

Experimental Investigation on Density Currents Propagating over Smooth and Rough Beds

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Abstract

Density currents occur when fluid of one density propagates along a horizontal boundary into fluid of a different density. They are also called turbidity currents when the main driving mechanism is from suspended sediments. Reservoir sedimentation is often related to sediment transport by turbidity currents. The leading edge of a density current is deeper than the following current and is called head or front. In this paper, the effects of bed roughness on density currents propagation were studied. Experiments were carried out over a smooth bed as well as three artificially roughened beds by cylindrical roughness elements. Temporal and spatial evolutions of the current front were analyzed. In experiments performed over rough beds, the measured head velocities were smaller than that of smooth bed. The observed trend is that as the surface roughness increases the front velocity decreases.

Keywords: Density Currents; Rough Bed; Cylindrical Roughness, Smooth Bed, Reservoir Sedimentation

1. Introduction

Density currents occur when a fluid flows into another fluid with a different density. The density difference can be due to a difference in temperature, salinity or to the presence of suspended sediments (Bombardelli *et al.*, 2009). Density currents are also known as turbidity currents when the main driving mechanism is gained from suspended sediments. A large variety of examples of density currents can be found in nature such as large scale atmospheric movements, thunderstorms outflows, sea breeze fronts, and snow avalanches (Kneller and Buckee, 2000). The industrial examples are oil spillage in oceans, waste water discharge in rivers and propagation of toxic gases in mines.

Dam construction creates a reservoir with extremely low velocity flow and as a result an efficient sediment trapping environment. One of the important features of a dam is its

useful life time, i.e. the time period when dam is in operation. The useful life time can be greatly influenced by reservoir sedimentation (Ghomeshi, 1995). Reservoir sedimentation can also block bottom outlets, reduce the capacity of reservoir and damages the dam power plants (Cesare *et al.*, 2001). Furthermore, some environmental problems can be posed by the reservoir sedimentation, for instance, the effects on water quality, aquatic life and nutrient supply at the downstream. According to what has been mentioned earlier, reservoir sedimentation and its governing mechanisms are major concerns.

According to Ohey (2003), reservoir sedimentation is often related to sediment transport by turbidity currents. Some countries including Malaysia are stricken by several major flood events during intense rainfall season and the sediment discharge of the rivers flowing into the reservoir is typically very high during floods (Diman and Tahir, 2012). As the turbid flood water flows into less dense water of the reservoir, the turbid inflow displaces the ambient water until it reaches a balance of forces and then it plunges under the water surface. This point is called plunge point and is typically located downstream of area of delta deposition in reservoirs. Thereafter, a turbidity current is formed which propagates over the reservoir bed. The current advances through ambient fluid by a front or head which is deeper than the following current and has a raised noise at its foremost point (Hacker *et al.*, 1996).

Managing reservoir sedimentation as a mean for preventing the loss of reservoir storage capacity is really vital for countries like Malaysia. Turbidity currents in reservoirs have the dominant effect on reservoir sedimentation and can unload or even resuspend bed materials during passage (Sequeiros *et al.*, 2010). Tackling sedimentation problems and improving reservoir operation require controlling the turbidity currents in dam reservoirs (Fan and Morris, 1992).

Retarding turbidity currents in reservoirs can be employed as a preventive measure in reservoir sedimentation management. This paper presents an investigation into the gravity currents moving over different rough beds. The main aim of this paper is to assess temporal and spatial evolution of density currents over rough and smooth beds through laboratory experiments.

2. Experimental Setup

The experimental apparatus consisted of three main components: the glass-wall flume, mixing system and head tank (Figure 1). The flume was 7.8 m long, 0.35 m wide and 0.7 m

deep with variable bed slopes. The flume was divided into two separate sections by a sliding vertical gate placed at a distance 0.8 m from the upstream end of the flume. The right part was filled with fresh water with density of ρ_1 , while the left portion was filled with saline water with the density of ρ_2 which was greater than ρ_1 . The fluid densities are presented in Table 1. Both sides were filled at the same depth. The depth of ambient fluid was kept constant during each experiment by a weir at the downstream end of the flume.

