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EXPERIMENTAL WORKS ON THE HYPORHEIC ZONE INFLUENCE ON RIVER DYNAMICS.

I. BED DEFORMATION

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Abstract: Some experimental works are presented in order to analyze the effect of upward seepage on sediment transport mechanisms at the laboratory scale. Groundwater flow was induced by provoking hydraulic pressures in the lowest part of the bed being constituted by a fine sandy soil. The bed evolution is compared for three different flow rates (with and without seepage). Additionally, another series of experiments was carried out at a constant flow rate but at different hydraulic pressures. The results of the experiments demonstrate that the bed deformation with seepage is smoother than without seepage, especially in the zones where secondary flows arise due to scouring at the entrance to the experimental flume.

1. INTRODUCTION

In river engineering and water resources management, sediment transport can pose problems in the regulation of natural streams and waterways; hence this is a topic to be researched by water stakeholders. Many are the effects that the water –sediment interaction provokes, such as erosion (bed degradation), transport of coarse material, entrainment of fine material or modification of the river morphology.

This paper is focused on the effect of the seepage on the bed changes (bed evolution). Some experimental works have been carried out in the laboratory of the Chair of Hydroengineering at the Wrocław University of Technology (WUT) in order to check the influence of the flow through the porous medium on the channel bed deformations.

The second section of the paper takes a glance at the interaction between the groundwater and the surface water flows and shows how it can influence river dynamics. The third section describes the laboratory facilities and how the flume is modified to carry out the experiments, namely to induce groundwater flow in the *z*-direction. Some results of these experiments are described. The comparison of the bed evolutions at three flow rates is made with and without seepage as well as the comparison of the bed evolutions at one flow rate with seepage in the channel bed. Seepage tends to smooth the bed degradation due to secondary flows in the channel. The results are briefly analyzed in the last part of the paper.

2. SEEPAGE FLOW AND RIVER DYNAMICS

Seepage can be defined as the motion of any fluid through a porous medium; in water engineering, seepage flow is equivalent to the percolation of water through the soil from unlined canals, ditches and/or watercourses. The importance of the seepage for engineering problems lies in the fact that this groundwater flow has a direct relation to the resistance and behaviour of soils. Seepage occurs if the material that constitutes the dam (figure 1) or the river bed is permeable and if there is a difference between the upstream water level and the downstream tail water level. Figure 1 shows the stream lines as well as the direction of the flow downstream. It is possible to identify that beyond the dam, there are some groundwater velocities in the vertical direction.

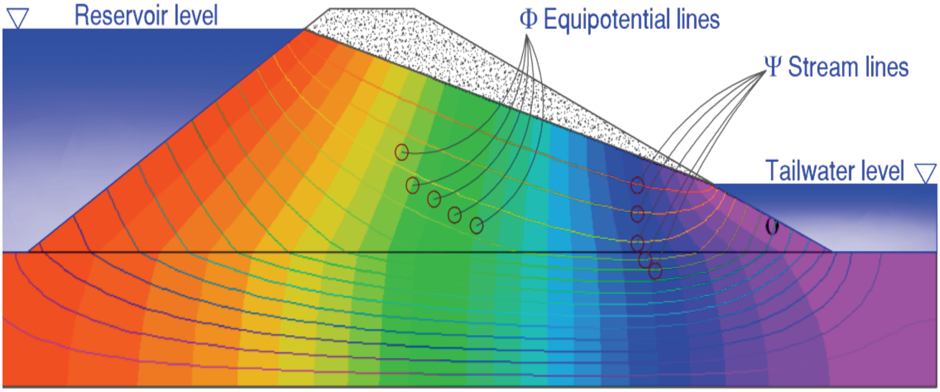

Fig. 1. Ideal seepage flow downstream hydraulic structures

Considering that there are nonpermeable dikes or dams, buoyancy forces are expected to appear and the influence of the seepage flow in sediment transport processes can be significant. The velocities in the vertical direction can affect the mechanisms of the sediment transport downstream (HERRERA GRANADOS [1], [2]).

