IMPACT OF DOWNWARD SEEPAGE ON PLANE BED ALLUVIAL CHANNELS

MAHESH PATEL
Dr B R Ambedkar National Institute of Technology Jalandhar, Jalandhar, India,

patelm@nitj.ac.in

ANURAG SHARMA
Institute of Infrastructure Technology Research and Management, Ahmedabad Gujrat, India,

anuragsharma@iitram.ac.in

BIMLESH KUMAR
Indian Institute of Technology Guwahati India, Guwahati, India,

bimk@iitg.ac.in

ABSTRACT

Alluvial channels are often encountered with surrounding ground water table (GWT) in which channels lose considerable amount of water through their bed and banks if GWT is lower than the flow level in channel. To address this phenomenon, experiments were carried out on a 20 m long plexiglassed tilting flume in the conditions of no seepage (mobile bed channel) and with seepage. It has been observed that during the no seepage condition, particles were in the motion condition but no signature of bed-features was seen even after several hours (10h) of the run. However, after the application of seepage, movement of sediment particles significantly increased and these sand particles deposited at the adjacent section in the form of thin sheet layers without increasing the inflow discharge. Also, these sheet layers prograded towards the flow direction and formed a thick sheet layer after 24 h of the seepage run. For understanding this process of developing sheet layers, turbulent flow properties (time-mean velocities and Reynolds shear stresses) have been obtained in no seepage and conditions. We found that time-mean velocities and Reynolds shear stresses were increased significantly after implying the downward seepage, suggesting larger sediment transport in the form of sheet layers. These layers further influenced the turbulent flow properties as time mean velocities increased because of reduction in flow depth in the presence of sheet layer.

Keywords: Downward seepage, Shields stress, turbulent flow, sheet layers

1. INTRODUCTION

Depending on the difference between water surface level in alluvial channels and surrounding ground water table, water can either seep into or out of alluvial channels through their porous boundaries. These phenomena are called injection and suction, respectively. Both of these seeping events influence the stability of the near bed particles of the porous boundaries of the channels. Several researchers (Patel et al., 2015; Deshpande and Kumar, 2016; Patel et al., 2017) have observed that downward seepage influences the flow properties in terms of increase in bed stress increases, time mean velocities and Reynolds shear stress, resulting sediment movement on a curvilinear channel cross section.

In alluvial channels, bed-features can vary in shape and size in accordance with channel cross-section. Also, they can turn in different type of forms such as bedforms and sheet layers depending upon the increase in bed shear stress from its critical value provided by the imposed flow. Several studies have performed to define the bed-features over sand bed channels. In this regard, sheet flow contributes extensively to bed load transport over mobile bed channels. In the sheet flow, a large amount of sediment is transported in the form of layers of bed material (Gotoh and Sakai, 1997). Sheet flow is the thin layer of high sediment concentration that occurs above plane, noncohesive, sediment beds. Available literature on laboratory and field observations of the sheet flow of bed material suggests that under sheet flow conditions the bed remains fairly plane where ripples and other bed topography features are absent and the bed material movement is restricted to a layer a few centimeters in thickness and comprised of moving sediment particles (Dingler and Inman, 1976; Wilson, 1987; King, 1991; Conley and Inman, 1992; Ribberink and Al-Salem, 1994; Sumer et al., 1996).

Characteristics of sheet flow layer are the function of hydraulics of flow and sediment size, for example, many researchers observed an approximately linear relation between the nondimensional sheet flow layer thickness and the Shields parameter (Wilson, 1989; Asano, 1992; Sumer et al., 1996). However, few researchers (Liu, 1957; Bogardi, 1959; Southard and Dingler, 1971) reported stable beds with little sediment transport and no signatures of bedforms were seen. In addition to this, Venditti et al. (2005) observed that the flat sand bed (median diameter < 0.7 mm) appear to be stable, for the condition of incipient motion for a longer period of run. Also, they found that a little increase in inflow discharge, sediment movement was sporadic in nature and absence of notable bed-features along the channel length up to 2 to 3 hours run.

In spite of the highlighted studies and progress regarding bed-features dynamics till date are not significant to give assured answer to the general questions such as the cause of initiation of bed-features, including variation in physical characteristics, variability, and statistical natures (ASCE, 2002). In our recent studies (Patel et al., 2015; Deshpande and Kumar, 2016) observed sheet flow on a curvilinear cross section threshold alluvial channel with coarse grained (median diameter = 1.1 mm) after the application downward seepage. Aforementioned studies are carried out to observe the bed-features on curvilinear shape cross section sand bed channel, however, influence of seepage has been neglected on their development and flow characteristics on plane bed channel with mobile bed conditions. Therefore, this study is oriented to incorporate the effect of seepage on bed morphology and turbulent flow structure over mobile plane bed channels. In this study, we have observed the sheet layers over mobile bed under the seepage environment and have examined the corresponding turbulent flow characteristics.