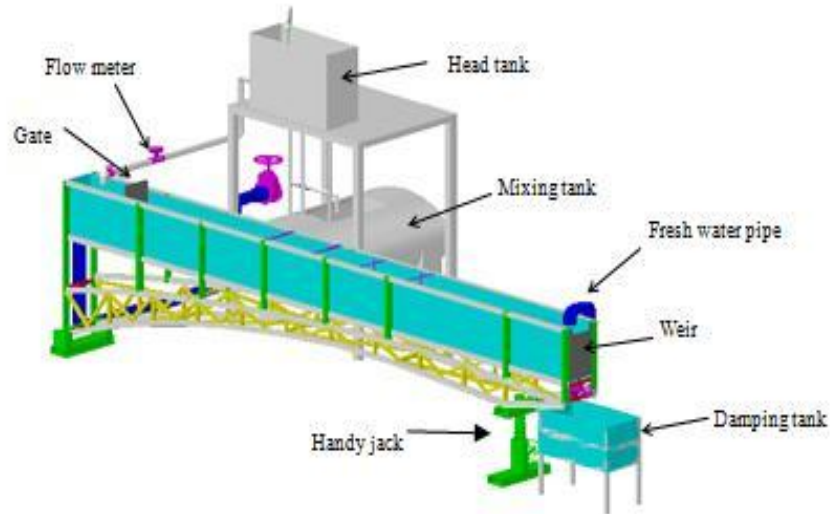


Figure 1: Schematic view of experimental apparatus

Table 1: Experimental parameters

Run	ρ_1 (kg/m ³)	ρ_2 (kg/m ³)	ϵ (cm)
1	1000.377	1013.637	0.0
2	1000.658	1013.136	1.0
3	1000.767	1013.960	2.5
4	1000.782	1013.885	4.0

Dense fluids were prepared in a mixing tank and then pumped into a head tank which was located above the mixing tank. The head tank was used for transferring the denser fluid to the flume with a fixed head. The flow discharge could be adjusted by the means of an electromagnetic flow meter prior entering the flume. The experiments started with the sudden removal of the gate and completed when the front reached the downstream end of the flume. The gate was opened 5 cm in all experiments. Four experiments were performed with a fixed discharge of 1 L/s, a bottom slope equals to 2% and initial concentrations were 20 g/L. Three

rough beds and a smooth bed were used in the experiments. The length of all rough beds was 3.75 m starting at 1.56 m from the gate. The desired roughness (ϵ) was obtained by gluing roughness elements on the bed in staggered form as depicted in Figure 2. Roughness elements were in cylindrical shape as illustrated in Figure 3. The evolution of the front was recorded by videotaping.

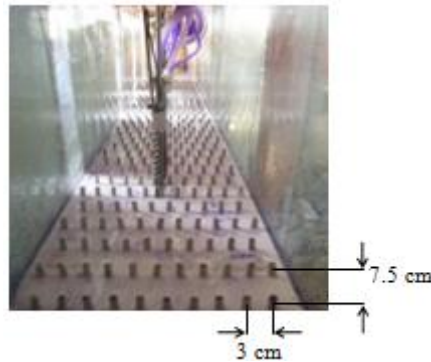


Figure 2: An artificially roughened bed using 2.5 cm roughness elements

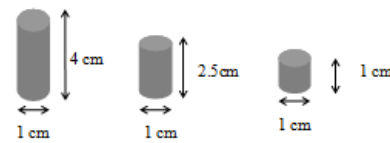


Figure 3: Illustration of geometric parameters of roughness elements

3. Results and Discussion

The temporal experimental front positions for all the experiments are illustrated in Figure 4. For a constant time, the gravity current moving over a smooth bed at a further distance than those moving on rough beds. This means that the speed of the gravity currents decreases as the bed roughness increases.

