Experimental investigation of the effect of salt wedge on concentration of suspended non-cohesive particles in turbid flow

To cite this article: Xiaoling Yin *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **310** 042045

View the article online for updates and enhancements.

Experimental investigation of the effect of salt wedge on concentration of suspended non-cohesive particles in turbid flow

Xiaoling Yin[1, 2], Bangjian Yang[1], Zeng Ying[1], Shuqin Huang[1], Lanxin Yu[1] and Chen Lu[2*]

[1]School of Civil Engineering and Transportation, South China University of Technology, Guangzhou, Guangdong, 510640, China

[2]Key Laboratory of the Pearl River Estuarine Dynamics and Associated Process Regulation, Guangzhou, Guangdong, 510641, China

[*]Corresponding author's e-mail: 25698051@qq.com

Abstract. To have an insight of the effects of salt wedge on suspended sediment concentration (*SSC*), we carried out experiments of intruding salt wedge in flume with fresh turbid water of non-cohesive particles and salt water free of sediment. Two sets of Acoustic Doppler Velocity Profiler (ADVP) were used to record instantaneous velocity profiles in the saline affected zone near the bed. The acoustic back scattered signal amplitudes (*AMP*) in the measurements were used to estimate SSC at the same point and the same time. The results show that around the interface shear of exchange flow is remarkable and SSC increases noticeably. Flow analysis indicates that large scale turbulence from interfacial instability is the main power source to enhance sediment carrying capacity of the flow. It weakens and retards the particles in the upper turbid layer sinking to the lower saline zone. However, the energy dissipation doesn't show much change.

1. Introduction

The river meets the sea at the estuary, and the density difference leads to the density flow and vertical stratification. Salt wedge is a typical high stratification state, which often appears in the river dominated estuaries [1]. The existence of salt wedges and their movement and dynamic characteristics have a great influence on sediment suspension, transport and deposition in the estuary [2-4]. However, due to the complexity and numerous factors, the internal mechanism of the actions remains to be explored.

Experimental methods have always played an important role in the study of density flow. Current development, mixing and stratification, interface entrainment, turbidity sediment, bed erosion and etc. have been studied through experiment [5-7]. In previous studies the ambient flow are mostly clear and fresh [8-10]. There are few experiments on salt wedge in turbid flow to study the sediment suspensions.

In this paper the laboratory experiments of salt wedge in turbidity currents are presented. The purpose is to investigate the influence of salt wedge on concentration of suspended fine particles as well as the physical mechanisms associated with that.

2. Experimental setup and procedure

The horizontal experiment flume is shown in figure 1. The size, length, width and height, is of 5m×0.2m×0.2m. The fresh muddy water is prepared in advance and well stirred continuously in a pool. The water is pumped steadily into upstream of the flume with a controlling valve on the pipe. A filter mesh is put in the flume to make the inflow smooth and stable. The water levels can be modified by a tail plate in L shape at the outlet downstream. Well mixed salt water, driven by a steady head and also controlled by a valve, is discharged into the flume through a pipe open to the flume bed near the downstream end. In the experiments, after a turbidity uniform flow has been formed in the flume, the salt water valve is opened slowly to let the saline water enter the flume from the bottom and intrude beneath the fresh turbid current with a constant discharge.
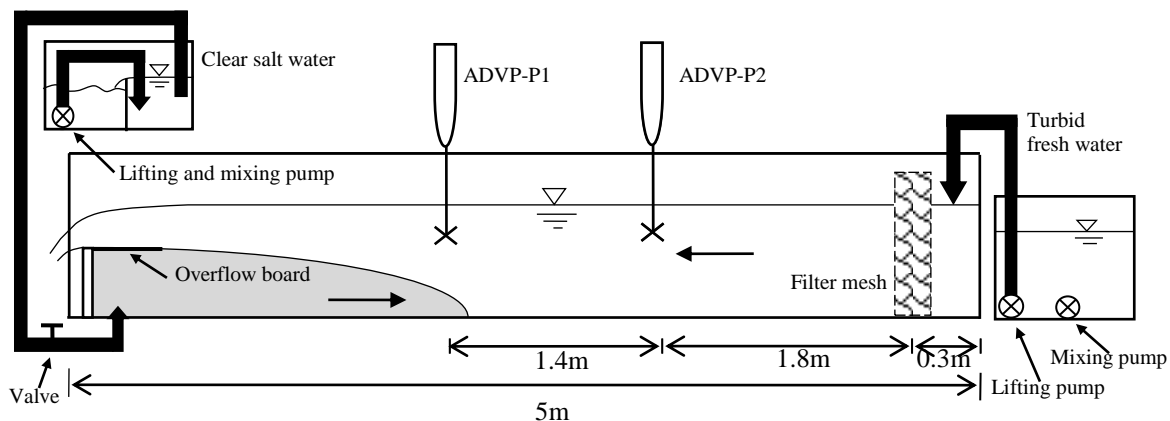

