

## EFFECT OF SEEPAGE ON SEDIMENT TRANSPORT IN CHANNELS

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**Abstract:** Understanding the behavior of sediment beds is important to Earth scientists, Civil and Marine Engineers. The behavior of sediment beds can be influenced by seepage flow through the sediment bed and seepage can sometimes cause structures to fail. This paper deals mainly with an experimental investigation into the effect of seepage on sediment bed load transport and bed forms.

Experiments were conducted in the Civil Engineering Department of the University of Liverpool. The object was to obtain bed load transport rates for flows with, and without, seepage. The effect of seepage on the shape of the resulting bed forms was also studied. In addition, detailed velocity-distributions were obtained using an Ultrasonic Velocity Profiler.

**Key words:** Seepage flow, Sediment transport, Bed form

### 1. INTRODUCTION

This paper deals with the effect of seepage, injection or suction of a fluid flow into a sediment bed, on the sediment bed load transport and the bed forms, which will arise when there is a horizontal flow in a marine environment. Such an environment can be a sea, river or estuary. Upward seepage exists when the water pressure is lower than the average pressure in the sediment bed and downward seepage when the water pressure is higher. It is usually assumed that sediment moves more readily with upward seepage than with downward seepage. The bed load transport can have a great influence on the depth of dredged channels and therefore the passage depth for vessels, which are approaching a harbor. The bedforms are related to the sediment bed load transport.

### 2. THEORETICAL CONSIDERATIONS

#### 2.1 BED LOAD TRANSPORT FORMULAE

We used two bed load formulae in this paper. The first was that of Einstein (1950) which gives:

$$\phi_b = 40\theta_b^3 \quad (1)$$

where

$$\phi_b = q / [g(S-1)d_{50}^3]^{1/2} \quad (2)$$

$$\theta_g = u_*^2 / g(S-1)d_{50} \quad (3)$$

where

$q$ = sediment bed load transport rate ( $m^2/s$ );

$g$ =acceleration due to gravity;

$S$ =specific gravity particles;

$d_{50}$ =median particle size, and

$u_*$ =shear velocity.

The second bed-load relationship was that of van Rijn (1984):

$$q = k_*(T^{2.1} / D_*^{0.3}) \quad (4)$$

where

$$k_* = 0.053[(S-1)g]^{1/2} d_{50}^{3/2} \quad (5)$$

$$T = (\tau_b - \tau_c) / \tau_c \quad (6)$$

Where

$D_*$  = dimensionless particle parameter:

$$D_* = [g(S-1)/\nu^2]^{1/3} d_{50} \quad (7)$$

$\nu$  = kinematic viscosity;

$\tau_b$  = critical bed shear stress, and

$\tau_c$  = bed shear stress

## 2.2 BED SHEAR STRESS

In general, injection has been found to lead to a reduction in bed shear stress. Truscotte (O'Donnell, 2000) produced the following relationship:

$$\frac{\tau_{b,s}}{\tau_b} = 1 - 13.89 \left( \frac{v_s}{u_*} \right) \quad (8)$$

$\tau_{b,s}$  = bed shear stress with seepage, and

$v_s$  = seepage velocity at the boundary.

## 2.3 VELOCITY DISTRIBUTION

Cheng and Chiew (1998a) presented results from a series of flume experiments examining the effect of injection on turbulent open-channel flow. An increase in velocity over the entire water depth was found to exist, with the greatest occurring near the water surface. A gradual reduction in bed shear stress was also observed for increasing injection velocity. A modified logarithmic law was developed (Cheng and Chiew (1998b)) to account for the influence of injection:

$$\frac{u}{u_*} = \frac{1}{K} \ln \left( \frac{y}{y_0} \right) + \frac{v_s}{4u_*} \left[ \frac{1}{k} \ln \left( \frac{y}{y_0} \right) \right]^2 \quad (9)$$

where

$u$  = the horizontal velocity at a distance,  $y$ ;

$K$  = Von Karman's constant;

$y_0$  = value of  $y$  at which  $u=0$ .