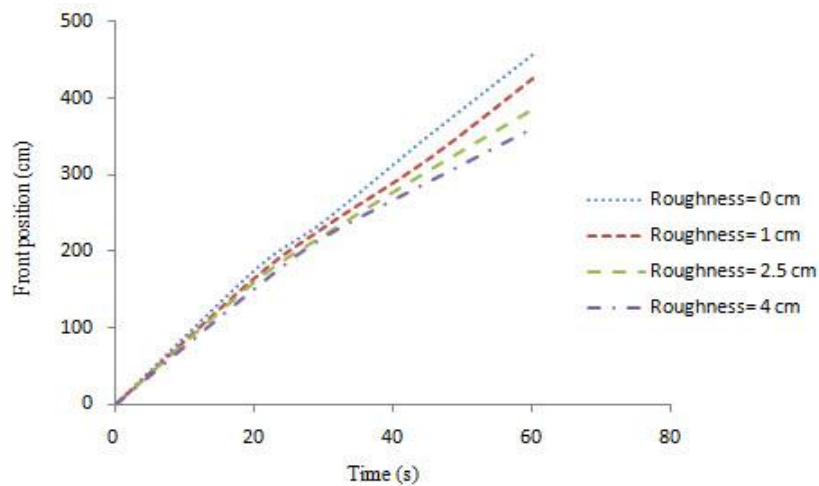


Figure 4: Front position versus time for all experiments

Figure 5(a) and (b) show the comparisons of the measured currents front profiles for all experiments. The profiles are shown at two different time steps (t) after release, i.e. $t=30$ S (Figure 5(a)) and $t= 60$ s (Figure 5(b)). The Figure 5(a) illustrates that 30 seconds after the gate opening experiments carried out over a smooth bed (Run 1), covered a distance of 238 cm. Over the same time, the covered distance for Run 2 ($\epsilon= 1$ cm) was 231 cm, for Run 3 ($\epsilon=2.5$ cm) was 221 cm and for Run 4 ($\epsilon=4$ cm) was 218 cm. This reveals that density current advances slower over rough beds. The friction between the density current and the floor are expected to increase with an increase in surface roughness, thus the influx of fresh water into the head rises. Driving force of density currents is the density difference between the current and ambient fluid. The entrainment of this extra fresh water into the front leads to a reduction in the front velocity.

Figure 5(b) demonstrates the front profiles 60 seconds after the gate opening. At this stage, the retarding effects of density current were more obvious, i.e. there was a larger gap between covered distances for different surface roughness. At this time, the gravity current for smooth surface covered 457 cm. Also, in terms of $\epsilon=1.0$ cm, $\epsilon= 2.5$ cm and $\epsilon= 4.0$ cm, the covered distances were 434 cm, 384 cm and 362 cm, respectively. Therefore, the distance that was covered by the gravity current decreases as the beds gets rougher. This figure shows that head enlarges with increasing surface roughness and this can be attributed to growing amount of entrained fresh water into the head. The influx of this extra fresh water into the head results in a reduction in the head density excess. Therefore, density current speed decreases by increasing surface roughness.

