Evolution of Channel Profile with Seepage

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Abstract **- Most of the stable channel predictors are empirical or semi-empirical in nature except Lane's (1953). Lane (1953) has derived the stable channel parameters analytically by solving various forces those can act on the sediment-water flow. It has been noticed that existing stable channel predictors or Lane's (1953) theory do not account seepage as independent parameters. Seepage flow from the alluvial channel modifies the channel hydrodynamics, which may result in new equilibrium state other than Lane's geometric profile. Experimentation shows that channel based on Lane's geometric profile remains stable in case of no movement of water from channel in downward direction. In case of downward movement of water, channel attains a new equilibrium state, which is very much different from the Lane's geometric Profile.**

Keywords- **Alluvial channel, Lane's theory, incipient motion, seepage**

I. INTRODUCTION

In alluvial channel design, stability depends on both the channel geometry and composition of the boundary materials. An alluvial channel has three degrees of freedom to adjust its cross-section for a given flow condition. These three degrees of freedom are in width, depth and slope. Their magnitudes are determined by the independent variables of sediment inflow, water inflow, and bank composition. According to Lane (1953) "A stable channel is an unlined earth canal for carrying water, the banks and bed of which are not scoured by the moving water and in which objectionable deposits of sediment do not occur". Stable channel shape proposed by Lane (1949) is derived on the basis that the tendency of motion of a particle in the direction transverse to the flow is proportional to the slope of the stream bed, as measured by the tangent of the angle with the horizontal, and the direction of flow is proportional to the depth of the stream.

Stability and the mobility of the channel is affected by seepage which has common occurrence due to porosity of the granular material as well due to level difference between ground water and surface water in the channel. The presence of seepage from a channel (termed as suction) or into it (termed as injection) leads to a change in the bed deformation conditions and consequently the hydrodynamic characteristics of the channel (Lu et al., 2008).Maclean and Willets (1986), Maclean (1991), Rao and sitaram (1999), Rao et al. (2011) and Sreenivasulu et al. (2011) have shown that suction increase the sediment transport rate and injection decrease it. Oldenziel and Brink (1974), Cheng and Chiew (1998a,b), Krogstad & Kourakine (2000), Ali et al. (2003), Chen and Chiew (2004,07), Dey and Nath (2010), Dey et al. (2011), Liu and chiew (2012) have indicated that velocity near the bed is increased in case of suction. Channel seepage has been also identified as a significant loss from the irrigation channels from both water quantity and environmental degradation perspectives. Seepage losses from alluvial channels have been estimated to range from 15 to 45% of total inflow (Van der Leen 1990). Thus, it is important to study and analyse seepage phenomena that undergoes in alluvial channels.

The movement of sand bed due to suction may result in new equilibrium state, different from the existing regime predictors. Hence the present work is aimed to investigate the seepage effects on the shape of sand bed channels.

II. EXPERIMENT

Experiments were conducted in a glass-sided flume. Mechanical arrangement has been provided beneath the flume which is used to change the bed slope either in positive or even negative direction if need be. Dimensions of flume are 17.24 m in length, 1m in width, and 0.72m in deep. A tank of dimensions 2.8 m long, 1.5 m wide and 1.5 m deep is provided at the upstream of the flume which serves to straighten the flow prior to its introduction in to the flume. The upstream tank gets water through the overhead tank where water is pumped by three pumps of 10 HP capacities each. A control valve is located at the overhead tank and is used to regulate the flow in the main channel. A wooden baffle is installed in the upstream tank which prevents turbulences in the water coming from the overhead tank, to enter the main channel.

The flume consists of a seepage chamber, length of which is 16 m from the downstream end of the flume. It is 1 m wide and 0.22 m deep, which collects and allows the free passage of flow through the sand bed. Two meters of upstream length of the main channel bed is made non-porous and the remaining length of the channel is made porous by covering a fine mesh (0.1 mm).This mesh arrangement is supported by steel tube structure of 0.22 m height which is placed on the bottom of the bed. The area between the bottom of the channel and the mesh forms the bottom pressure chamber. The fine mesh prevents the bed material entering into the chamber. This pressure chamber is used to remove the water from the main channel through the sand bed (uniformly) in perpendicular direction. A couple of valves located at the downstream end of the chamber that allow uniform and controlled amount of seepage in the form of suction.

A tail gate is provided at the downstream end of the main channel which can be raised or lowered to control the flow depth. The tail gate is operated manually by a geared mechanism with edges, which allows precise positioning of the gate. A tank is provided at the downstream of the flume to collect the water from channel and release it to the underground trench, which delivers it to an underground tank from where the water is pumped into the overhead tank. This way the water is re-circulated in the experiment.