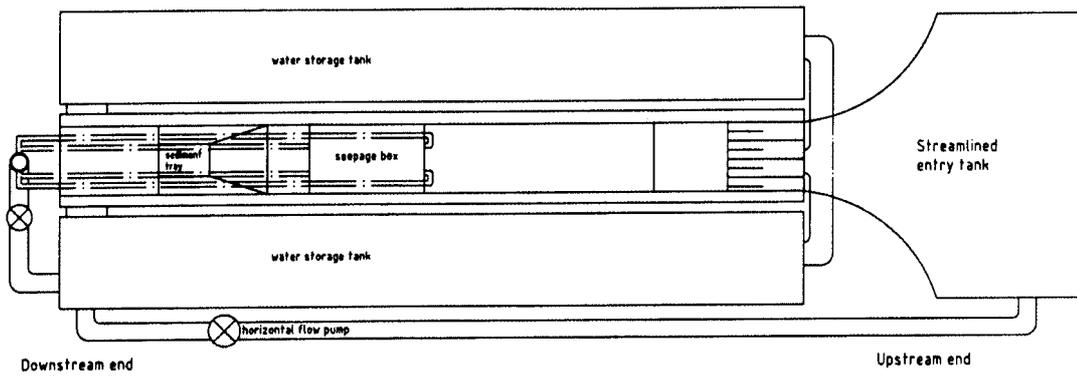
## 3. EXPERIMENTAL ARRANGEMENTS

The present experiments were conducted in a specially designed recirculation flume. The glass-sided flume was 5.5m long, 0.6m wide and 1m high. Fig. 1 illustrates the flume. The length of the sediment bed was approximately 3.0 m. A seepage box was positioned at the downstream end of the channel as can be seen in Fig. 2. Seepage flow was delivered using a calibrated submersible pump.

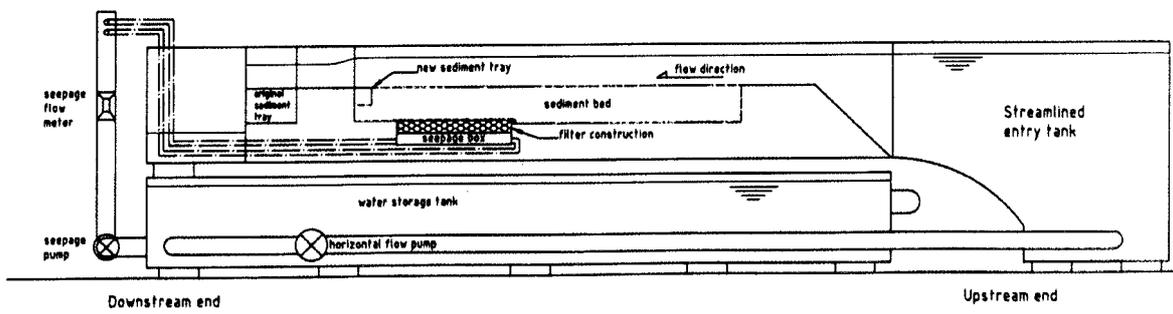
Median sand was used in the present experiments and its various characteristics are given in Table 1.

**Table 1** Sediment properties

$D_{10}$ [ $\mu\text{m}$ ]	$D_{50}$ [ $\mu\text{m}$ ]	$D_{60}$ [ $\mu\text{m}$ ]	$D_{90}$ [ $\mu\text{m}$ ]	$C_u$ [-]	$\rho_{dry}$ [ $\text{kg}/\text{m}^3$ ]	$k$ [ $\text{m}/\text{s}$ ]
90	230	245	400	2.72	2555	$9.61 \times 10^{-5}$

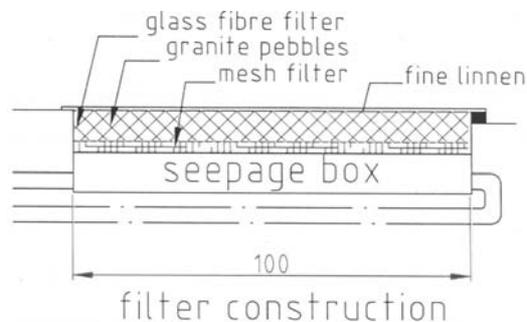


Aerial view



Side view

**Fig. 1** Views of experimental flume



**Fig. 2** Filter Construction

In Table 1,  $C_u$  = uniformity coefficient,  $\rho_{dry}$  = dry density of the particles and  $k$  = coefficient of permeability. The specific gravity of the particles was 2.56 and the average fall velocity was 0.0292m/s. The grain size parameter,  $D_*$  ( $D_* = [g(S-1)/v^2]^{1/3} d_{50}$ ) was 5.42.