Figure 1. Side view of the experimental set-up (not to scale).

As shown in figure 1, two sets of ADVP (Nortek Vectrino Profiler of 10MHz), called P1 and P2 respectively hereafter, are used in the experiments. Their sampling frequency is set to be 100 Hz. The probes are 7cm away from the bed, with a 3 cm measuring section above the bed due to the blind area of 4 cm adjacent to the probes. The layer thickness is set to be 2 mm for P1 and 1mm for P2 respectively. The particles in fresh water are non-cohesive quartz sand with an average size of 0.016 mm. The concentration of the muddy water is about 0.1 kg/m^3. The salinity is in range of 4-10 ppt. The flow depths are around 12 cm.

Previous studies have indicated that under the conditions of fine particles in low concentration (SSC<1 kg/m^3), there is a good positive correlation between the average backscattered sound intensity and the average sediment concentration [11]. According to our previous inversion experiments on the instruments, the measured AMP values of each layer have a strong temporal response to SSC variation while their spatial responses are weak. So the sediment concentration profiles can not be inverted directly before the correction between layers are found. Nevertheless, we put our focuses on time variation of the measured values of each layer to estimate the changes owing to the salt wedge intrusion.

3. Results and discussions

3.1. Longitudinal velocity and suspended sediment concentration

In the experiment, fitting analysis of the 3 cm velocity profiles of the upstream inflow near the bottom shows a logarithmic distribution. Large scale vortex are generated on the interface behind the salt head due to shear instability. Taking a representative run as example, the 5s averaged stream-wise velocities are shown in figure 2(a) and 2(b). Within the measuring zone, we take three layers at different height to represent the upper, middle and lower layers respectively, in which the middle is associated with the interface between the fresh and the salt. Before the wedge head, the velocities of each layer are