2. EXPERIMENTAL METHODOLOGY

In the present study a glass-walled tilting flume of 20 m length, 1 m width, and 0.72 m depth was used for conducting the experiments in the laboratory (Figure 1). A collection tank of dimensions 2.8 m long, 1.5 m wide, and 1.5 m deep was provided at the upstream end of the flume with a couple of wooden baffles installed in it to prevent highly turbulent flow from entering the channel. The entire length of the main channel bed, except a 2-m length at the upstream limit, was made porous by covering it with a fine stainless steel mesh (0.1 mm) supported by a steel tube structure of 0.22 m height, 1 m width, and 15.20 m length, which was placed on the bottom of the flume. A bottom pressure chamber was formed by the area between the bottom of the flume and the fine mesh. A fine grained uniform river sand was used as median particle diameter is 0.62 mm. Sand can be considered uniform if the value of geometric standard deviation (σg) is < 1.4 (Marsh et al., 2004), which has been found to be 0.77 for the sand used in the present study. Bed material was placed on the fine mesh in order to prevent the entrance into the bottom chamber. Three pumping units (10 HP each) were used to supply discharge to an overhead tank and then supplied to the main channel. An adjustable tail gate was provided at the downstream end of the flume to maintain the required depth of flow in the channel during experiments.

The bottom pressure chamber was used to extract water from the main channel through the sand bed in a perpendicular direction in the form of downward seepage. The amount of downward seepage was controlled by a couple of valves connected to the bottom pressure chamber at the downstream end and was measured with the help of two electromagnetic flow meters. Flow discharge from the main channel was measured by recording the depth of flow over the rectangular notch provided at the downstream collection tank. Pitot tubes attached to a digital manometer and a digital point gauge were used to measure water surface slope and flow depth in the channel, respectively. To minimize the effects of flow entrance and exit conditions in the channel, the test section in the present experiments was considered as 8 m in length in the middle of the flume (4-12 m from the downstream end).

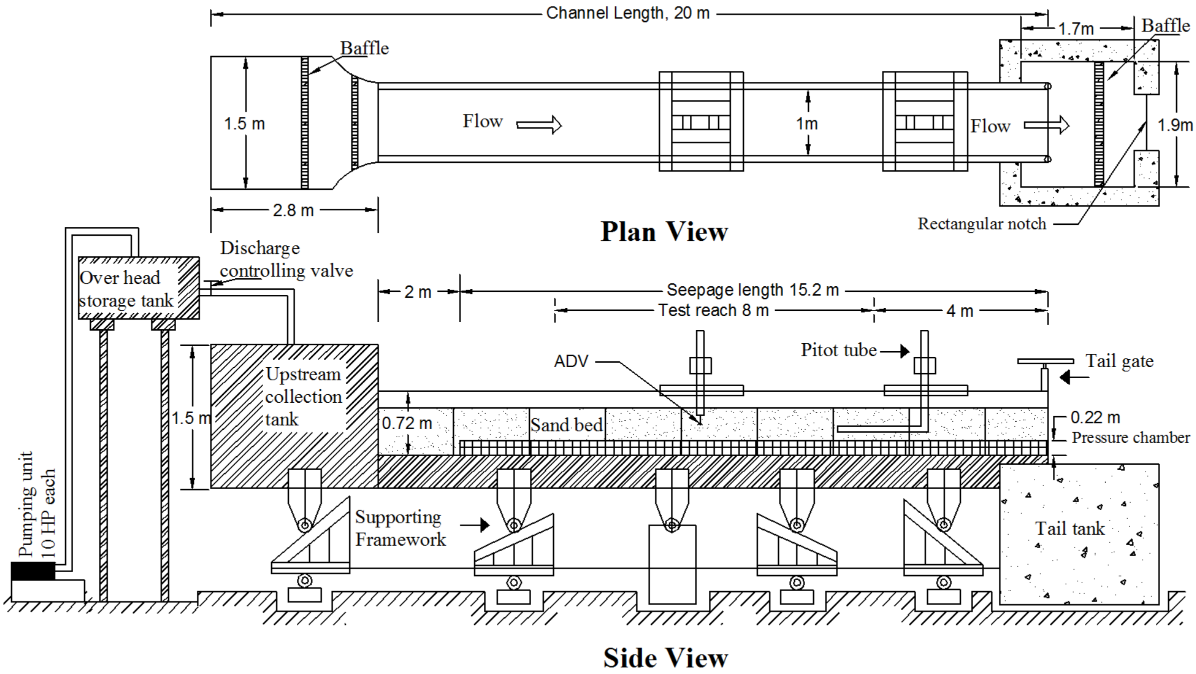

Figure 1. Schematic diagram of the experimental setup and measurements facilities

