Analysis of Turbulent Flow Measurements in a Flume with Induced Upward Seepage

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Outline

Abstract

- The aim of this research is to analyze the effect of the groundwater flow in free-surface hydrodynamics.
- Several series of turbulent flow measurements were carried out in a flume where upward seepage was induced by external hydrostatic pressures acting in the lowest part of the channel bed.
- The differences between the open-channel hydrodynamics with and without seepage are compared.
- The upward seepage influenced the open-channel hydrodynamics (velocity fluctuations and some turbulence parameters).

Outline

The Reynolds averaging form (RANS) of the NSE is the basis of the most popular numerical approaches in engineering. The *RANS* equation can be expressed as

$$\frac{\partial U_i}{\partial t} + U_j \frac{\partial U_i}{\partial x_j} = \frac{1}{\rho} \frac{\partial}{\partial x_j} \left(-P\delta_{ij} - \rho \overline{u_i' u_j'} \right) \tag{1}$$

where δ_{ij} is the *Kronecker* delta. The velocity is divided in two terms U and u'. The last term of (1) represents the *Reynolds* or *turbulent* stresses, that can be modeled by(2)

$$-\rho \overline{u_i' u_j'} = \rho \nu_T \left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i} \right) - \frac{2}{3} \rho k \delta_{ij} \tag{2}$$

where ν_T is the eddy viscosity and k is the TKE.

There are cases where the uppermost layer of river beds constitute a porous medium where seepage can take place.

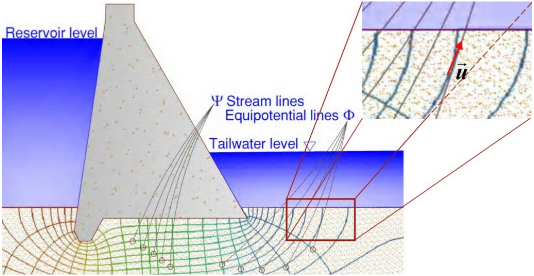
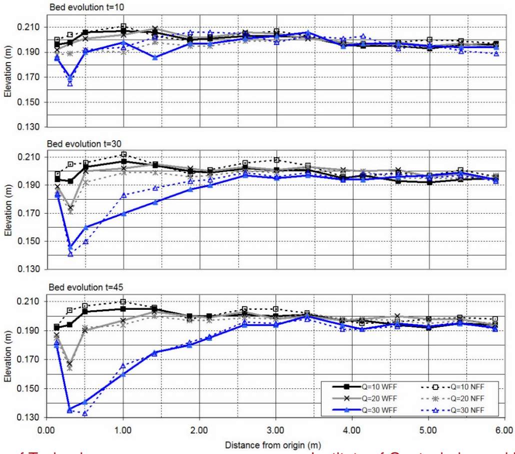


Figure: Upward seepage downstream a concrete dam

Downstream these structures, seepage is almost upward.

As demonstrated in (Herrera Granados 2008), seepage influences the sediment transport rate in a particular way.



Outline

The laboratorial research was carried out at the open air laboratory of the Wrocław University of Technology. The experimental zone was 8m long, 0.5m width and 1.0m high. The first two meters of this experimental zone were used to stabilize the flow in order to address it into subcritical regime to the region where the measurements were taken.

Figure: The Flume at the Laboratory of the WUT

This figure depicts the location of the velocimeter P-EMS in three cross sections of the flume (X=1.0, 3.0 and 5.0m according to the established reference frame).

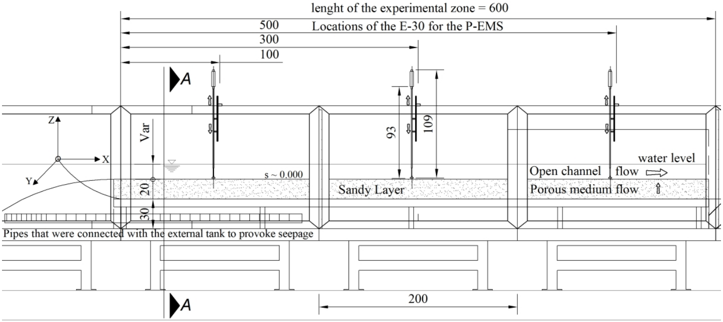


Figure: The Flume and the tank that provoked seepage

The turbulent flow measurements were taken in 35 different points at each cross section. A thin layer of geotextile was allocated in between the sandy layer and the metal base that was symmetrically drilled to allow upward flow.