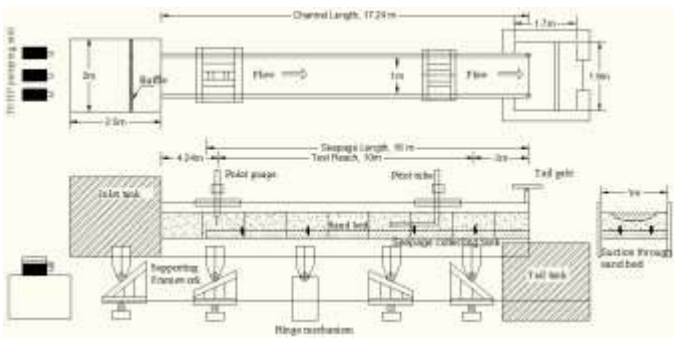


Fig. 1. Schematic of experimental setup

Initially, the required size of the sand has been sieved and loaded in the main channel. The desired bed slope has been obtained with the help of total station and the required shape of channel which has been given by Lane (1949) was provided and then water was pumped into the main channel. Tail gate was adjusted for a desired flow depth. Next, the flow was allowed to stabilize over a period of time (several minutes to several hours). Water surface slope and depth of water were recorded by using digital manometer attached to a Pitot tube and a digital point gauge. Amount of seepage was measured by two magnetic flow meters present in the downstream side and connected though the pipes with the seepage chamber. In the experiments, major variables were inlet discharge (Q_0), seepage discharge (q_s), outlet discharge after applying seepage (Q'), mean velocity, flow depth (y), channel width (B), water surface slope (S_f), bed condition (whether no-transport, incipient or transport), median size of the bed material (d_{50}), bed roughness, and sediment characteristics (size distribution, shape, and density). Sand of median diameter d_{50} = 1.1mm has been used as bed material for both seepage and no seepage study in the experiments.

III. RESULTS and DISCUSSION

Experiments have been performed in following sequence:

- Quantify the Lane's geometric profile when there is no downward movement of water or suction
- Observing the new equilibrium state due to bed movement caused by suction

Yalin's (1976) criterion for incipient motion has been used to ensure the incipient motion in the channel, which is as follows:

$$\frac{m}{A_o T_1}\sqrt{\frac{\rho d^5}{\gamma_s}} = \varepsilon \qquad (1)$$

where, m is number of detachments (m = 25), ε is constant, A_o is area of observation for particle motion (in cm^2) , γ_s is specific weight of solid, d is diameter of particle (in mm), T_1 is time for about and up to 25 detachments being observed within the test-section of observation, ε is a constant value. Theoretically the value of ε in Eq. (1) should be zero for incipient motion. But for practical purposes, a value of 10^{-6} has been chosen. Lane's (1953) shape has been used for the experimental run when there is no downward movement of water. Initially Lane's (1953) profile has been provided in the channel as shown in the Figure 2. In order to check the stability of Lane's geometric profile on incipient motion condition at no seepage case, top width of 0.70 m has been used. For top width of 0.70 m (shape 70), maximum depth of flow can be calculated by rearranging eq. (2):

$$y_{\max} = \frac{B\tan\varphi}{\pi} \qquad (2)$$

For top width of 0.70 m, $y_{\max}$ comes out to be 0.135 m, cross-sectional area 0.0603 m^2, and discharge 0.037 m^3/s. Then the inflow (Q) was allowed so that the sediment particles were at critical condition, i.e., equal to critical condition ($\tau_{b0} = \tau_{c0}$). By keeping the tail gate condition undisturbed the discharge was increased slowly and steadily in steps, so that the average shear value was gradually increased until a stage, when the hydro-dynamic forces of the flow exceeded the resistive forces of the bed particles and eventually started moving. The time required for twenty five particles to pass the test section was recorded and averaged over five trials. This run was continued for several hours so that the channel geometry and longitudinal slope adjusted on its own such that the sediment movement remains to threshold state in the channel. Thus the stable conditions were achieved. In order to quantify the new equilibrium state due to bed movement caused by suction, certain amount of seepage (suction) has been applied i.e., ($\tau_{bs} > \tau_{cs}$) and continued the run for several hours until the channel geometry and longitudinal slope were adjusted on their own so that new incipient state reached with seepage ($\tau_{bs} = \tau_{cs}$).During this process no additional sediment was allowed from the upstream of the channel. It was observed that bed movements have initiated erosion and deposition in the channel. Eroded sediment particles from one section got deposited in the adjacent next section and vice versa, this process kept on continuing the phenomenon of erosion and deposition by altering the channel geometry everywhere throughout the channel. During this process, the inflow and outflow discharges, the seepage discharge, depth of flow and water surface profiles were recorded at regular intervals. Finally, after channel reached into a full equilibrium state, the experiment was stopped and the measurements were recorded as like no-seepage run.

