Water Utility Journal 10: 37-43, 2015.

The influence of transition from vegetation to gravel bed and vice versa in open channels using the PIV method

E. Keramaris[1] and G. Pechlivanidis[2]
[1] *Department of Civil Engineering, University of Thessaly, Volos, Greece, e-mail: ekeramaris@civ.uth.gr*
[2] *Department of Civil Infrastructure Engineering, Alexander Technological Educational Institute of Thessaloniki, Greece, e-mail: gpexliva@cie.teithe.gr*

Abstract: In this study the influence of transition from vegetation to gravel bed and vice versa in open channel is investigated experimentally. This experimental investigation is based on the 2D Particle Image Velocimetry (PIV) method, which allows data acquisition at fine spatial-temporal resolution. For the simulation of the two porous beds: a) a grass-like vegetation and b) gravel bed of 2cm height were used to represent the permeable bed, since these conditions are typical of flows encountered in sediment transport problems. In total, 24 experiments were carried out. The experiments were conducted in a horizontal channel of 6.5m length, 7.5cm width, and 25cm height. The velocity is measured above the permeable bed and at two different discharges (0.735 and 0.970lt/s) and three different flow depths (4, 7 and 10cm). The experiments were performed in four different locations of the channel (over the vegetated bed, in the transition point from vegetated to gravel bed, over the gravel bed, and in the transition point from gravel bed to vegetated bed). 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.

Key words: Turbulent flow, particle image velocimetry, permeable bed, velocity distribution.

1. INTRODUCTION

The transition from permeable to another different permeable bed on turbulent flow in an open channel has particular importance. In nature it is observed a growth of vegetated or gravel beds both in rivers and open channels in small or large lengths. The presence of a permeable bed in an open channel has as a result the change of depth flow and velocity. Also the presence of different permeable beds (for example vegetated and gravel bed) has a great influence in the turbulent characteristics of the flow.

Initially in an experimental study, Beavers and Joseph (1967) used a porous block with high permeability in a closed channel and found an empirical relationship for the interfacial slip velocity which takes into account the Darcy velocity within the porous region, the permeability of porous medium and a slip parameter assumed to be independent of velocity.

The study of turbulent flow over and within a permeable layer is rather limited since there are further difficulties because of the turbulence. Stephan and Gutknecht (2002) investigated the resistance of submerged flexible aquatic vegetation on the flow. They described the flow resistance of the natural macrophytes used by means of equivalent sand roughness and they found out that the latter as well as the zero plane displacement of the logarithmic velocity profile were of the same order of magnitude as the mean deflected plant height and increased with increasing plant height.

Carollo et al. (2005) conducted experiments in a grass-like vegetation flume in order to analyse flow resistance for flexible submerged elements. The authors concluded that a flow resistance equation, linking the friction factor with the shear Reynolds number, the depth-vegetation height ratio and the inflection degree can be established.

Pokrajac and Manes (2009) presented an experimental investigation of the interaction between the turbulent flow in an open channel and the turbulent flow within its very permeable bed. The bed was composed of uniform-size spheres packed in a cubic pattern. Fluid velocities were measured by Particle Image Velocimetry. They investigated the effect of bed porosity on these flow properties by comparing the results of two experimental configurations: one with an impermeable bed composed of a single layer of spheres and another with a permeable bed composed of five layers. For the latter case, PIV measurements of velocities were also carried out inside two pores adjacent to the bed surface. This data provides an insight into the mechanisms of momentum transfer between the turbulent open channel flow and the turbulent flow within its very permeable bed.

Pechlivanidis et al. (2012) investigated experimentally the turbulent characteristics of open-channel flow using Particle Image Velocimetry. Results show that velocity over the vegetation region is a function of the vegetation height and the total flow depth; velocity decreases as the vegetation height increases. In addition, we show that velocities above the vegetation region are much lower than velocities above an impermeable bed. This is due to the turbulent shear stresses and the existence of turbulence in the vegetation region, which reduce the mean velocity above the vegetation region.

The width of the channel is only 7.5cm but does not influence the magnitude of the velocities. Keramaris et al. (2013) carried out experiments to investigate the impact of lateral walls on the velocity profile in an open channel with the width of 7.5cm. Results from these experiments showed that the lateral walls influence the velocities only in a distance of 0.4cm from the walls. This result indicates that the wall doesn't influence the instantaneous velocities in the central area of the channel in which the velocity measurements are usually conducted. The impact of the lateral walls on the flow dynamics in the rest of the channel is negligible.

