the two bed materials used.

[4] studied experimentally the characteristics of turbulent flow in an open channel above the permeable bed (grass vegetation and gravel bed) using a part a PIV. Hydraulic characteristics such as distributions of velocities, turbulent intensities and Reynolds stress are investigated and the results show that the bed type can significantly influence the turbulent characteristics of the flow.

In the study of [5] the turbulent characteristics of the flow in an open channel with horizontal and inclined impermeable bed were studied experimentally using a PIV. The channel slope influences significantly the turbulent characteristics of the flow such as the variation of longitudinal turbulent intensity the variation of vertical turbulent intensity, the turbulent kinetic energy and Reynolds stresses.

The influence of transition from vegetation to gravel bed and vice versa [6] and the effects on the velocity distribution of turbulent flow in a half-separated (impermeable and permeable) bed [7] in open channel is investigated experimentally. In the first case results show that the influence on the turbulent characteristics of transition from vegetation to gravel bed is different in comparison with those of transition from gravel to vegetated bed. This is due to the fact that the presence of gravel bed increases the turbulent characteristics of the flow in regard to the vegetated bed due to the great roughness which is observed near the interface gravel bed-water because of the presence of the gravel bed and this increase the turbulence. In the second case results show that the presence of half-separated impermeable and permeable bed influences the values of velocity distribution in comparison with situations over permeable or impermeable bed. The comparison with the same experiments when it has transition from permeable to impermeable bed and vice versa shows that there are a lot of differences on velocity distribution.

As regards the numerical studies initially [8] and [9] developed a method for the determination of the velocity profile which separates the flow region in two layers, one inside the vegetation and the other over the vegetation. This theory was based on the two layer method. Contrary to the theory of [8], [10] developed a model for the calculation of mean velocity and turbulent characteristics of the flow in an open channel with vegetation. Their theory was based on the fact that the vegetation resistance has an impact not only in the momentum equation but and in k-ε model equations.

[11] modified these two models in order to examine the vegetation geometry and the drag resistance as a function of the flow depth. In this theory they added the turbulent kinetic energy equation for two layers model. [12] used 3D finite element program (SSIM) for the study of the vegetation influence in velocity distribution. This model solves the momentum and continuity equations for each element and uses the k-ε model for the turbulence modeling.

In this study in order to experimentally and numerically investigate the turbulent flow in an open channel with porous (vegetation) and impermeable bed, 2D PIV and a CFX model were used. For the simulation of the porous bed a grass-like vegetation was used. Vertical distributions of velocities above the impermeable bed and above the vegetation for the porous bed for the same different total heights were evaluated. Results show that there is a good agreement between experimental and numerical study.