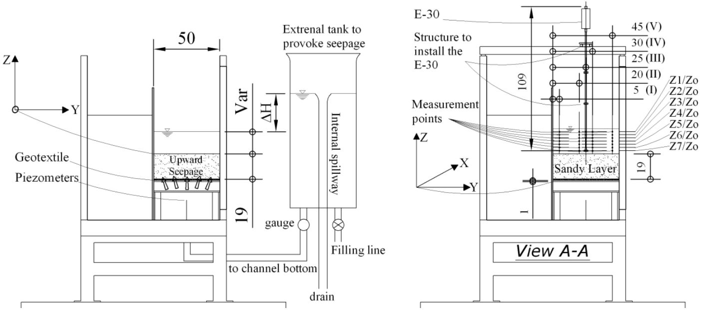


Figure: View from A-A and measurements points

This figure depicts one of many of the V_x and V_y time-series taken at the laboratory; the mean (red dot-dashed line) $\pm$ the std. deviation (blue dashed lines) are shown as well.

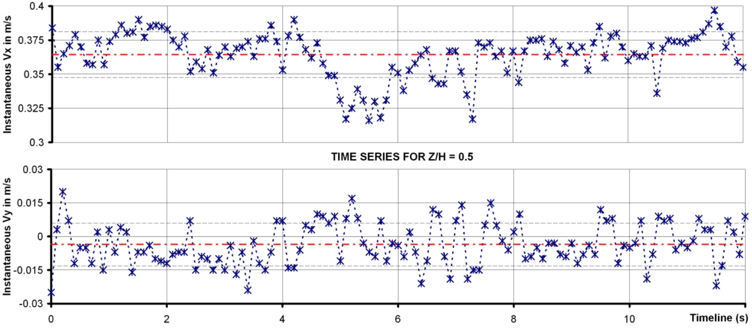


Figure: Velocity time series in the x and y direction

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Other turbulence parameters that were compared with and without seepage are the *TKE* and some *Reynolds* Stresses.

The Reynolds stresses in the xy-plane are directly calculated from the velocity fluctuations while the *TKE* is defined by the equation (Garcia et al. 2005):

$$k = \frac{1}{2}\left(V_x'^2 + V_y'^2 + V_z'^2\right) \tag{3}$$

where $V_x'^2$, $V_y'^2$ and $V_z'^2$ are the the variance of the flow velocity components in x, y and z respectively. A correction of the *TKE* was applied because the velocimeter used for the experiments only provided the velocity components in two directions (Liiv and Lagemaa 2008)

$$k = \frac{1.33}{2}\left(V_x'^2 + V_y'^2\right) \tag{4}$$

This figure depicts the mean velocity profiles as a function of the relative depth at the cross section X=1.0m without seepage and with induced hydraulic heads corresponding to 10cm and 30cm acting in the bottom.

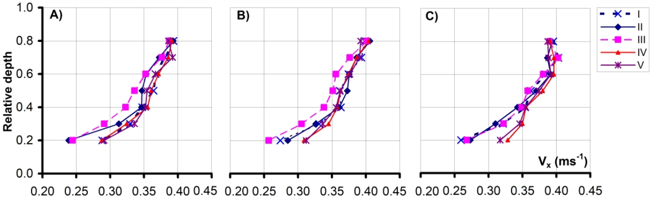


Figure: Velocity profiles of the experiments

There is not clear evidence that the seepage influences the open-channel hydrodynamics.

Nevertheless, seepage is influencing the turbulence parameters as depicted in the following figures

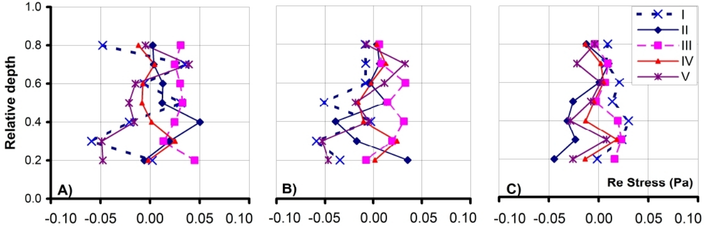


Figure: Re Stresses

the Reynold stresses are more regular with the presence of seepage.