positive and nearly constant. During the head passage, the velocities of all layers of P1 and lower layer of P2 decrease rapidly owing to reverse movement of the denser and lower salt water. After the head, the velocities of the lower layers or in the salt water body become negative to be against the turbidity flow. The distributions of velocities indicate the characteristics of longitudinal circulation and exchange flow.
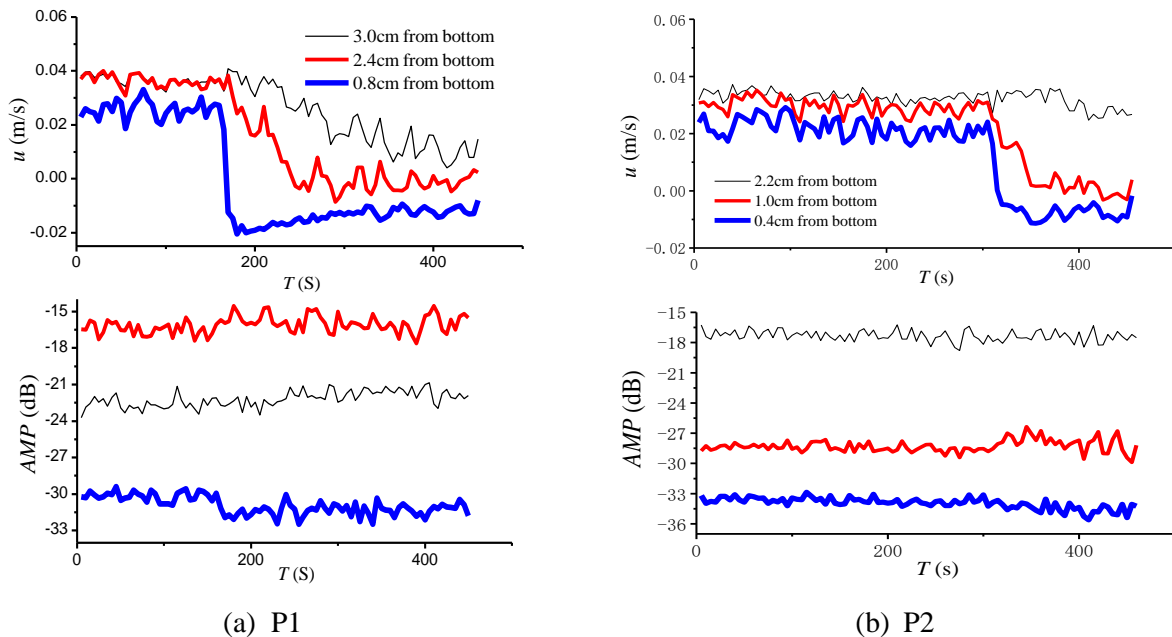

Figure 2. The processes of longitudinal velocities and related *AMP* values.

In figure 2(c) and 2(d), when the salt wedge did not arrive, *AMP* values of each layer don't have significant changes, indicating that *SSC* are stable. Despite the arrival of saline water, *AMP* values in the upper zone out of notable influences of the salt wedge, e.g. the upper layer of P2, have little changes. But, the positions certainly affected by the salt wedge have three types of *AMP* processes. (1) Around and above the interfaces, the *AMP* values increase gradually when the velocities began to decrease and the higher values maintain for some time. The increase intensity is the greatest around the interface i.e. at the middle layers where salt intrusion leads to near-zero velocities. (2) Where the salt wedge rapidly covers, e.g. the lower layers of P1 and P2, the *AMP* values decrease, indicating that the local flow is dominated by the low-sediment currents and not affected by the upper turbidity greatly. (3) In the positions between the above two cases, the variation of *AMP* values depend on the combined action of this two opposite effects. They may be enhanced, unchanged or declined after the salt head comes.

3.2. Spatial dynamic analysis

The instantaneous velocity u in longitudinal x direction and the instantaneous velocity w in vertical z direction are expressed respectively as

$$u = \bar{u} + u' , w = \bar{w} + w'$$

where $\bar{u}$ and $\bar{w}$ denote the average velocities, u' and w' the fluctuating velocities, respectively. If the flow density ρ is assumed to be constant, the vertical shear can be represented by the time-averaged velocity gradient $\partial \bar{u} / \partial z$, the turbulent shear stress by $\overline{u'w'}$ and the turbulent dissipation rate ε by $\overline{(\partial u'/\partial z)^2}$, where the top bar is for time-averaged operation.