Finally in the study of Pechlivanidis et al. (2014) the impact of permeable to impermeable (and vice versa) bed transition on the velocity distribution of turbulent flow in an open channel is investigated experimentally. A grass-like vegetation of 2cm height was used to represent a permeable bed. The velocity is measured above the vegetation for the permeable bed and above the impermeable bed. Results show that the velocity distribution in channels with transited permeable-impermeable beds (and vice versa) is different to distributions of velocity in solely permeable or impermeable channel beds. Also there are differences between the two transitions especially in the mixing to the high velocities and in the influence of the bed friction.

In this study the influence of transition from vegetation to gravel bed and vice versa in open channel is investigated experimentally. For the simulation of the two porous beds : a) a grass-like vegetation and b) gravel bed of 2cm height were used to represent the permeable bed. The velocity is measured using the Particle Image Velocimetry (PIV) method, which allows data acquisition at fine spatial-temporal resolution 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.

2. EXPERIMENTAL PROCEDURE – MEASUREMENTS

For the simulation of the two permeable beds: a) a grass-like vegetation and b) gravel bed of 2cm height were used to represent the porous bed. In total 24 experiments were carried out in a laboratory of Hydraulics in the department of Civil Infrastructure Engineering of Alexander Technological Educational Institute of Thessaloniki, Greece. The experiments were conducted in a horizontal channel of 6.5m length, 7.5cm width, and 25cm height. The velocity is measured above the permeable bed and at two different discharges (0.735 and 0.970lt/s) and three different flow depths (4, 7 and 10cm). The experiments were performed in four different locations of the channel (over the vegetated bed, in the transition point from vegetated to gravel bed, over the gravel bed, and in the transition point from gravel bed to vegetated bed).

This experimental investigation is based on the 2D Particle Image Velocimetry (PIV) method, which allows data acquisition at fine spatial-temporal resolution. PIV is an optical method of fluid visualisation and is used to obtain instantaneous velocity measurements and related properties in fluids. The fluid is seeded with tracer particles which, for the purposes of PIV, are generally assumed to faithfully follow the flow dynamics (Wereley and Meinhart, 2010). The motion of the seeding particles is used to calculate the velocity profile of the flow. PIVs use the particle concentration method to identify individual particles in an image and follow their flow; however, tracking particles between images is not always a straightforward task. Individual particles could be "followed" when the particle concentration is low, a method called particle tracking velocimetry, whereas laser speckle velocimetry is used for cases where the particle concentration is high. The experimental uncertainty of the measured velocity with this technique is approximately ± 2%.

The measurements were conducted at a 12x10cm^2 region in a distance of 4m from the channel's entrance, where the flow is considered fully developed. The full development of the flow was evaluated comparing the velocity distributions in two vertical sections with a 60cm separation distance. The uniformity of the flow was checked measuring the flow depth with point gauges at two cross-sections (4m between the two sections). The desirable flow depth in the downstream section could be controlled using a weir at the channel's outlet. The error of the measured flow depth (10cm) with the point gauge was ± 0.1mm.

The velocity fields were determined analysing 200 pairs of frames in each experiment. The time interval between two different pair of images of was about 0.675sec. The time between the two images of the same pair was about 1.5msec, that we do not focus on the time record but on the space record; however, the change in motion of the fluid elements can be monitored. The experimental apparatus is presented in Figure 1. The morphology of the permeable bed (vegetated and gravel bed) is illustrated in Figure 2.

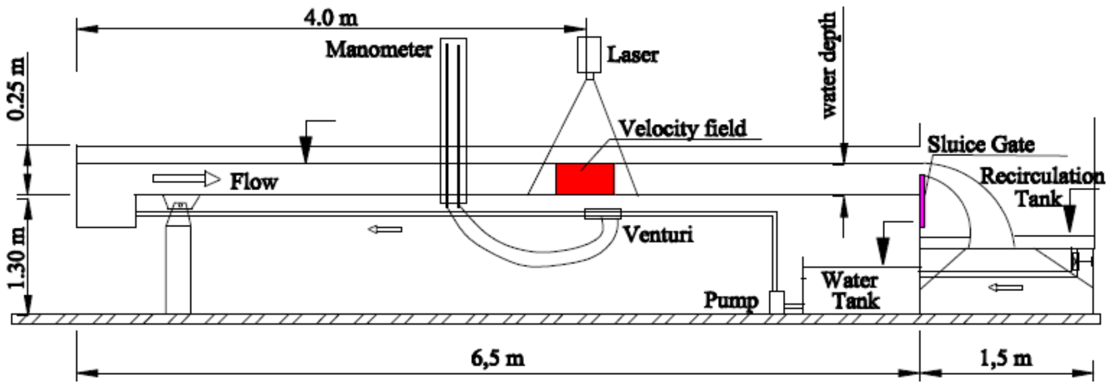

Figure 1. Experimental apparatus.