2.1. FORCES ACTING ON A SINGLE PARTICLE OF SEDIMENT

Two forces acting on a single particle of sediment from a loose bed are commonly considered in river engineering, namely the drag and lifting forces. The drag force is that being exerted on a body located in the medium and composed of friction forces acting parallel to the direction of the motion. The lifting force acts normal to the bed and arises mainly because of the difference in the flow velocities up to a vertical pressure gradient or because of the production of local velocity components due to turbulent eddying.

As an example of these forces, in their theoretical formulation of grain entrainment, FERREIRA et al. [4] presented the dragging (F_D) and lifting (F_L) forces acting on a single particle of sediment:

$$F_D = \frac{1}{2}\rho^{(w)} C_D C_e \pi \frac{d_i^2}{4} u_p^2 \cos(\delta)\,, \tag{1}$$

$$F_L = \frac{1}{2}\rho^{(w)} C_L C_2 \pi \frac{d_i^2}{4} u_p^2 \cos(\delta)\,, \tag{2}$$

where $\rho(w)$ is the density of the fluid in motion; C_D and C_L are the dragging and lifting coefficients, respectively; C_e is the exposure coefficient; C_1 and C_2 are shape parameters; d_i is the sediment class diameter; u is the longitudinal velocity at the height of the center of the mass of the particle, and δ is the pivoting angle, provided that the particle is supported by at least three other grains. The literature mentioned many ways to define the dragging and lifting coefficients, which affect directly the value of the dragging and lifting forces that provoke the motion of the sediment. LIU [6] mentioned that these values are commonly determined in the laboratory.

In the case of groundwater flow, the flow velocity in the z-direction acting on a single particle can affect the lifting forces (the hypothesis of the author) where the presence of secondary flows reduces considerably the surface water velocities.

2.2. SEDIMENT CONTINUITY

The equation for sediment continuity was presented by Exner at the beginning of the twentieth century and is used for modelling the bed evolution in channels. This equation can be presented in one-dimensional form as follows:

$$(1-\lambda_p)\frac{\partial z_b}{\partial t} = \frac{\partial q}{\partial x} v_s (c_b - E)\,, \tag{3}$$

where λ_p is the bed porosity; z_b is the bed level; q_b is the sediment transport rate of the bed; ($v_s \cdot c_b$) is the volume flux of the suspended sediment concentration, and ($v_s \cdot E$) is the volume flux of the sediment entrainment. This equation briefly describes the transport mode of the sediment close to the bed in the hyporheic zone. Due to the fact that the groundwater velocities are much smaller than the free-surface flow velocities, the sediment continuity should be fulfilled and the effects of the seepage flow could be neglected. Nevertheless, in the zones where there are secondary flows (down drift side of a groyne) the velocity of the water flow is considerably reduced and in hyporheic zones, the sediment transport mechanism can change drastically.

3. WORKS IN THE LABORATORY

The main laboratory of the hydroengineering chair is provided with two rectangular flumes for academic and research purposes. The biggest of these rectangular flumes was modified for the series of experiments (see figure 2). The total length of the flume is sixteen meters of which eight have a window wall that allows the visualization of the experiments. This zone is 8 m long, 0.5 m width and 1.00 m high.

