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Interaction between Flow and Seepage in an Alluvial Channel

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Abstract

The hydrodynamics of an alluvial channel was explored in a sloping flume by taking into account the significant impact of upward seepage. In a sand bed channel, Seepage occurs as lateral flow which is an important explicit parameter. To understand the sediment transport and to keep an active river ecosystem in a channel, the configuration of the main flow and seepage flow in a channel is essential. Therefore, to determine the impact of upward seepage on the hydrodynamic of an alluvial channel, experiments were carried out for both the no seepage and upward seepage runs. The 3-D instantaneous flow velocity was measured at a certain depth using Acoustic Doppler velocimeter (ADV) which give crucial outcomes related to the turbulence in flow. Various features of turbulent flow i.e., time-averaged velocity, turbulence intensity and Reynolds shear stresses, were analyzed for the case of no seepage and seepage flow. As per the results the degree of turbulence reduced with upward seepage, indicating less sediment movement. With an upward seepage, the turbulent length scale also diminishes, leading to reduction in energy and momentum transfer due to the size of the larger eddy at the region near to the bed surface, eventually leading to sediment flow due to upward seepage. Civil or hydraulics engineers will get benefit from the findings of this study as per the knowledge of the characteristics of seepage flow which will improve sediment management in natural rivers.

Keywords: Alluvial Channel; Turbulence; Upward Seepage

1. INTRODUCTION

In a sand bed channel, seepage is an essential explicit parameter which appears in the form of lateral flow. upward seepage takes place when the water level in the stream is lower than the surrounding ground water level, and vice versa. Understanding of the interface between the main stream flow and seepage flow is important to determining the sediment movement. With the application of upward seepage to the channel, Nezu (1977) noted a decreased in the flow velocity profile at the bed flow region. By using the Prandtl's mixing-length theory Clarke et al. (1955) proposed a different law for the upward seepage of the wall boundary. By resolving the Reynolds equations and empirically identifying the unknown components, Cheng and Chiew (1998) developed a new log law of flow velocity in the inner layer when upward seepage was tested in the channel. However, Watters and Rao (1971) used upward seepage to investigated the dynamic fluid force acting on sediment particles, and get that the turbulence intensity increased with seepage, resulting in a larger mass exchange between the flow and sediment layer. Krogstad and Kourakine (2000) examined the effect of upward seepage on the turbulent boundary layer of the permeable strip, confirming Nezu's (1977) discovery that upward seepage increases turbulent intensity. Rao and Sitaram (1999) applied a heated film anemometer to study the turbulence intensity in both the downward and upward seepage flows, and found that the velocity variation was higher in downward seepage flow than the no seepage and upward seepage flows.

The upward seepage affects the turbulent properties, but the literature still has different conclusions whether the turbulence decreases or increases with upward seepage. As a result, the purpose of this research is to investigate how upward seepage affects turbulence in a fine-sediment alluvial channel. The three-dimensional instantaneous flow velocities at a specific depth were measured using. Acoustic Doppler velocimeter (ADV) which provides significant results in term of flow turbulence.

2. EXPERIMENTAL METHODOLOGY

The experimental tests were performed in a rectangular inclined flume of 16.0 m length, a width of 0.5 m, and a depth of 0.5 m. To maintain a uniform flow, a pipe baffle was installed at the channel's upstream end.

The water depth was regulated by a tailgate at the flume's downstream end and the flow was controlled by a discharge regulating system. At the flume's test portion, a seepage chamber was made between the stainless-steel mesh and the channel bed. The test portion was chosen in the channel where it was to reduce the effects of inflows and outflows, and a channel length of 16 meters was adequate to acquire a fully developed flow in the test section. The role of the seepage chamber was to deliver water into the sand bed channel through upward seepage determined by an electromagnetic flow meter. All experiments were conducted with a channel having bed slope of 0.0025. The experiments were run against the main flow discharge Q=9.3 l/s. In the case of discharge Q, the channel bed is in mobile bed condition because the bed shear stress becomes more than the critical value. The flow depth (D) and Reynolds number of all experimental runs are maintained at 7.5 cm and 18,600 respectively. The median size of the fine sediment used in the channel is 0.27 mm. In addition, the experiments were performed under both the no seepage (NS) and upward seepage (US) conditions. According to Richardson et al. (1985) ranges are suggested, for the volumetric changes of water related to seepage and the associated seepage velocities, the upward seepage discharge was kept at 5% of the mainstream outflow.