Experiments were performed in two categories: (1) when inflow discharge was increased in such a way that no signature of bed features was observed after running the experiment for several hours at no seepage condition (2) when water was extracted in the downward direction through the channel boundary (with seepage experiment) without increasing the inflow discharge. In the no seepage run, discharge was slowly introduced to the channel so that the average value of the shear stress increased gradually until the hydrodynamic forces of the flow were slightly higher with the resistive forces of the bed particles (on the bed surface). This run was continued till 3 to 4 hours and sediment movement was sporadic in nature along the channel length. The increment of inflow discharge was maintained in a way that the bed particles were in mobile condition and no significant bed features were seen in the test section of the channel. At this condition, measurements of geometry, water surface slope, inflow discharge, and flow depth were taken. Further, for investigating the influence of downward seepage on a mobile bed channel, water was extracted through the channel bed in the form of downward seepage without increasing the inflow discharge. During seepage run, seepage discharge, depth of flow, and water surface slope were measured at different time intervals.

A Vectrino+ ADV was used to measure instantaneous flow velocities the centre line of the channel for all the experimental runs. Samples were collected for five minutes duration at a sampling rate of 100 Hz. Around 20 to 25 velocity samples were recorded in the vertical profile at the middle of the test section (8 m from downstream reach end) during both the experimental runs. The cross-sectional geometry along the length of the main channel was measured using a SeaTek 5 MHz Ultrasonic Ranging System that contains eight transducers attached to an automated trolley, which moves on a rail at constant speed. Resolution of the system and the accuracy in measurements are 0.1 and ±0.2 mm, respectively.

Main channel discharge and depth of flow were provided as 0.044 m3/s and 0.11 m, respectively for the no seepage condition. Similar experiment was performed on three channel bed slopes such as 0.00116, 0.00150, and 0.00176. In these seepage experiments, 10% of the main channel discharge was extracted through the channel bed in the form of downward seepage.

3. RESULTS AND DISCUSSIONS

Mobile bed condition of the sand particles on the channel bed during no seepage condition was validated by Shields curve (Rao and Sreenivasulu, 2009) that gives a relationship between Shields stress and shear Reynolds number (Figure 2). It has been observed that values of Shields stress (θc) and shear Reynolds number ($R*$) are lied on the higher side of variation (±20%) of Shields curve, indicating slight increase in bed shear stress. This indicates particles in the mobile bed condition and may turn into bed-features if further strength of flow was increased by increasing the inflow discharge. For achieving this condition, several experiments were performed in the manner of no significant presence of bed-features during no seepage run.

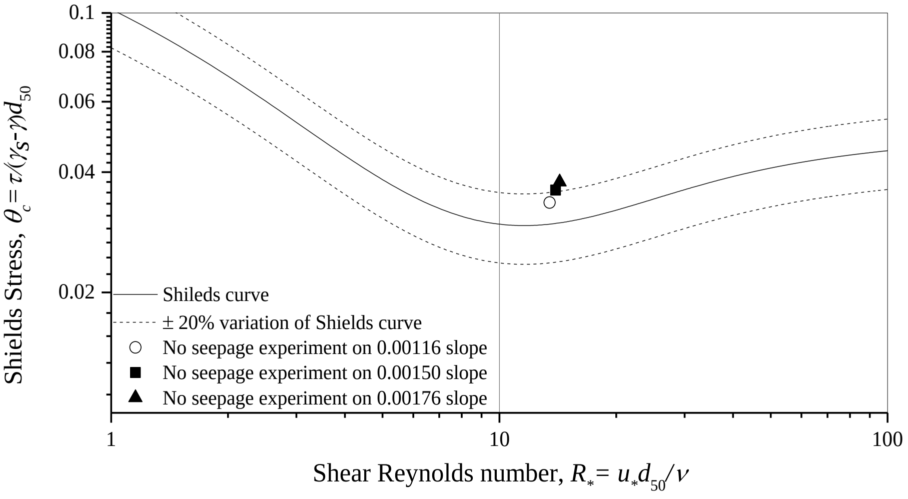

Figure 2: Shields curve for all the no seepage experiments, where band is indicating the ±20% variation with mean values of Shields curve.