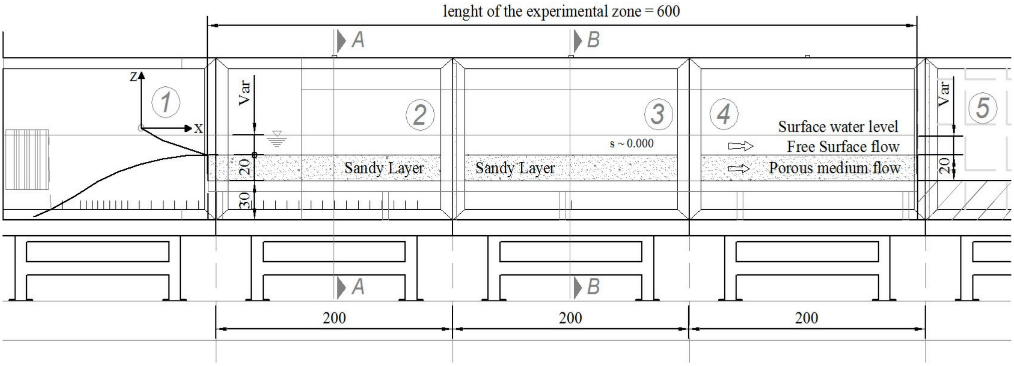

Fig. 2. General scheme of the experimental flume

The flume has a 0.9-m step at the near end of the experimental zone deriving from a waterfall. Hence, the flume in its initial part of 2-m length dissipated the energy of this waterfall and allowed the water under subcritic regime to enter the zone, where the bed changes were measured. At the lowest point of the channel, the height of the boundary between the channel bed and the water at the beginning of the experiments was 0.50 m.

In order to place the sandy bed, a special structure was built 0.30 m over the lowest part of the flume to protect the piezometers at the bottom of the channel. These piezometers played an important role in the experiments because these small pipes drained the water from an external tank (see figure 3) and generated distributed hydraulic pressures acting on the lowest part of the channel. The function of this tank was to feed the zone under the sandy layer in order to maintain a constant hydraulic depth higher than the flowing water level which provokes seepage flow through the porous medium in the vertical direction.

Fig. 3. The tank that provokes seepage flow in the *z*-direction

3.1. SEEPAGE INFLUENCE ON CHANNEL BED EVOLUTION

Sixteen cross sections (figure 4) were selected in order to measure the bed evolution during 45 minutes at three flow rates: 10, 20 and 30 dm^3/s. The bed evolution was measured using graduated rules being located in each cross section, thus the profiles obtained from the experiments are characteristic of the bed evolution close to the window of the flume. It is necessary to highlight that the experiments without seepage were carried out before the tank installation.

