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Experimental investigations of Ship wave induced interaction on the waterways Bed

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ABSTRACT: Waterways are subjected to ship wave loading associated with relatively fast water level drawdown. During the drawdown excess pore pressure develops in the river bed resulting in an upwards seepage which interacts with main flow over the river bed surface. Consequently, the bed shear stress and the incipient motion of the sediment could be affected. This process is also associated with a vertical deformation for the upper layer of the river bed which can reach to liquefaction. To investigate the interactions on the river bed and their implications for bed shear stress, two sets of experiments were conducted on the River Bed Simulator at the BAW. The first set of experiments investigated the deformation of the near-bed region, while the second set focused on the effect of the upwards seepage flow on the the main velocity profile and the bed shear stress. Both sets of measurements employed Particle Image Velocimetry (PIV).

1 INTRODUCTION

Completely or partially removing the riprap bank protection on waterways in order to apply more nature-based solutions requires a good understanding of the interactions induced by ship-waves on the riverbed. This interaction includes, on the one hand, the reduction of the weight of the sediment particles due to upwards seepage forces. On the other hand, the upwards seepage affects the near-bed flow and therefore the bed shear stress. Consequently, the initiation of sediment erosion may be affected. Previous studies have shown that seepage flow alters the flow velocity profile. Cheng and Chiew (1998a) introduced a modified logarithmic law for the velocity profile under seepage flow conditions. They found that the injection seepage flow (upwards seepage) generally reduces the near-bed velocity and the bed shear stress. However, the findings across the previous studies are inconsistent regarding injection effects on velocity profile, incipient motion and sediment transport (Arif et al.,2019). In this study experiments were conducted to investigate the effect of the drawdown associated with a ship-wave on the bed stability.

2 EXPERIMENTAL SETUP

2.1 River bed simulator (GeSi)

The River Bed Simulator (Ewers, 2020) is a closed-conduit equipped with two pumps that can circulate flow up to 3 m/s. The device has a diffuser and a reach of 10 m, which allows for a uniform flow to be developed at the erosion section where the sample container is installed, see Figure 1. The soil specimen container has the following dimensions: depth: 1.2 m; width: 0.4 m; length of erosion surface: 1.5 m. The specimen container is equipped with pressure sensors at various heights to measure the vertical profile of the pore pressure. The wave action is simulated in GeSi as time-dependent pressure provided from an Alternating Flow Apparatus described in Kayser et al. (2016). Fine to medium sand with a mean diameter of 0.18 mm was used in the study.

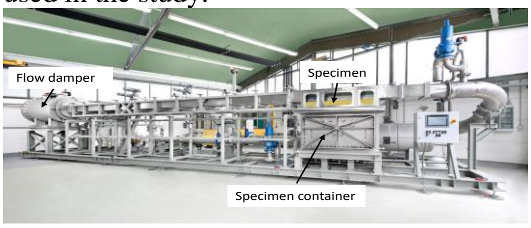

Figure 1. River Bed Simulator (GeSi)

2.2 Deformation measurement setup

Particle Image Velocimetry (PIV) was used to measure the deformation of the sand specimen. Only wave effect without a main flow in the channel was simulated in this experiment. To simulate a linear draw down of 2 m in 20 s, the pressure was first increased linearly from 1.325 bar to 1.525 bar. It was then kept constant for 30 s before it falls down to 1.325 in 20 s (Figure2 b). A camera was located in front of the side glass window. Video with 50 fps was recorded for the upper 14 cm of the specimen.

2.3 Flow velocity profile under seepage flow

To address the interaction of the upward seepage flow in the soil specimen and the main flow and its implications on the bed shear stress five experiments were carried out. The main flow in GeSi was kept constant for all experiments. The first experiment was carried out without seepage flow. The seepage flow was then introduced and increased stepwise from 1.9 10^{-05} to 6.5 10^{-05} m/s. PIV-System was used to measure the main flow velocity in GeSi (Figure 3 a).