Looking at the Turbulent Kinetic Energy:

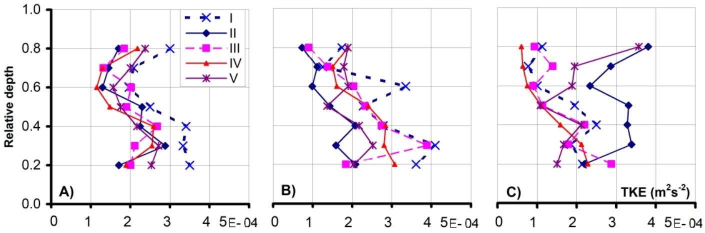


Figure: TKE for different hydraulic heads

Nevertheless, the Turbulent Kinetic Energy is more irregular with seepage.

Looking at the histograms of two experimental series with and without seepage. The histogram A is closer in shape to the normal distribution than B and B is right skewed with a kurtosis lower than zero. Nevertheless these histograms represent only one of the time-series.

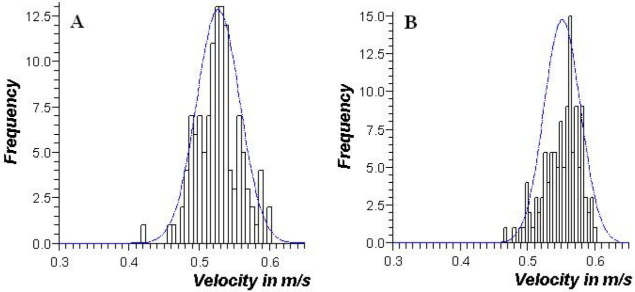
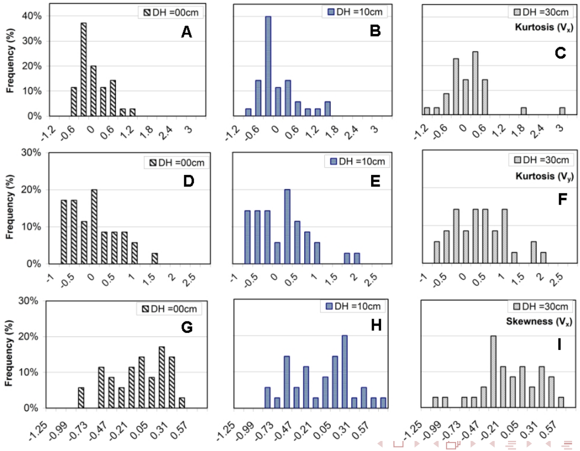


Figure: Histogram of velocity turbulent measurements

Comparing the Histogram of V_x, V_y kurtosis and V_x skewness:



Outline

To model the studied phenomenon by a numerical approach is the next step of this research.

The output of the numerical model will be compared with the experimental results.

Further Research

There are two possible ways to model this case study:

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- The zero boundary condition at the channel bed has to be changed considering seepage as Dirichlet boundary condition (upward inflow = constant).
- Integrating the interaction of seepage and channel hydrodynamics in the same numerical approach. That means that there is a necessity to analyze together laminar or quasi-laminar seepage and turbulent flow in the same model.

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It is evident that the second option is more complex. Additionally, to model sediment transport under these conditions is even a more difficult task.

Further Research

So far, modelling both phenomena (without sediment transport) is the ongoing task of this research, as shown below.

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The previous analysis demonstrates that the presence of upward seepage mainly influences the velocity fluctuations of the open channel turbulent flow.

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- The presented figures showed that the velocity field is more irregular when flow through the hyporheic zone exists.
- Additionally, the TKE and the Reynolds stresses are affected by the presence of this seepage.
- The modification in the behavior of the turbulent stresses can be one of the reasons why seepage is smoothing the bed evolution and bed forms above all in places where secondary flows arise and entrain the material from the bed [3].

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- Treating the seepage flow as a new boundary condition in a turbulent model.
- Integrating the interaction of both processes; which means that there is a necessity to analyze together seepage and open-channel hydrodynamics in the same numerical approach.

This researching will be continued in order to know better the effects of seepage flow in river hydrodynamics.

Bibliography I

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Thank you very much

for your attention