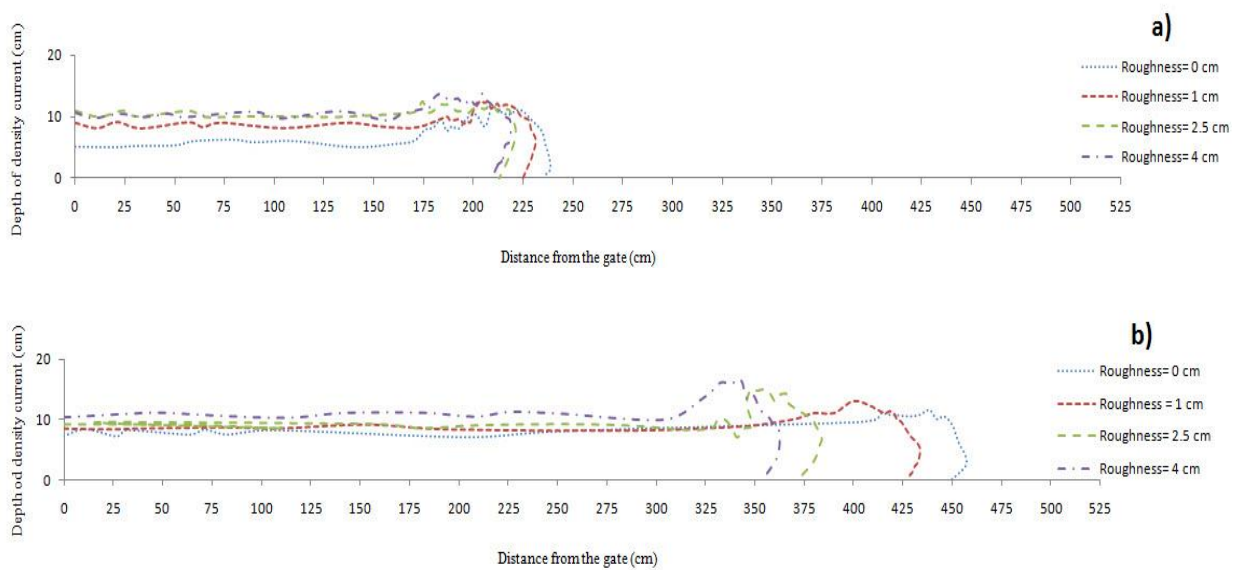


Figure 5: Comparisons of currents profiles at two different time steps: (a) $t=30$ s; (b) $t= 60$ s

Table 2 shows the mean frontal velocity of density currents propagating over the smooth and artificially roughened beds. This was observed that 1 cm roughness elements reduced the frontal speed 12.3% compared to the smooth bed. For 2.5 cm roughness elements, this velocity reduction was 27.3%. Regarding 4 cm roughness elements, the front speed was lowered by 40% in comparison to the smooth bed.

Table 2: Front mean velocity (U_f) for all experiments

Run	ϵ (cm)	U_f (cm/s)
1	0	7.27
2	1.0	6.38
3	2.5	5.29
4	4.0	4.40

4. Conclusions

This paper investigates, by laboratory experiments, lock exchange gravity currents propagating over both smooth and rough beds. In all the conducted experiments the initial density of the gravity current and bed slope were fixed, as three artificially roughened beds and one smooth surface were examined. In the experiments performed with rough beds, the measured front velocities were observed to be less than the head velocity over a smooth bed. The observed general trend is that an increase in bed roughness causes a decrease in the head speed. Also, the retarding influence of rough beds was analyzed by measuring the mean frontal velocities. It was found that surface roughness could reduce the frontal velocity up to 40% at 4 cm roughness elements.

References

- Bombardelli, F. A., Cantero, M. I., Garcia, M. H., and Buscaglia, G. C. (2009). Numerical Aspects of the Simulation of Discontinuous Saline Underflows: the Lock-exchange Problem. *Journal of Hydraulic Research*. 47(6): 777-789.
- Cesar, G.D., A. Schleiss and Herman, F. (2001) Impact of Turbidity Currents on Reservoir Sedimentation. *Journal of Hydraulic Engineering*. 127(1): 6-16.
- Diman, C. P. and Tahir, W. (2012). Dam Flooding Caused a Prolonged Flooding, *International Journal of Civil and Environmental Engineering*. 12(6): 71-75.
- Fan, J. and Morris, G. L. (1992) Reservoir Sedimentation II: Reservoir Desiltation and Long-term Storage Capacity. *Journal of Hydraulic Engineering*. 118(3): 370-384.
- Ghomeshi, M. (1995) *Reservoir Sedimentation Modelling*. PhD Thesis, University of Wollongong, Australia.
- Hacker, J., Linden, P. F. and Dalziel, S. B. (1996) Mixing in lock-release gravity currents. *Dynamics of Atmospheres and Oceans*. 24: 183-195.
- Kneller, B. and Buckee, C. (2000). The Structure and Fluid Mechanics of Turbidity Currents: A Review of Recent Studies and Their Geological Implications. *Journal of Sedimentology*. 47(1): 62-94.
- Oehy, C., (2003). *Effects of obstacles and jets on reservoir sedimentation due to turbidity currents*. Communication 15, A.J. Schleiss, ed., Laboratory of Hydraulic Constructions, Ecole Polytechnique Fédérale de Lausanne, Lausanne, Switzerland.
- Sequeiros, O.E., Spinewine, B., Beaubouef, R.T., Sun, T., Garcia, M.H. and Parker, G. (2010) Characteristics of velocity and excess density profiles of saline underflows and turbidity currents flowing over a mobile bed. *Journal of Hydraulic Engineering*. 136(7): 413-433.