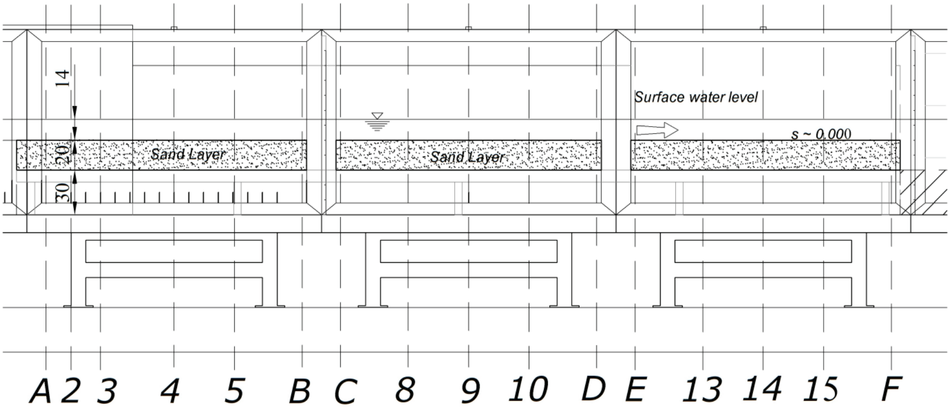

Fig. 4. Cross sections where the bed deformation was measured

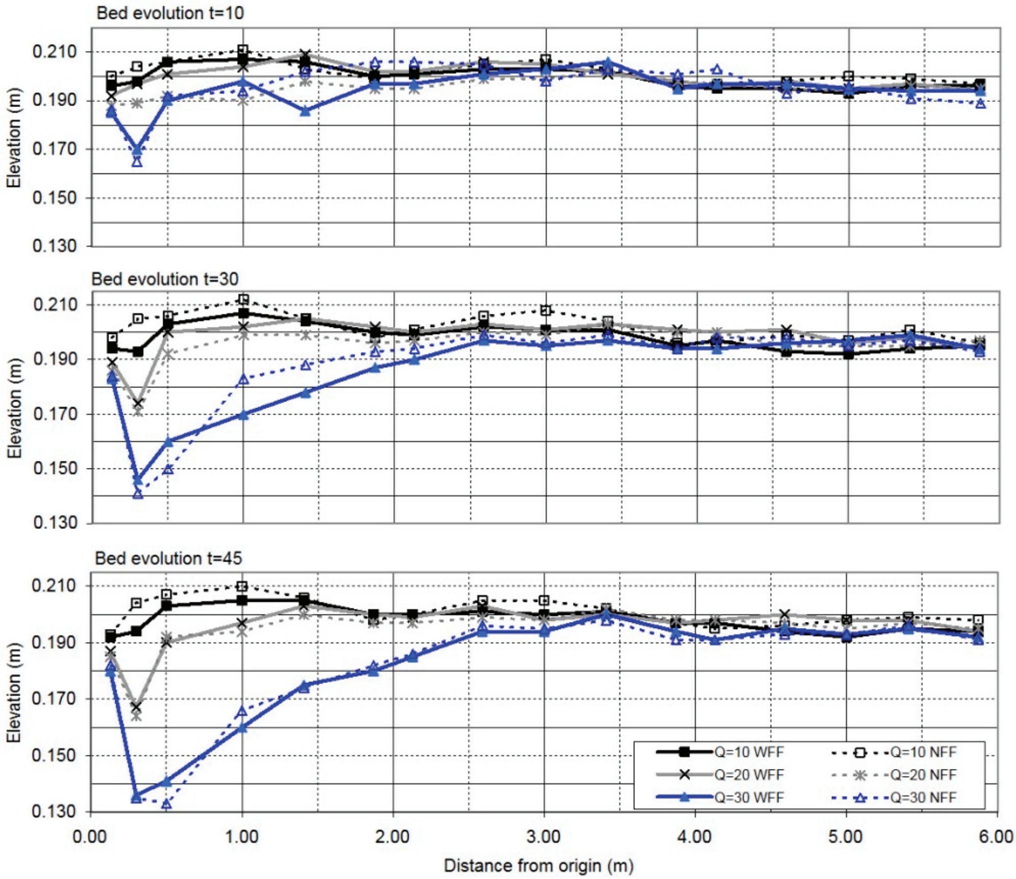

Fig. 5. Bed evolution measurements at three different times

Figure 5 summarizes the results of the experiments in order to compare the bed evolution proceeding with and without groundwater flow.

In figure 5, WFF means the seepage within the sandy layer during the experiments, and NFF represents the measured bed evolution without seepage for different times ($t = 10$, 30 and 45 minutes). Six profiles were plotted at each time in order to compare the bed evolution at three flow rates with and without seepage. The results of the experiments show that the evolution of the bed with seepage is smoother than that without seepage. The second series of experiments was carried out at a constant flow rate ($Q = 25$ dm^3/s) but for different hydraulic heads. The height of the tank was changed in order to vary the additional hydraulic head from 10 cm to 30 cm. This means that the groundwater flow rates have changed.

