Experiments on Density Currents Dynamics over Conic Roughness Elements

R. Nasrollahpour[1, a], M. H. Jamal[2, b], M. Ghomeshi[3, c], P. Roushenas[4, d]

[1,2,4] Department of Hydraulics and Hydrology, Faculty of Civil Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia
[3]Professor, Department of Hydraulic Structures, Faculty of Water Sciences Engineering, Shahid Chamran University of Ahvaz, Ahvaz, Iran

(E-mail: [a]nreza7@live.utm.my, [b]mhidayat@utm.my, [c]ghomeshi@scu.ac.ir, [d]rpeiman2@live.utm.my,)

Keywords: Density current, Conic roughness, Bed roughness, Reservoir sedimentation

Abstract. Density currents are flows driven by density differences caused by suspended fine solid material, dissolved contents, temperature gradient or a combination of them. Reservoir sedimentation is often related to sediment transport by density currents. This sedimentation can block bottom outlets, reduce the capacity of reservoir and harms the dam power plants. The head is the leading edge of density currents. In this paper, the influences of artificially roughened beds on dynamics of the frontal region of density currents are investigated experimentally. Three rough beds using conic roughness elements and a smooth bed were tested. The observed trend is that as the surface roughness increases the head concentration and velocity decreases.

Introduction

Density currents occur when fluid of one density propagates along a horizontal boundary into fluid of a different density [1]. The density difference can be created by suspended materials, temperature gradients, dissolved contents or a combination of them. These currents are also called turbidity currents when the major driving force is gained from suspended sediments.

Turbidity currents are the main sedimentation mechanism in dam reservoir and can unload or even resuspend bed materials [2]. Turbidity currents reduce reservoir storage volume by sedimentary deposition, pose the risk of blocking water intake structures and facilitate sediment entrance into dam power plants [3]. 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 [1].

In dam reservoirs, density currents are usually underflows which consist of three main parts: plunge point, body and head. The front is the leading edge of turbidity currents which is deeper than the following flow and has a raised noise at its foremost point. The head can be described as a mixing area. There are two major kinds of instabilities that are responsible for mixing in the front [4]: firstly, Kelvin-Helmholtz billows which are responsible for mixing at the end of the head. These types of billows are created at the interface between two fluids of different density, moving relative to each other. Secondly, a shifting pattern of lobes and clefts that is caused by the displacement of ambient fluid by the head. In [5], head velocity was expressed as a function of head height and reduced gravity. The head height increases with slope, because the body velocity increases and materials move more rapidly into the head [6]. The deposition process reduces the head speed and increases the thickness of current front [7]. In [8], it was shown that turbidity currents by a large flood could entrain considerable amounts of existing sediment deposits and transport it to an area of deposition near the dam. They also reported that the optimal opening time of the bottom outlets can be determined in order to pass a significant proportion of sedimentary depositions by the means of turbidity currents during floods. The front into three distinct regions by [9]: energy-conserving region, dissipative wake region and tail. They concluded that only the energy-conserving region has a velocity roughly equal to the front speed. The key role of bed materials in self-reinforcing mechanism of the head was discussed in [2]. A self-a1ccelerating current is a particle-driven gravity current whose velocity goes up as moving downstream. It means that the gravity current erosion of bed materials is more than its deposition onto the bed. The suspended materials increase the density and thus the speed of the current. In [10], experiments were performed with a smooth bed as well as two rough beds (ε=0.7 and 4.5 mm) that were made out of sand. They noticed that as the roughness increases the head velocity decreases.

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 [2]. Tackling sedimentation problems and improving reservoir operation require controlling the turbidity currents in dam reservoirs [3]. The main objective of this paper is to investigate the retarding influence of conic roughness elements on density current dynamics.

Materials and Methods

The experimental apparatus had three main parts: glass-wall flume, mixing system and head tank. The flume was divided into two parts by a sliding vertical gate. The flume was divided into two parts by a sliding vertical gate placed at a distance of 0.8 m from the upstream end of the flume. The left part was filled with dense fluid, but the right part was filled with tap water. The height of ambient fluid was kept constant during each experiment through a weir at the downstream end of the flume. Dense fluids were prepared in a mixing tank and pumped to a head tank which was installed above the mixing tank. The head tank was employed for transferring the dense fluid to the flume with a fixed head. The flow discharge could be adjusted via an electromagnetic flow meter before entering to the flume.