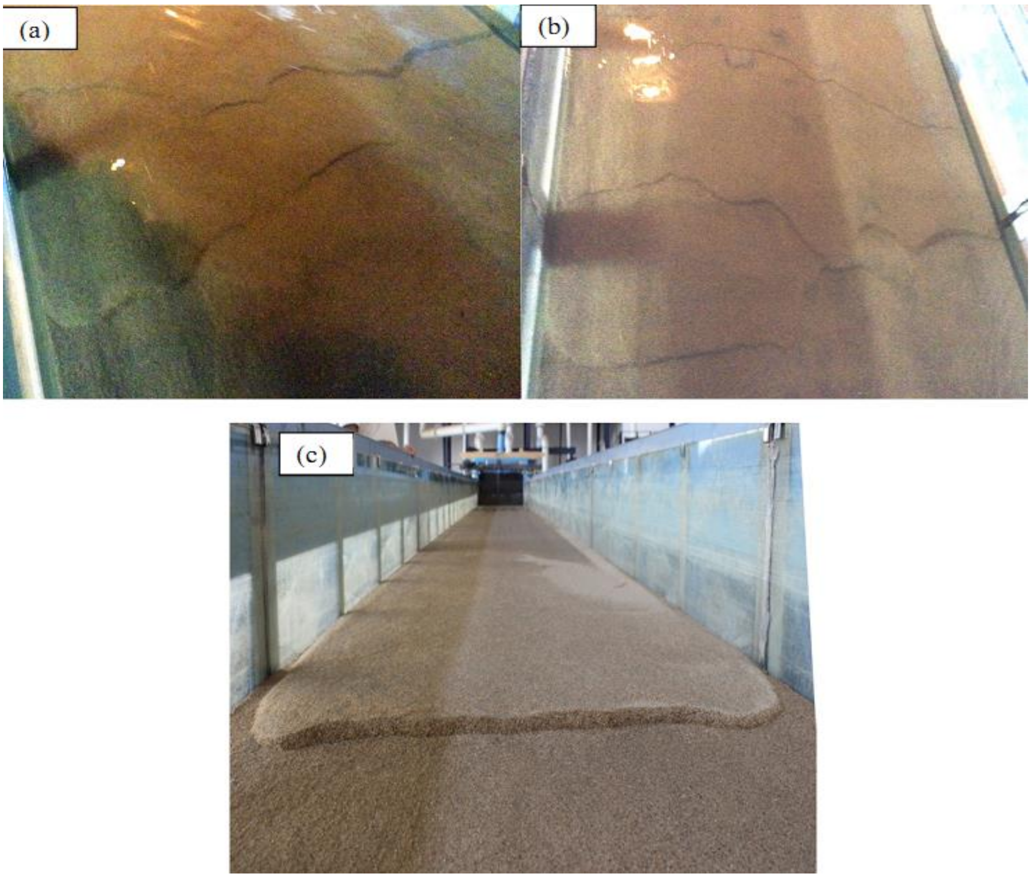

Figure 3: Snapshot of the channel (a) beginning of seepage experiment (b) during experiment (c) at the end of experiment in the seepage condition

Figure 3 shows the snapshots of the channel affected by the presence of seepage. It was observed that during the no seepage condition, particles were in the motion condition but no signature of bed-features was seen even after several hours (10 h) of the run. However, after the application of seepage, small size of sheet layers developed at upstream section (Figure 3a) and prograded along the flow. These sheet layers then increased in their length and thickness by continuously supplied of sediment from upstream side (see Figure 3b). Also, these sheet layers were combined and formed a thick sheet layer after 24 h of the seepage run (Figure 3c).

In order to understand the influence of downward seepage on turbulent flow structure, time-mean velocities and RSS are obtained for the no seepage and with seepage experiments. Figure 4(a) shows the vertical distribution of streamwise time-mean velocities and Reynolds shear stresses against the normalized depth for the no seepage run, seepage run and over the sheet. Careful observation from Figure 4(a) ascertains that with the application of seepage, velocities are increased in the near bed region and decreased towards the water surface. This suggests that the higher velocity zone shifts towards the channel boundary under the action of downward seepage. Variation in the velocity profile near the channel bed leads to the formation of sheet layers of flowing sediment particles. Time-mean velocities over the sheet layer further increased because of the reduction in the depth of flow because of development of sheet layers.