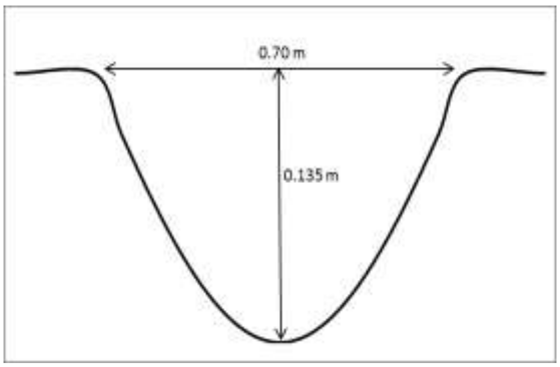
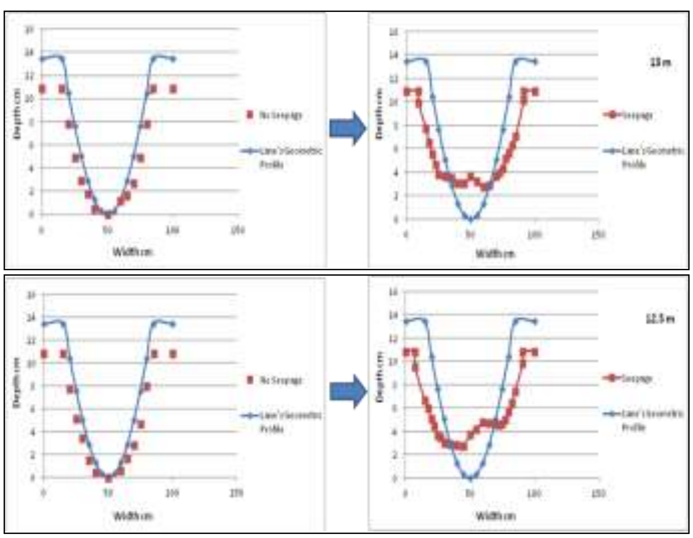