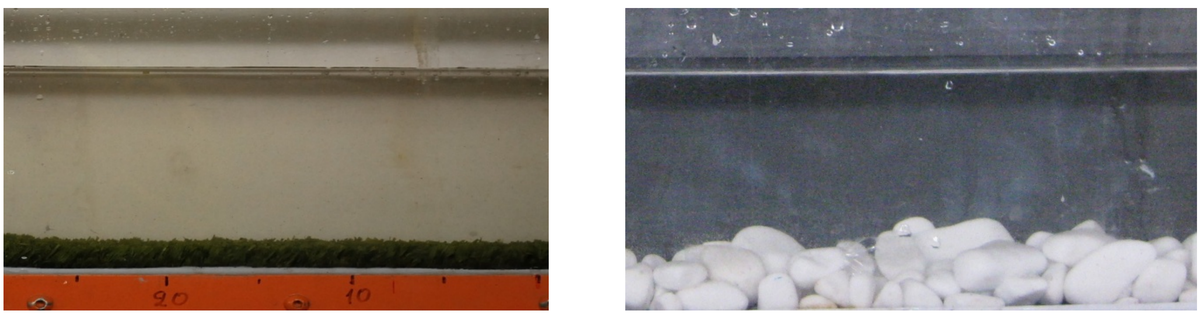

Figure 2. a) Grass Vegetation of 2cm height b) Gravel Bed of 2cm height.

3. ANALYSIS OF RESULTS

Experiments were performed for the flow determination and for the influence of transition from vegetation to gravel bed and vice versa on the velocity distribution. Two hundred (200) pair of pictures for each experiment were taken. The validation of the images was further based on the

INSIGHT 3G program. The velocity profiles at various positions were determined by the fields of the velocities with the use of MATLAB, which is integrated in the INSIGHT 3G program.

Figure 3 illustrates the impact of permeable bed for water depth equal to h=4, 7 and 10cm on the velocity profile; hence height of permeable bed (vegetation and gravel bed) and discharge are kept constant and equal to 2cm and 0.970lt/s respectively. The velocities are measured over the vegetated and over the gravel bed. The velocities over the gravel bed are greater as regard the velocities over the vegetation bed. This is due to the greater penetration of the flow in the case of the grass vegetation as regards the penetration for the gravel bed. The presence of the flexible grass vegetation reduces significantly the velocities over the permeable bed.

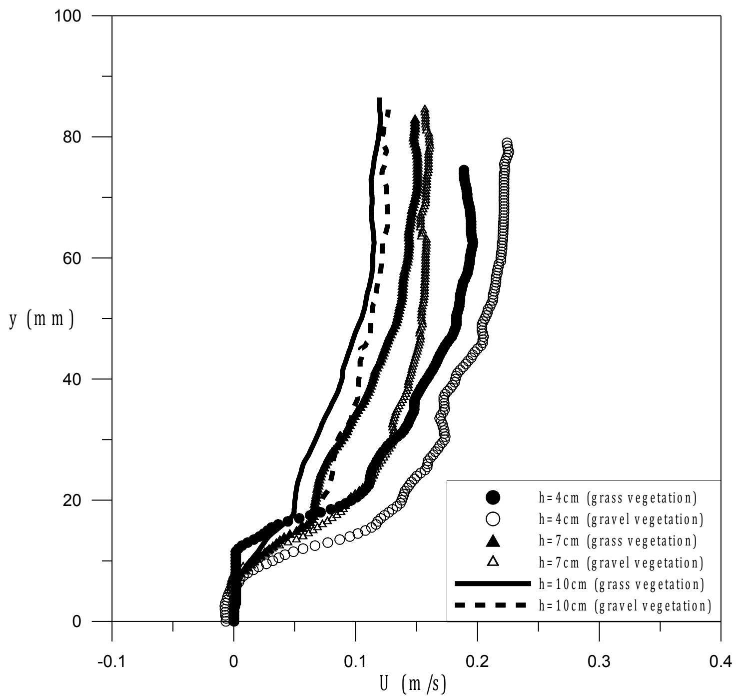

Figure 3. The effect of permeable bed on the velocity distribution. Vegetation height and discharge are constant and equal to 2cm and 0.970lt/s.