Velocity distributions were obtained using an Ultrasonic Velocity Profile. This device obtained instantaneous velocities at 128 separate points along the measurement line.

Bed loads were obtained using a sediment tray positioned at the end of the channel. Bed forms were obtained using a video camera, together with a fine grid attached to the side of the channel.

#### 4. EXPERIMENTAL RESULTS

O'Donnell (2000) used his mathematical model for seepage to show that the seepage velocity distribution is two-dimensional. The velocity distribution in the sediment bed is

uniform across the width of the flume. The velocity distribution along the flume was also uniform over a considerable length of the seepage section.

#### 4.1 BED LOAD TRANSPORT WITHOUT SEEPAGE

The experimental bed load transport results were compared with those calculated using Einstein's (1950) and van Rijn's (1984) relationships. Einstein's relationship gave much better agreement with the experimental results than the Van Rijn equation.

#### 4.2 BED LOAD TRANSPORT WITH SEEPAGE

The effect of seepage on transport rate is demonstrated in Fig. 3. The transport rate is plotted against  $R_e$  for the experimental results with and without seepage.  $R_e = k_s u_* / \nu$  where  $k_s$  = effective bed height roughness;  $u_*$  = shear velocity and  $\nu$  = kinematic viscosity of water. This figure shows that the results with seepage give a lower sediment transport rate compared to those with seepage. The influence of seepage results in a lower particle Reynolds number, which implies a smoother boundary. When the boundary is smoother, the particles will have less inter-granular collisions and therefore there will be less sediment in motion. It was found that the average dimensionless sediment transport rate in the case of bed failure was 0.0069. This value was 35 times bigger than that for the experiments without seepage and 55 times bigger than those with seepage. The experiments with bed failure had an average seepage velocity of  $1.02 \times 10^{-2}$  m/s while the appropriate seepage velocity was  $1.44 \times 10^{-4}$  m/s. With this difference in seepage velocity for a low permeability sediment it is expected that the sediment bed would fail.

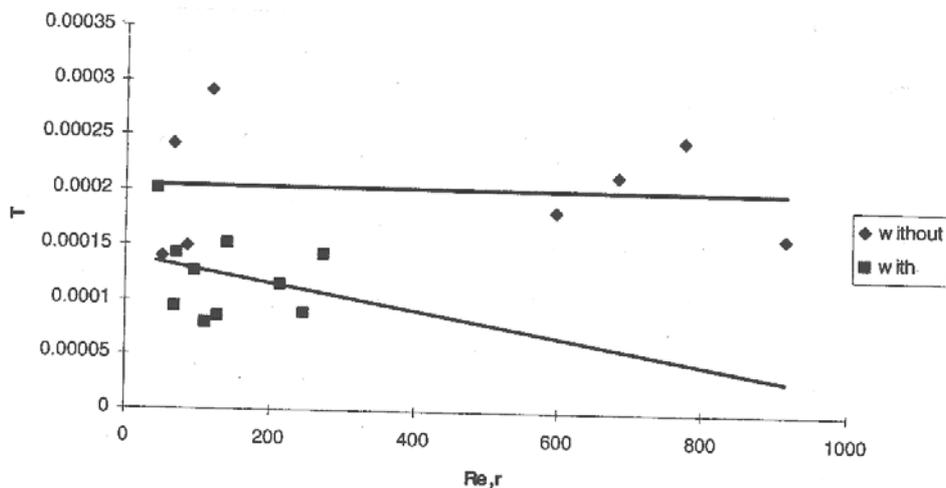
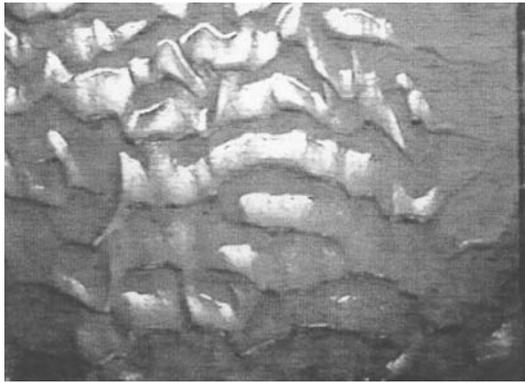