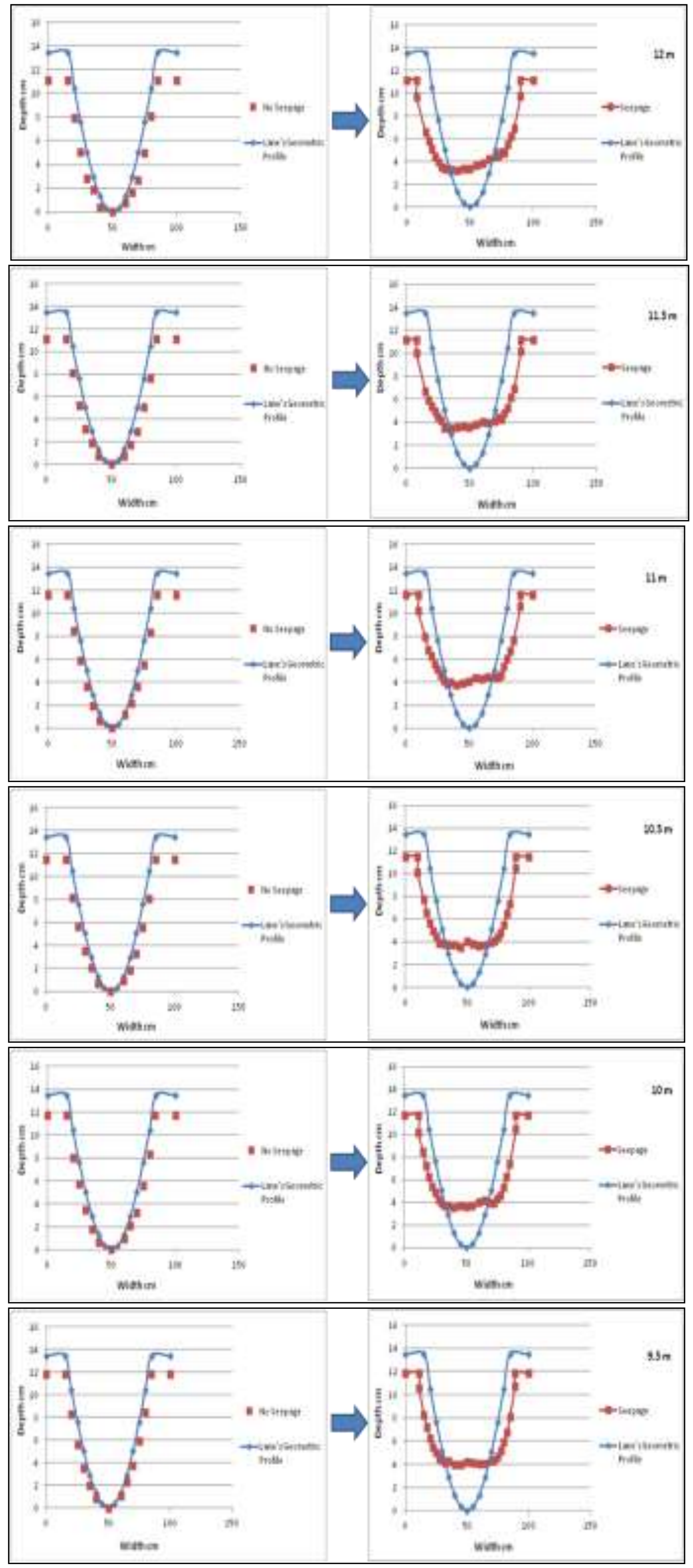
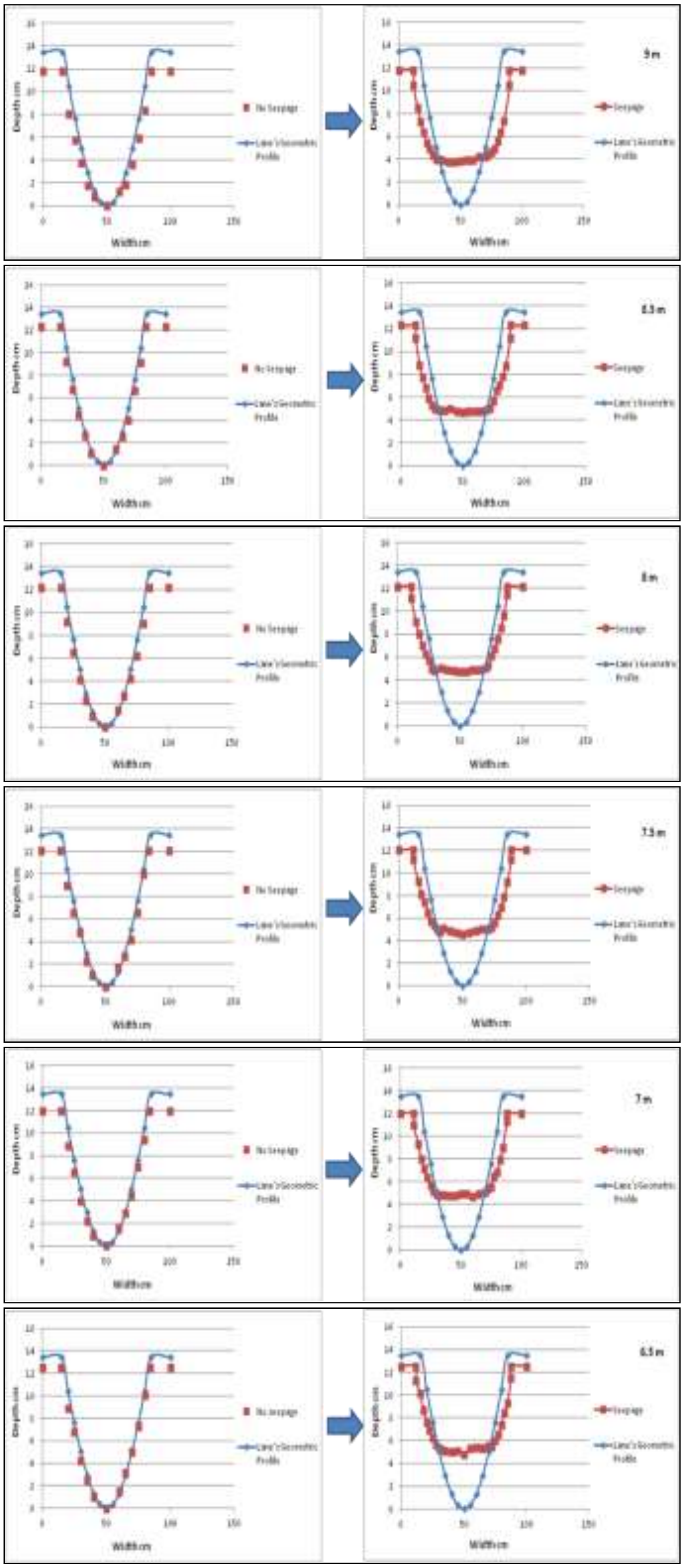