In figure 3, the vertical distributions of some hydrodynamic indicators in 3cm near the bed are presented for three periods, i.e. before, during and after the intrusion head. Large shears usually occur

at two locations, near the bed and around the zero velocity layer. The former is caused by the influence of bottom boundary and the latter by the interface. Leaving the bed aside, the turbulent shear stresses are generally increased due to the effects of the salt wedge. At the upper layers after the head the stresses increase more than at the lower layers, which implies turbulence generated by the high shears has been transported upwards to some extent. However, the turbulent dissipation of each layer does not seem to change significantly with the existence of saltwater. It suggests that a number of large-scale vortex on the interface have not transformed to small-scale eddies yet.
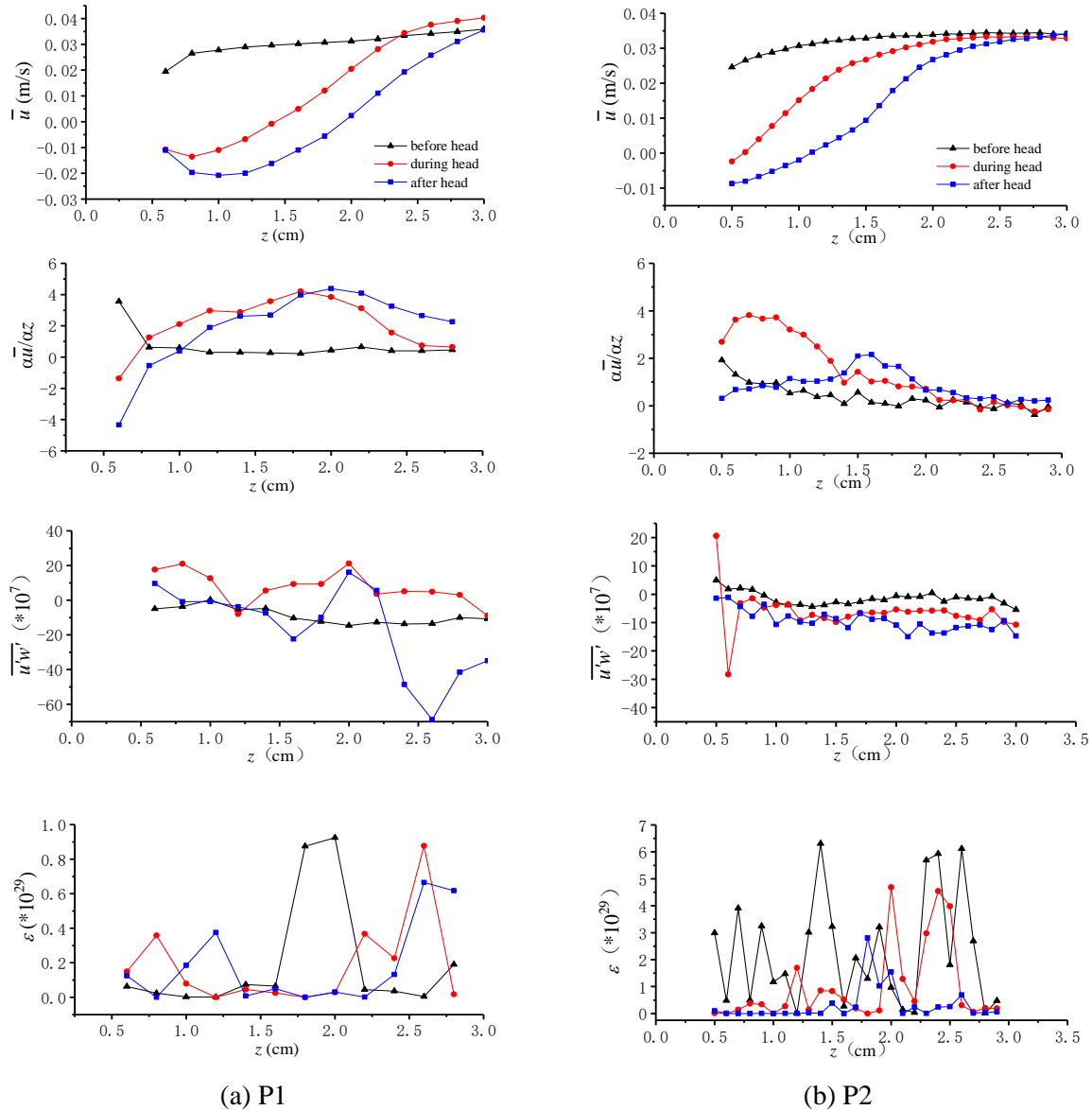

| (a) P1 | (b) P2 |

Figure 3. Vertical distribution of the flow dynamics.