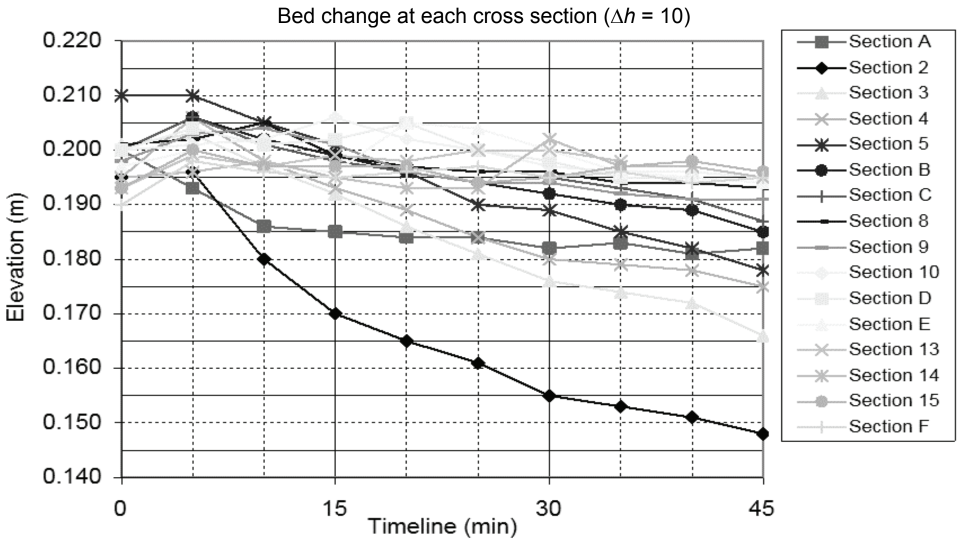

Fig. 6. Bed changes at $Q = 25$ dm^3/s and $\Delta h = 10$ cm

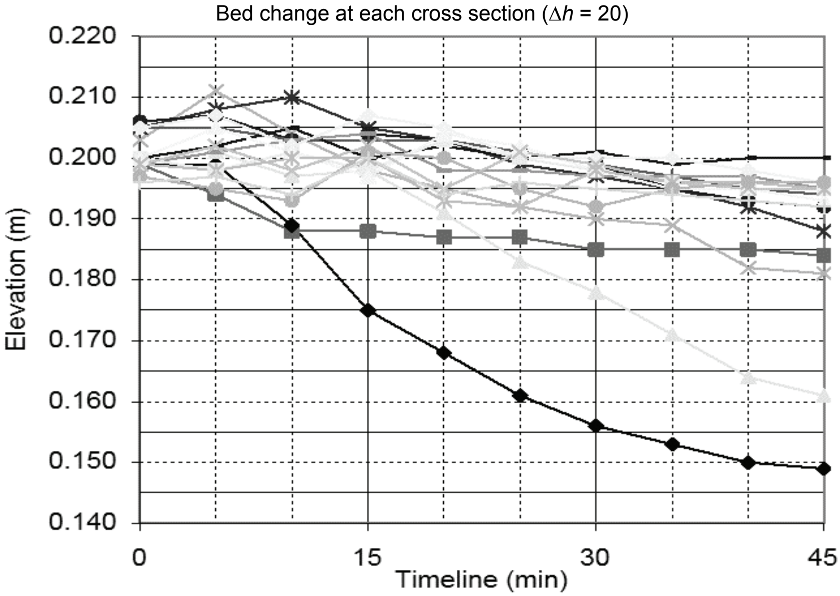

Fig. 7. Bed changes at $Q = 25$ dm^3/s and $\Delta h = 20$ cm

Figures 6, 7, 8 and 9 summarize the results of these experiments at each cross section varying with time (45 minutes).