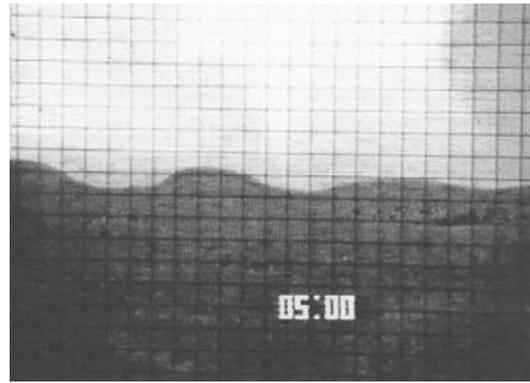
Fig. 3 Experimental results of transport rates with and without seepage.

#### 4.3 BED FORMS

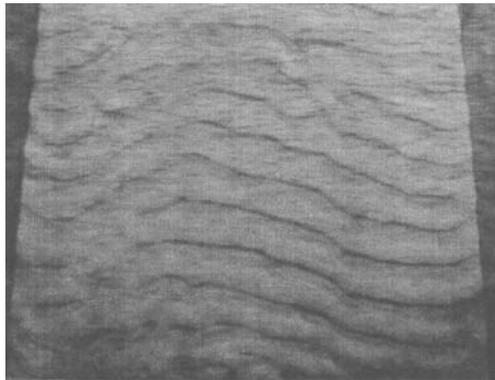
The crest line patterns found in the present experiments without seepage can be classified as sinuous and linguoid (Van Rijn). These can be seen in Fig. 4 and Fig. 5. Yalin (1985) gives  $\lambda = (5-10)\Delta$  where  $\lambda$  = ripple length and  $\Delta$  is the ripple height. The present experiments give  $\lambda = (8-11)\Delta$ . Seepage resulted in making the crest lines straighter than those with no seepage (Fig. 6 and 7). Therefore, the crest lines can be classified as mainly sinuous. The present experiments give  $\lambda = (9-15)\Delta$ . A picture of a failed sediment bed is shown in Fig. 8. These results show that the heights and length of the ripples are slightly bigger in the cases with seepage. The stability of the ripples is reduced because of the lifting forces acting on the sediment. Also, ripples are less steep on the side of the crest.



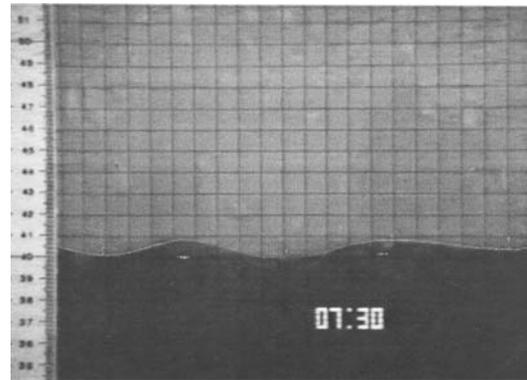
**Fig. 4** Crest line pattern without seepage