Figure 4 illustrates the impact of transition from vegetated to gravel bed and vice versa on the velocity distribution. The velocities are measured in the transition point from vegetated to gravel bed and in the transition point from gravel bed to vegetated bed. In the transition area a significantly reduce of velocities in comparison with these over the permeable bed (vegetated or gravel) is observed. This is due to the fact that the transition from a permeable bed to another influences the velocity distribution because there is a lot of mixing which increases the turbulent characteristics of the flow and reduces the velocities. Also the velocities in the transition point from gravel bed to vegetated bed are much greater in comparison with these in the transition point from vegetated to gravel bed. This is due to the greater penetration of the flow in the case of the grass vegetation as regards the penetration for the gravel bed.

Figures 5 and 6 show the dimensionless velocity profiles for the above figures. Figure 5 shows velocity profiles for flow depth 7cm and Figure 6 for flow depth 10cm. In Figure 5 for flow transition from gravel bed (profile a_1) to vegetated bed (profile a_2) a reduction of the mean dimensionless value of the velocity with a contemporaneous increase of the dimensionless flow depth it is observed. The same result for flow transition from vegetated bed (profile b_1) to gravel bed (profile b_2) it is observed. The velocity profiles (b) are better than the profiles (a), because in profiles (a) the presence of vegetation after the gravel bed reduce significantly the mean velocity of the flow. The same results in Figure 6 (profiles b and d) are observed. Also in the case of 10cm a significant approaching of the dimensionless flow depth with gravel bed (profile c_1) with the respective vegetation bed it is observed. This is due to the significant influence of the vegetation bed.

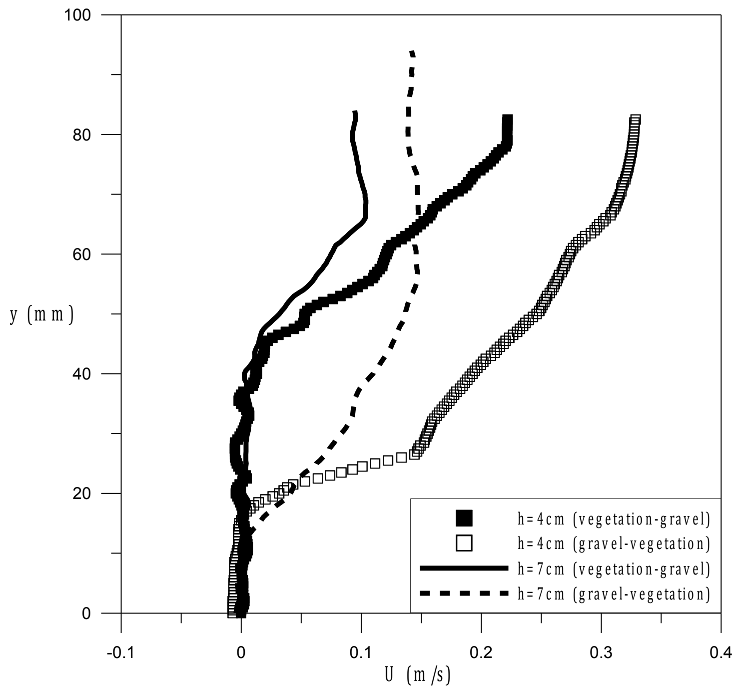

Figure 4. The effect of transition from vegetated to gravel bed and vice versa on the velocity distribution. Vegetation height and discharge are constant and equal to 2cm and 0.970lt/s.

4. CONCLUSIONS

In this study the influence of transition from vegetation to gravel bed and vice versa in open channel is investigated experimentally. For the simulation of the two porous beds: a) a grass-like vegetation and b) gravel bed of 2cm height were used to represent the permeable bed. The following conclusions can be derived:

- The velocities over the gravel bed are greater as regard the velocities over the vegetation bed. This is due to the greater penetration of the flow in the case of the grass vegetation as regards the penetration for the gravel bed. The presence of the flexible grass vegetation reduces significantly the velocities over the permeable bed.
- In the transition area a significantly reduce of velocities in comparison with these over the permeable bed (vegetated or gravel) is observed. This is due to the fact that the transition from a permeable bed to another influences the velocity distribution because there is a lot of mixing which increases the turbulent characteristics of the flow and reduces the velocities.
- The velocities in the transition point from gravel bed to vegetated bed are much greater in comparison with these in the transition point from vegetated to gravel bed. This is due to the greater penetration of the flow in the case of the grass vegetation as regards the penetration for the gravel bed.
- For flow transition from gravel to vegetated bed a reduction of the mean dimensionless value of the velocity with a contemporaneous increase of the dimensionless flow depth in all cases it is observed. This is due to the significant influence of the vegetation bed after the gravel bed.
- The main and significant conclusion of this paper is that the kind of permeable bed influence significantly with a different way the velocities over the permeable bed. The velocities over the transition area are much lower in comparison with these over a permeable bed and this is due to the great mixing which is created in the transition area. Also loss of energy in the

transition area is observed. This is due to the fact that the reduction of the velocity is accompanied with loss of energy.