The experiments lunched with the sudden removal of the gate and ended as the front reached the downstream end of the flume. Experiments were performed with a fixed discharge of 1 L/S, a bottom slope of 0.5% and dense fluids with the initial concentrations of 10 g/L.

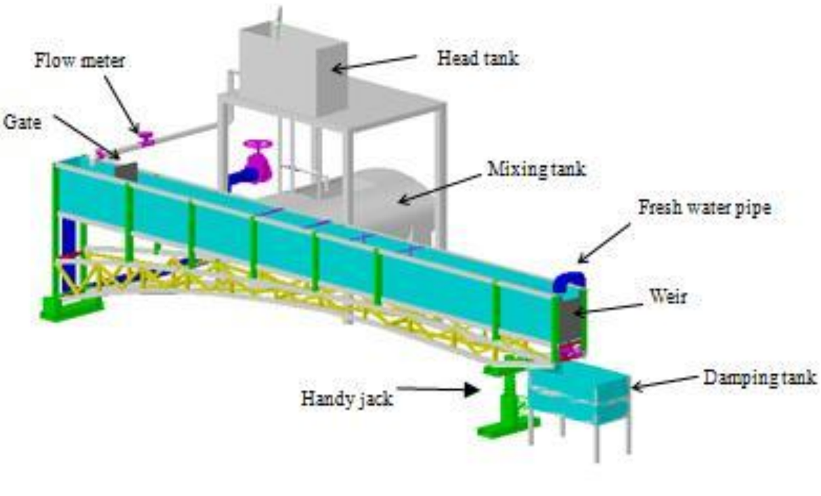

Fig. 1. Experimental apparatus

Three rough beds and smooth bed were employed in the experiments. The needed roughness was created by gluing conic roughness elements on the bed in staggered form. The length of all rough beds was 3.75 m starting at 1.56 m from the gate. Figure 2 illustrates geometry of roughness elements and Figure 3 illustrates a roughened bed using 2.5cm conic roughness elements.

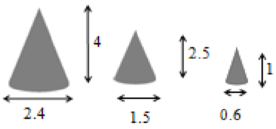

Fig.2. Roughness elements

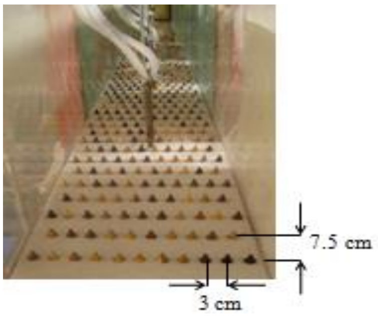

Fig. 3. Rough bed

Results and Disscussion

Concentration

Figure 4 was drawn to investigate the influence of roughness elements on the frontal concentration. For all the experiments, the frontal concentration decreases moving in the downstream direction. This is due to growing amount of entrained fresh water into the head moving downstream-wise. Also, the head is of less concentration as the bed roughness increases. This shows that as the surface gets rougher the influx of ambient fluid into the head increases.

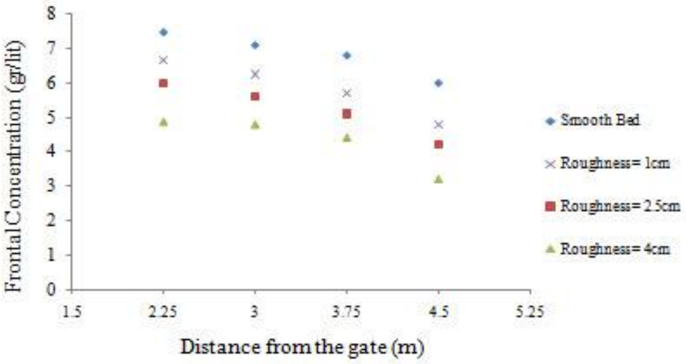

Fig. 4. Variations of head concentration along the flume

Velocity

Figure 5 shows head velocity for smooth and rough beds. For all beds, the head velocity decreses in the downstream direction. The head is an area of intense mixing and entrainment of ambient fluid into the head lessens the density difference moving in the downstream direction d and thus the head speed reduces.