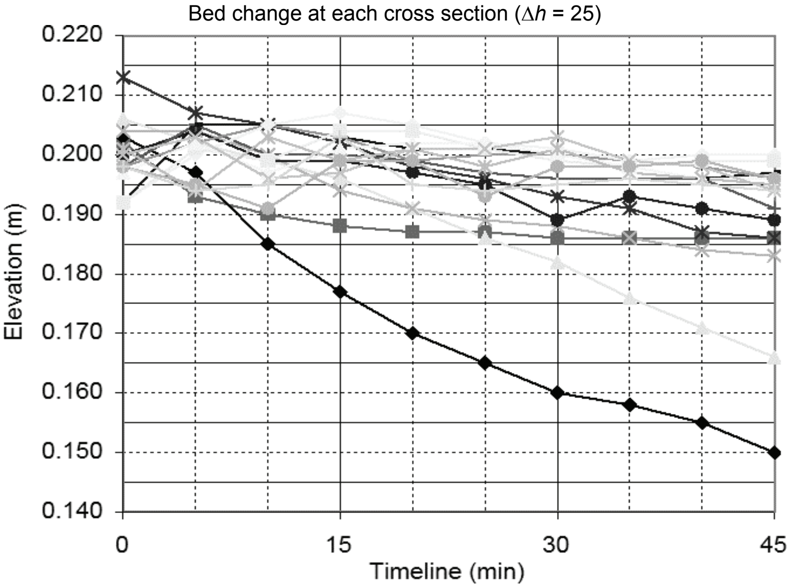

Fig. 8. Bed changes at $Q = 25$ dm^3/s and $\Delta h = 25$ cm

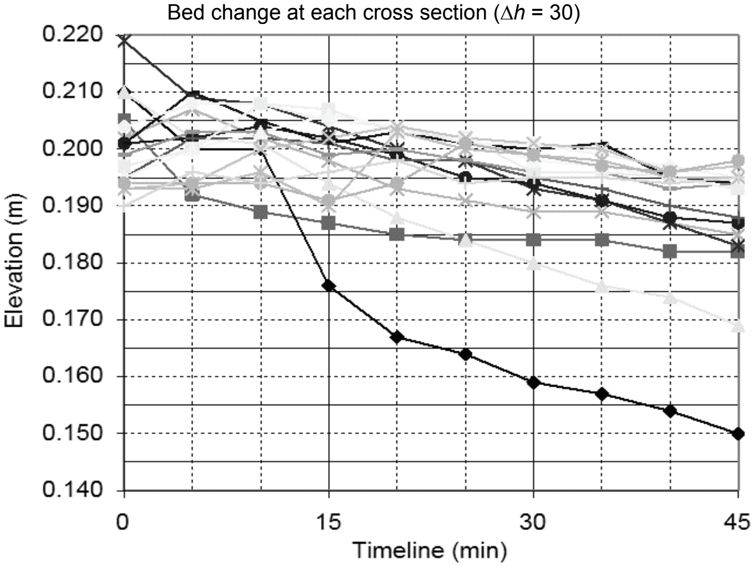

Fig. 9. Bed changes at $Q = 25$ dm^3/s and $\Delta h = 30$ cm

The height of the bed was measured every five minutes and it was possible to observe that the differences between the bed levels were smaller when higher hydraulic heads were used, especially in the initial part of the channel where a scour hole appeared few minutes after the beginning of the experiment. This phenomenon is interesting because the presence of the scour hole produced a secondary current which not only decreases the surface water velocities, but also changes the direction of the surface water flow. In the hyporheic zone, down the scour hole, the lifting forces acting on the sediment particles are affected by the seepage; hence, the entrainment of particles decreased as well. Consequently, the transport rates should decrease because less material is entrained than transported as suspended load downstream. Beyond the scour hole, the seepage velocities do not affect considerably the entrainment of the sediment particles.

4. CONCLUSIONS

Two series of experiments were carried out in order to estimate the channel bed deformation with and without the presence of seepage flow through the channel bed in the z-direction. These experiments demonstrate that the flow through the porous medium does affect the bed degradation as a function of the hydraulic head acting on the bottom part of the bed. With high hydraulic heads, the bed changes are smoother, especially in the initial part of the channel. In general, the results can be considered acceptable and consistent.

It is possible to observe that the bed changes are very similar and independent of the seepage in an initial 2-m part of the flume (see figure 4). This can be explained by the lifting forces that are not significantly affected because of the seepage. The sediment balance equation (3) shows that neither the sediment flux nor the sediment concentration is changed by the small seepage flow velocity. Nevertheless, at the near end of the flume, where a big score hole arises, the secondary flows causes that in the hyporheic zone of the channel, the sediment transport mechanisms are affected by the groundwater flow. The seepage in the z-direction affects the lifting forces acting on the sediment particles, and the entrainment of sediment particles is decreased. Hence the rates of the bed load and suspended load change.

The author is preparing the next paper: *Experimental works on the hyporheic zone influence on river dynamics*. II. *Velocity field measurements*, where the influence of the seepage flow on the surface water velocity field is analyzed.

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