Fig. 2. Lane's Geometric Profile at a cross-section

Figure 3 shows deformed cross-sectional profiles from downstream to upstream along the length of channel for no-seepage and seepage runs on shape 70 and slope 0.00249.







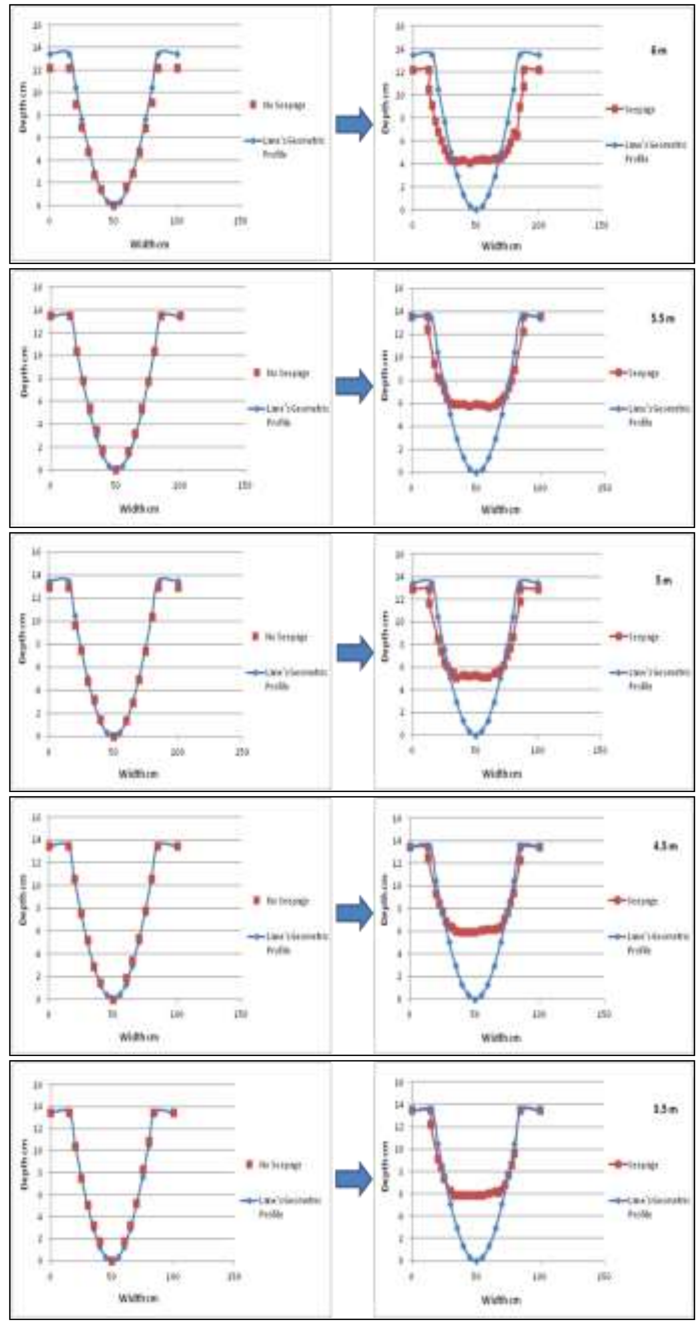


Fig.3. Cross-sections for no-seepage and seepage runs

Results shows that Lane's geometric profile is stable in case of no seepage condition but in the case of seepage it is not stable. Due to higher stream power more erosion take place in the upstream side and deposition occur in downstream side due to energy dissipation. In case of no seepage condition profile is similar to the Lane's profile but in case of seepage whole channel geometry is affecting and throughout the channel it is varying with the original Lane's profile. Depth of channel also reducing along the channel and the parameter, cross section of the channel is also affected due to seepage.

IV. CONCLUSION

Experiments show that channel with Lane's geometric profile remains stable in case of no downward movement of water (no suction). Seepage through a sand bed in a downward direction reduces the stability of particles resting on the boundary and it can even initiate their movement. The imminent movement of bed particles results in a new equilibrium state, which is entirely different from Lane's geometric profile. The nature of the flow is spatially varied flow in case of suction; channel undergoes erosion and deposition due to the variation of stream power along the length of the channel.

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