3 RESULTS

The PIV-measurements showed displacement in the upper 14 cm of the specimen each 0.2s. The results close to the soil surface showed a maximum vertical displacement of about 3 mm after the pressure drawdown (Figure 2b), which decreased again when the pressure is kept constant. The deformation velocity of the soil close to the surface is highest and decreases with depth, (Figure 2a).

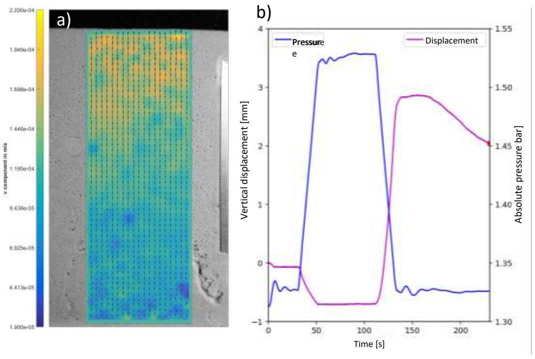

Figure 2. Deformation measurement (a) vertical soil velocity (b) vertical displacement and absolute pressure at the bed surface with time

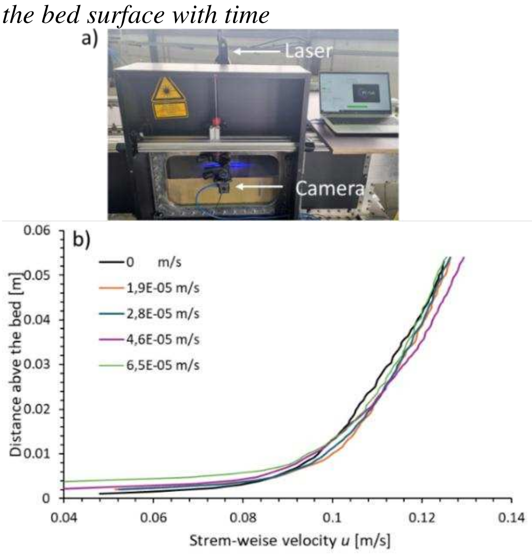

Figure 3. PIV-System (a) Stream-wise velocity profiles for different seepage flow velocities (b)

The near-bed flow velocity with seepage flow is shifted away from the bed (Figure 3b). The flow velocity under seepage conditions and above 1cm from the bed is generally higher than in the case without seepage flow.

Figure 4 shows the turbulent shear stress $-\rho\overline{u'w'}$ where u' and w' are the velocity fluctuations in the stream-wise and the vertical directions respectively. The bed shear stress τ_b which is used to assess the erosion stability can be found bei extrapolating the trent line $-\rho\overline{u'w'}$ to the bed (Nikora and Goring, 2000). The bed shear stress under seepage conditions is lower than in the case without seepage.

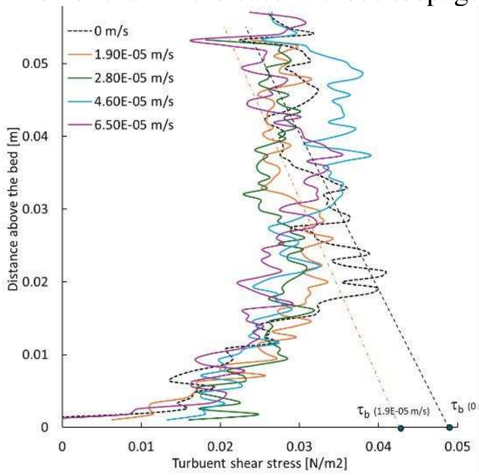

Figure 4. Turbulent shear stress profile with τ_b for seepage flow 0 m/s

4 CONCLUSIONS

The deformation of the upper layer of the bed during the draw down was successfully measured with high spatial and time resolution. Considering this deformation the shift of the flow velocity away from the bed needs to be further investigated as this could be related to the shift of the bed level. The bed shear stress under seepage flow conditions (during the drawdown) is lower than in the absence of seepage.

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