4. Conclusion remarks
In the density currents of salt wedge in turbid ambient flow of our experiments, suspended sediment around the interface come from two sources, one from the near-bottom particles brought by the circulation near the head and the convergence of the upstream turbid flow and the other from settlement of the particles in upper layers. Although the velocities are close to zero on the interface, sediment particles can still be trapped in this region and carried on downstream because of the high

shears and consequent large-scale energetic vortices. Therefore, *SSC* herein increases most significantly and can maintain a considerable distance. Also, the large-scale vortices at the interface contribute to the upward turbulence transportation and decomposition, so it can be seen that the sediment suspension in the upper layers is enhanced but with an intensity weaker than on the interfaces. As a result, there are less sediment sinking into the lower layers and there is a low particle concentration in the salt body. The interface is like a hydrodynamic net to hold and support the sediment of the turbid flow over it. Despite strong shear and large-scale turbulence coming up around the interface, the turbulent dissipation does not grow much which may help to retain the energy of the flow.

In our experiments, the particles are fine and the concentration are small. Although the salt wedge interface facilitates the particle suspension and aggregation within a certain range, the sediment carrying capacity practically depends on the combined action of grain gravity and flow turbulence. If either or both of the particle diameter and concentration are large enough to allow them breaking through the interface and getting into the salt body, a number of deposition will likely occur owing to the weak turbulent diffusion.

References
[1]   Dyer, K. R. (1997) Estuaries: A Physical Introduction. John wiley & Sons Ltd, England. pp. 107-110.
[2]   Ralston, D. K., Geyer, W. R., Lerczak, J. A., Scully, M. E. (2010) Turbulent mixing in a strongly forced salt wedge estuary. Journal of Geophysical Research Oceans, 115(C12024): 1-19.
[3]   Yellen, B., Woodruff, J. D., Ralston, D. K., Macdonald, D. G., Jones, D. S. (2017) Salt wedge dynamics lead to enhanced sediment trapping within side embayment in high-energy estuaries. Journal of Geophysical Research Oceans, 122: 2226–2242.
[4]   Burchard, H., Baumert, H. Z. (1998) The Formation of Estuarine Turbidity Maxima Due to Density Effects in the Salt Wedge: A Hydrodynamic Process Study. Journal of Physical Oceanography, 28(2): 309-321.
[5]   Zordan, J., Juez, C., Schleiss, A. J., Franca, M. J. (2018) Entrainment, transport and deposition of sediment by saline gravity currents. Advances in Water Resources, 115:17–32.
[6]   Nogueira, H., Adduce, C., Alves, E., Franca, M. J. (2014) Dynamics of the head of gravity currents. Environment Fluid Mechanics, 14:519-540.
[7]   Dai, A. (2017). Experiments on two-layer density-stratified inertial gravity currents. Phys. Rev. Fluids, 2: 073802.
[8]   Bhaganagar, K., Pillalamarri, N. (2017) Lock-exchange release density currents over three-dimensional regular roughness elements. J. Fluid Mech., 832: 793-824.
[9]   Parker, G., Garcia, M., Fukushima, Y., Yu, W. (1987) Experiments on turbidity currents over an erodible bed. Journal of Hydraulic Research, 25(1): 123-147.
[10]   Janocko, M., Cartigny, M., Nemec, W., Hansen, E. (2013) Turbidity current hydraulics and sediment deposition in erodible sinuous channels: Laboratory experiments and numerical simulations. Marine and Petroleum Geology, 41: 222-249.
[11]   Thorne, P., Hurther, D., Moate, B. (2011) Acoustic inversions for measuring boundary layer suspended sediment processes. The Journal of the Acoustical Society of America, 130: 1188-1200.