**Fig. 5** Bedform development after 5:00 minutes without seepage



**Fig. 6** Crest line pattern with seepage



**Fig. 7** Bedform development after 7:30 Minutes with seepage

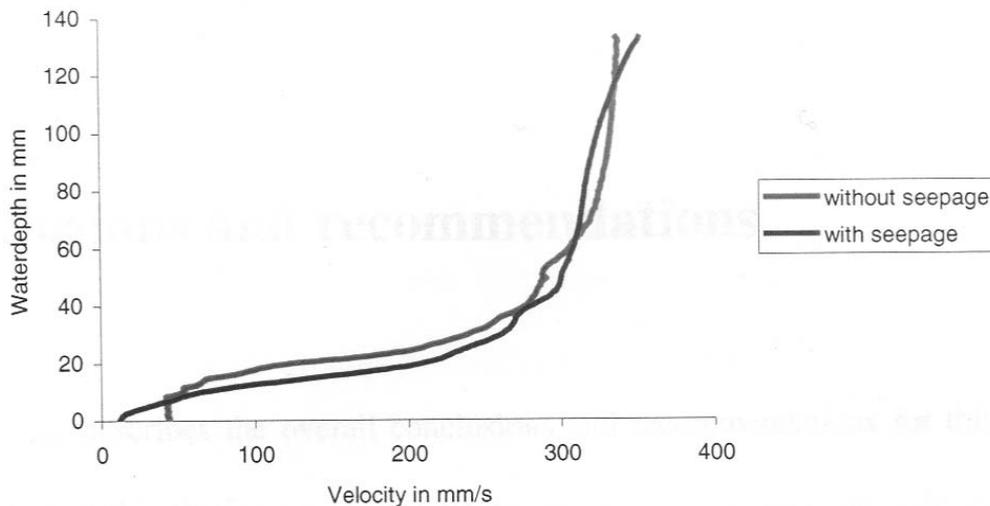


**Fig. 8** Failed sediment bed

#### 4.4 VELOCITY DISTRIBUTIONS

Velocity profiles were obtained using the Ultrasonic Velocity Profiler (Fig. 9). Thirteen runs were conducted without seepage and 16 with seepage. In the present experiments, a small range of water depths and discharges produced reasonable bed forms. The averages of the maximum, mean and shear velocities without seepage were 0.338, 0.268 and 0.046m/s. The corresponding values for the runs with seepage were 0.352, 0.275 and 0.039m/s. The lower shear velocity in the experiments with seepage confirms the lower sediment transport

rates in the experiments with seepage. Seepage influences the velocity distribution in the water column and causes a lower shear velocity and a lower critical shear velocity. Maximum and depth-averaged velocities become higher when there is seepage out of the sediment bed.



**Fig. 9.** Average velocity profiles without and with seepage

## 5. CONCLUSIONS

This paper presents an investigation into the effect of seepage on sediment transport and the resulting bed forms, together with any modifications to the velocity distributions and bed shear stresses. It was found that seepage caused a reduction in bed load transport. Einstein's (1950) method for calculating the bed load gives reasonable agreement with the measured values.

Seepage caused longer and higher ripples than in the cases without seepage. The stability of the ripples was less with seepage because of the lifting seepage forces acting on the sediment. Therefore, the steepness of the ripples is less. An aerial view of the bed forms shows that the ripple crests tend to be straighter with seepage.

Seepage causes a lowering of the shear velocity which confirms a lower sediment bed load transport rate and less steep ripples in the cases with seepage.

## REFERENCES

- Chenge, N. S., and Chiew, Y. M. (1998a), 'Turbulent Open Channel Flow with Upward Seepage', *J. Hydr. Res., IAHR*, 36(3), 415 -431.
- Cheng, N. S., and Chiew, Y. M. (1998b), 'Modified Logarithmic Law for Velocity Distribution Subjected to Upward Seepage', *J. Hydr. Eng., ASCE*, 124 (12), 1235 - 1241.
- Einstein, H. A., (1950), 'The Bed-Load Function for Sediment Transport in Open Channel Flows', U.S. Dept. Agric., Soil Conser. Serv., T. B. No. 1026.
- O'Donnel, C. (2000), 'The Effect of Pore Pressure on Sediment Transport', Phd. Thesis, University of Liverpool.
- Van Rijn, L. C. (1993), 'Principles of Sediment Transport on Rivers, Estuaries and Coastal Seas', Aqua Publications, Amsterdam.
- Yalin, M. S. (1985), 'On the Determination of Ripple Geometry', *Journal of Hydraulic Engineering*, Vol. III, No. 8.