On the midline of the test section was used to detect the instantaneous three-dimensional flow velocities. Because of the interference between both the reflected and transmitted pulses, the instantaneous velocities recorded from the ADV measurements carried some spikes. In this study, to remove the spikes from the velocity data (Goring and Nikora, 2002), the acceleration threshold approach was used. The signal to noise ratio (SNR) and the correlation, which were adjusted to 15 and 70, respectively, were used to filter the velocity data. The velocity power spectra of the velocity component in the flow direction matches the Kolmogorov -5/3 scaling law of the inertial sub-range (Lacey and Roy, 2008), therefore the range of acceleration threshold value was adjusted to 1-1.5.

3. RESULTS AND DISCUSSION

Based on the ADV measurement, turbulence characteristics such as time average speed, Reynolds shear stresses (RSS), turbulence intensity, and turbulent integral scale are. The following equation was used to compute the time-averaged velocity in the flow direction:

$$u = \frac{1}{n}\sum_{i=1}^{n} u_i \qquad (1)$$

where, u_i is the instantaneous velocity in the flow direction, and n denotes the number of measurements. Figure 1 displays the profiles of time-averaged velocity against non-dimensional flow depth (y/D, where y is the distance measured from bed surface). The no seepage and upward seepage runs are represented by the solid and open triangles, respectively. With upward seepage the time-average velocity decreased, which may cause less sediment transport in the channel. Following figure shows that when the upward seepage was introduced, the time-averaged velocities at near-bed reduced by 3-8%, which was sufficient for the bed sediment to move slowly.

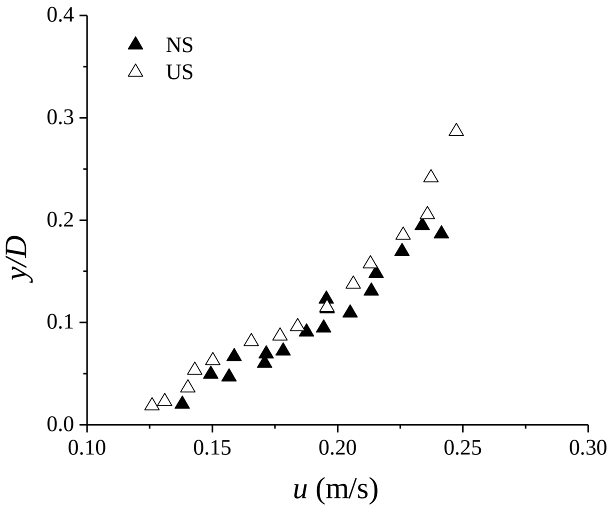

Figure 1. Vertical distribution of time-averaged velocity for no-seepage (NS) and upward seepage (US)

Reynolds shear stress (RSS) describes the transfer of momentum from the upper flow to the bed sediment and vice versa. The following equation was used to determine the Reynolds shear stress:

$$\overline{u'w'} = \frac{1}{n}\sum_{i=1}^{n}(u_i - u)(w_i - w) \quad (2)$$

$$\tau_{uw} = -\rho\overline{u'w'} \quad (3)$$

RSS were determined for both the no seepage and upward seepage runs, and figure 2 illustrates the vertical variation of RSS and the non-dimensional flow depth y/D for all the runs, where the solid and open triangles denote the no seepage and upward seepage runs, respectively. The RSS value peaked at the inner layer and subsequently dropped towards the bed surface due to the presence of viscosity or roughness sub-layer in the near-bed area. All the experimental runs had comparable RSS characteristics, however the magnitudes of RSS differed. When compared to no seepage runs, the magnitudes of RSS with upward seepage were reduced by 5-15% implying that there was less momentum exchange towards the bed and hence less sediment movement.