It is observed that all conic roughness elements managed to decrease the head velocity in comparison with the smooth bed. Moreover, the head velocity falls as the surface roughness increases. The driving force of density currents is the density difference between the current and ambient fluid. The increased surface roughness facilitates entrainment and hence the head velocity drops.

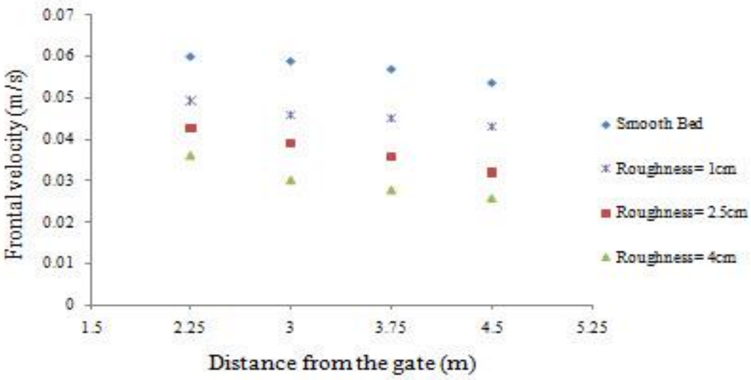

Fig. 5. Variations of head velocity along the flume

Table 1 illustrates the mean frontal velocity of density currents propagating over the smooth and three rough beds. This was seen that 1 cm roughness elements reduced the frontal velocity 19.3% compared to the smooth bed. For 2.5 cm roughness elements, this velocity reduction was 35%. Regarding 4 cm roughness elements, the frontal speed was lowered by 47.4% in comparison to the smooth bed. The front velocity reduces at a higher rate as the surface roughness increases.

Table 1. Front mean velocity for all the experiments

Bed Roughness (cm)	**Frontal Velocity (cm/s)**
0	5.7
1	4.6
2.5	3.7
4	3

Conclusions

This paper investigates 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. Three artificially roughened beds and one smooth surface were examined. The frontal concentration declines while moving in the downstream direction. The head concentration decreases as the surface roughness increases. The head velocity has a downward trend moving along the flume. The head velocity diminishes with increasing the roughness. Also, the retarding influence of rough beds was analyzed by measuring the mean frontal velocities. It was found that surface roughness reduce frontal velocity up to 47.4% at 4 cm roughness elements.

References

[1] J. Hacker, P.F. Linden, S.B. Dalziel, Mixing in lock-release gravity currents, Dynamics of Atmospheres and Oceans. 24 (1996) 183-195.

[2] O.E. Sequeiros, H. Naruse, N. Endo, M.H. Garcia, G. Parker, Experimental study on self-accelerating turbidity currents. Journal of Geophysical Research. 114 (2009).

[3] J. Fan, G.L. Morris, Reservoir sedimentation II: reservoir desiltation and long-term storage capacity, Journal of Hydraulic Engineering. 118 (1992) 370-384.

[4] J.E. Simpson, Gravity Currents: in the Environmental and Laboratory.” Ellis Horwood Press, Chichester, 1979.

[5] M. Ghomeshi, Reservior sedimentation modelling.” PhD Thesis, University of Wollongong, Australia, 1995.

[6] R.E. Britter, P.F. Linden, The motion of the front of a gravity current travelling down an incline. Journal of Fluid Mechanics. 99(3) 531-543, 1980.

[7] S. Altinakar, W.H. Graf, E.J. Hopfinger (1990), Weakly depositing turbidity current on a small slope, Journal of Hydraulic Research. 28 (1) 55-80, 1990.

[8] G.D. Cesar, A. Schleiss, F. Herman, Impact of turbidity currents on reservoir sedimentation. Journal of Hydraulic Engineering. 127(1) 6-16, 2001.

[9] R.J. Lowe, P.F. Linden, J.W. Rottman, A laboratory study of the velocity structure in an intrusive gravity current.” Journal of Fluid Mechanics. 456, 33-48, 2002.

[10] C. Adduce, V. Lombardi, G. Sciortino, M. Morganti, Roughness effects on gravity currents dynamics, Proceedings of 33rd IAHR Congress, Vancouver, 2009.