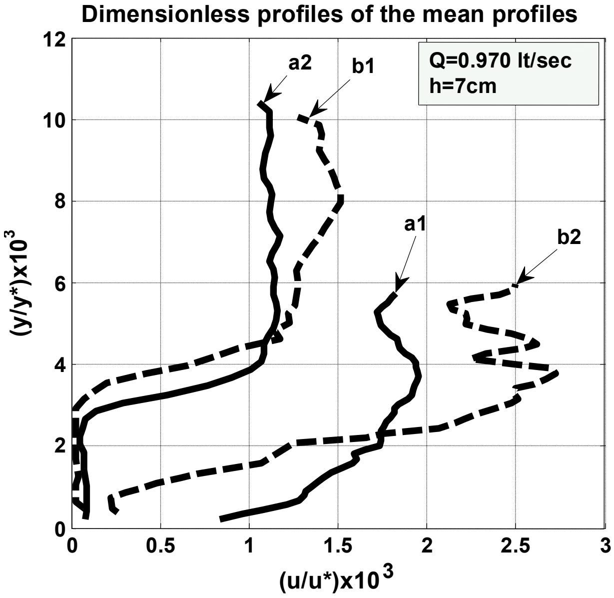

Figure 5. Dimensionless velocity profiles (a and b).

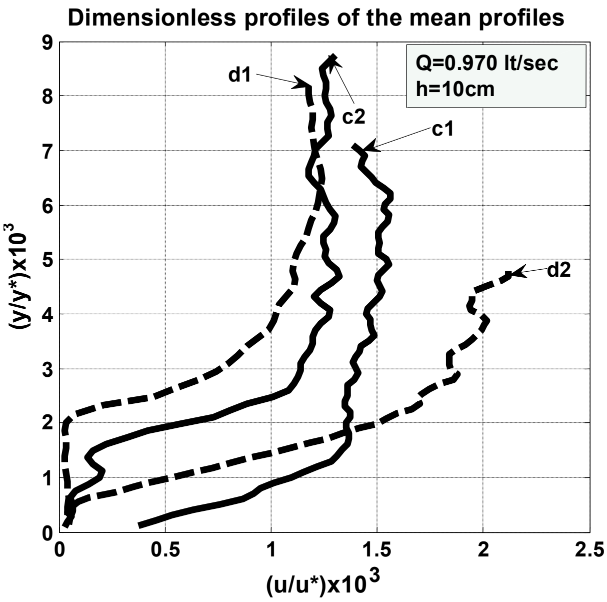

Figure 6. Dimensionless velocity profiles (c and d).

REFERENCES

Beavers, G. S., Joseph, D., D., (1967). Boundary Conditions at a Naturally Permeable Wall, J. Fluid Mech., 30(1): 197–207.

Carollo, F.G., Ferro, V. and Termini, D. (2005). Flow resistance law in channels with flexible submerged vegetation, J. of Hydraulic Engineering, 131(7): 554-564.

Keramaris, E., Pechlivanidis, G., Pechlivanidis, I., Samaras, G. (2013). The impact of lateral walls on the velocity profile in an open channel using the PIV method, 13th International Conference on Environmental Sience and Technology (CEST 2013), Athens, Greece.

Pechlivanidis, G., Keramaris, E., Pechlivanidis, I. (2012). Measurements of turbulent characteristics in an open channel using PIV (Particle Image Velocimetry), Global Nest Journal, Volume 14 (3): 378-385.

Pechlivanidis, G., Keramaris, E., Pechlivanidis, I., (2014). Transition from permeable to impermeable beds and vice versa in open channels: Effects on the velocity distribution of turbulent flow, Proceedings of the International Conference on Fluvial Hydraulics, RiverFlow 2014, Lausanne, Switzerland. pp.81-87

Pokrajac, D., Manes, C., (2009). Velocity Measurements of a Free-Surface Turbulent Flow Penetrating a Porous Medium Composed of Uniform-Size, Transp Porous Med, 78: 367–383.

Stephan, U., Gutknecht, D., (2002). Hydraulic resistance of submerged flexible vegetation, Journal of Hydrology, vol. 269, (1/2): 27-43.

Wereley, S.T., Meinhart, C.D., (2010). Recent advantages in micro-particle image velocimetry, Annual Review of Fluid Mechanics, 42(1): 557-576.