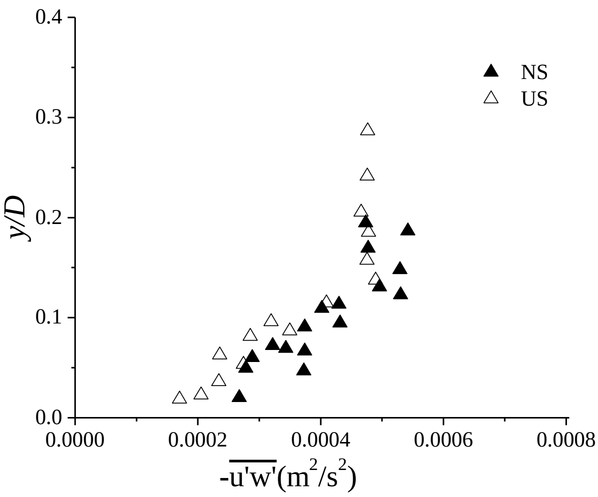

Figure 2. Vertical distribution of Reynolds shear stress for no-seepage (NS) and upward seepage (US)

The root mean square of the fluctuating components of velocities is known as the turbulence intensity. The streamwise turbulence intensity σ_u, was estimated as

$$\sigma_u = \left[\frac{1}{n}\sum_{i=1}^{n}(u_i - u)^2\right]^{0.5} \quad (4)$$

Figure 3 shows the vertical distributions of σ_u. Likewise, the solid and open triangles indicate the no seepage and upward seepage flows, respectively. Because of the decreasing RSS, the maximal value of σ_u was found near to the water surface, while the least value was found near to the bed zone. After applying upward seepage, the degree of streamwise turbulence intensity reduced, indicating that the velocity fluctuation lowered by the upward seepage.

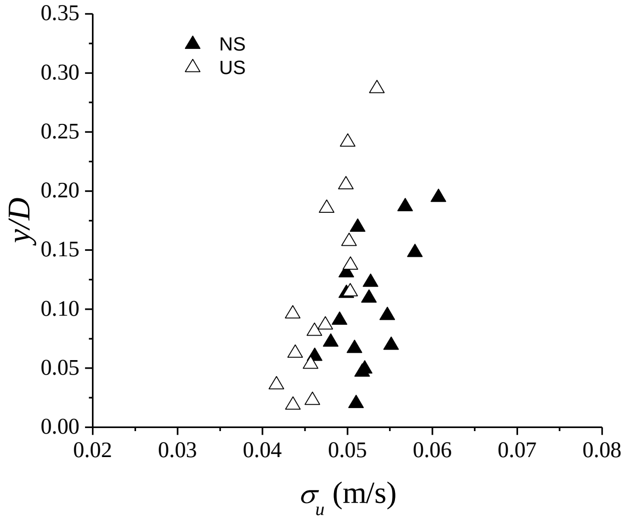

Figure 3. Vertical distribution of streamwise turbulence intensity for no-seepage (NS) and upward seepage (US)

The turbulent integral length scale is represented by the magnitude of large eddy in the flow while the turnover time of the eddy at a certain point defines the integral time scale. The scale of integral length can be estimated by Taylor (1935)

$$E_L = E_T u \quad (5)$$

where, E_T is integral time scale

$$E_T = \int_0^T R(t)dt \quad (6)$$

Where at time T, the autocorrelation function $R(t)$ is nearly equal to zero and the term dt expresses the lag distance. The transform of momentum and turbulent kinetic energy from the flow to the sediment bed is caused by the larger eddies. Due to the turbulent integral scale nearer to bed flow, the bed morphology eventually develops (Venditti et al., 2005; Sharma and Kumar, 2017). To detect the change of turbulence with the upward seepage, the integral length scale, EL, was determined in the nearer to bed area (y = 8mm) utilising time series data of instantaneous velocity. Table 1 shows the estimated E_L near the bed region. The results demonstrate that the value of E_L reduced by 13.8% with upward seepage, indicating a decrease in the flow momentum transfer and energy to the sediment bed.

Table 1. Time-averaged integral length scale and time scale at *y*= 8 mm above the bed surface

Flow condition	E_T (s)	*u* (m/s)	E_L (m)
Upward seepage	0.23	0.155	0.0356
No-seepage	0.252	0.164	0.0413

4. CONCLUSIONS

In this study, the tests were carried out for both the no seepage and upward seepage flows to investigate the impact of upward seepage on flow turbulence. The presence of upward seepage resulted in smaller RSS vertical profiles, indicating a reduced momentum exchange to the bed surface level. Due to reducing turbulent fluctuation, within the inner layer of flow the RSS profile had a damping nature and therefore the turbulence intensities dropped with the upward seepage. Meanwhile, upward seepage lowered the integral length scale by 13.8%. The time-averaged longitudinal velocity, RSS, were lowered by 3-8%, and 5-15% respectively in the presence of upward seepage, compared to the no seepage run. A detailed characterization of the turbulence can more efficiently link the hydrodynamics with sediment transport.

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