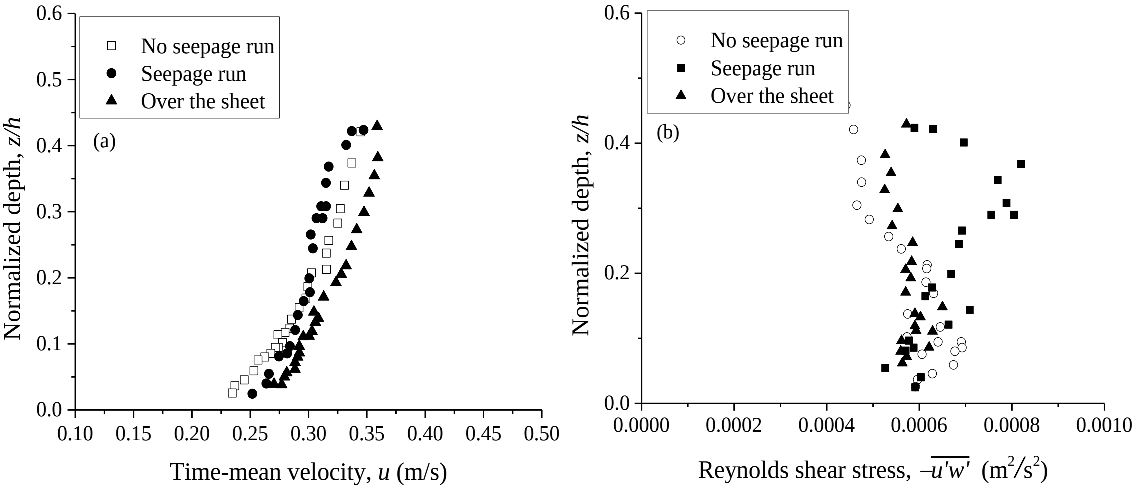

Figure 4: Profiles of the (a) streamwise time-mean velocities and (b) Reynolds shear stresses for the no seepage run, seepage run, and over the sheet layer.

Figure 4(b) shows the vertical distribution of RSS for the no seepage run, seepage run, and over the sheet layer. It can be observed that the RSS are increased significantly after the application of seepage and obtains maximum value somewhere away from the bed and then declines further. It is an indication of the presence of a roughness sublayer in the near-bed region. The distance of the maximum value of RSS from the channel bed increases under the action of downward seepage indicating an increase in the thickness of sublayer. This seepage phenomenon can be occurred due to larger roughness because bed particles were in the higher velocity zone, indicating larger momentum transfer in the zone of $z/h=0.4$. It can be suggested that the transfer of higher momentum transfer towards the channel bed, leading to sediment transport and development of sheet layers in the channel. RSS over sheet shows the reduction of bed shear stress it may reduce because of sediment transport in sheet layers and flow required less tractive force to transport the bed particles.

It can be observed that turbulence plays an important role in sediment movement mechanisms, which are largely governed by the coherent structure of the turbulent flow in the near-bed region (Patel et al., 2015). Downward seepage does initiate sediment movement, which can be inferred from the increased time mean velocities and Reynolds stresses after applying the seepage, resulting larger sediment transport and development of sheet layers as shown in Figure 3. Later on, these thin sheet layers progaded towards the flow direction and accumulated in one thick layer. Thus, influence the flow properties significantly in terms of larger turbulence in the flow.

4. CONCLUSIONS

The present experimental study has shown very interesting findings to understand the influence of downward seepage on mobile bed channels. Two types of experiments were designed such as no seepage and downward seepage. During no seepage condition, experiments were carried out to obtain the conditions of mobile bed channels in which no bed features were developed after running several hours (10 h). For verifying this condition, Shields curve has been used and it has been observed that values of Shields stress and shear Reynolds number lies within the band (±20%).

In order to understand the impact of downward seepage on these mobile bed channels, some percentage of water extracted through channel bed. It was observed that movement of bed particles further increased. These bed particles accumulated in the form of very thin layers. With the passage of time, these sand layers then combined and formed a thick layer. For understanding this phenomenon, turbulent flow structure analysed during no seepage (mobile bed condition) and downward seepage condition. It was found that time mean velocities were increased in the near bed region and decreased towards the water surface, indicating particles on channel bed exposed to higher velocity zone. After developing thick sheet layer depth of flow decreased and observed further increment in time mean velocities. Also, Reynolds shear stresses were increased after applying the downward seepage, causing impending of sediment transport and development of sheet layers. Observations of this study shows that after applying the downward seepage on mobile bed channel, turbulent flow properties significantly change and cause evolution of sheet layers. In future, the study can be carried out on the estimation of total drag because of development of bedforms developed in the presence of downward seepage.

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