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EXTENDED ABSTRACT

Experimental Investigation of Water Entrainment of Salty Density Current Over the Bed with Cubic Roughness

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Introduction

Each year rivers transport a lot of sediments, especially for flood times, to dams' reservoirs and the main cause for this transportation is density current phenomenon. This phenomenon forms when a liquid with a density of ($\rho_d = \rho_a + \Delta\rho$) flows in another liquid with density of (ρ_a). This density deference could be due to the temperature, or dissolve solids, or suspended solids deference or a combination of them (Graf and Altinakar, 1998). Vargavand (2013) made a density current using the solution of water and salt and investigated the effect of a bed with cylindrical and conical roughness on water entrainment coefficient. His results showed that the water entrainment coefficient not only affected by Richardson number but the height of bed roughness is also an important parameter. Daryaee (2014) investigated the water entrainment coefficients for four bed slopes, two sediment concentrations and four different bed roughness height in a sedimentary density current. The results of this research showed that by increasing roughness height velocity decreases and this increases Richardson number and a result water entrainment coefficient decreases. However, roughness blocks cause for more turbulent flow which extended up to interface of density current and ambient water and this phenomenon makes more water entrainment.

The aim of this research is to investigate the effect of bed roughness, bed slope, and hydraulic parameters of density current such as flow rate and concentration on water entrainment of a salty density current.

Methodology

Three flow rates of (0.6, 0.9 and 1.2 lit/s), three bed slopes of (0, 1.7 and 3.4%), four bed roughness heights of (0, 5, 10, and 15mm) were the main variables in this study. Experiments were conducted in a tilting flume with 800cm long, 35cm width and 70cm height with density current being provided using a solution of water and salt with a constant concentration of 20 gr/cm^3. The cubic blocks with dimensions of 1.5×1.5cm with desired height were used in bed as roughness elements and were distributed in zigzag pattern with an average of 25% surface coverage. Velocity profiles from body of density current were measured using DOP2000 and two siphon series were designed to be able to provide samples from the whole entire flow depth. Concentrations were measured using an EC meter, HACH model, and a calibrated mathematical equation which relates EC and concentration.

Dimensional analysis was carried out using the well-known π theorem and the following equation is proposed:

$$E_w = f(\frac{k_s}{h}, \frac{q_0}{Uh}, R_i) \quad (1)$$

Where, E_w refers to water entrainment coefficient; $\frac{k_s}{h}$ is relative roughness; k_s is the height of cubic blocks; h states for body depth of current; Uh is density current rate at the unit width for body of flow; U is the average velocity of density current body; $\frac{q_0}{Uh}$ refers to relative discharge; q_0 is the inlet discharge of density current; $R_i = \frac{g'hcos\theta}{U^2}$ is Richardson number; g' refers to reduced acceleration due to gravity (=$g\Delta\rho/\rho$); θ is the bed slope.

Results and Discussion

The effect of bed roughness on water entrainment is shown in Figure 1. The average water entrainment coefficients for different inlet flow rates and bed slopes were calculated and are illustrated against Richardson number for four bed roughness elements in Figure 1. As many researchers reported in the literature it is found that water entrainment coefficient has adverse relationship with Richardson number. This figure also shows that for the same Richardson number water entrainment coefficient increases with increasing bed roughness and this is due to more turbulence along the depth of flow and this causes for more water entrainment. However, the results showed that by increasing bed roughness the velocity of body decreases and as a result Richardson number increases and this means lower water entrainment. Increasing inlet flow rate and concentration of density current have direct effect on water entrainment coefficient. Because increasing both parameters make higher velocity and lower Richardson number and this phenomenon increases water entrainment.

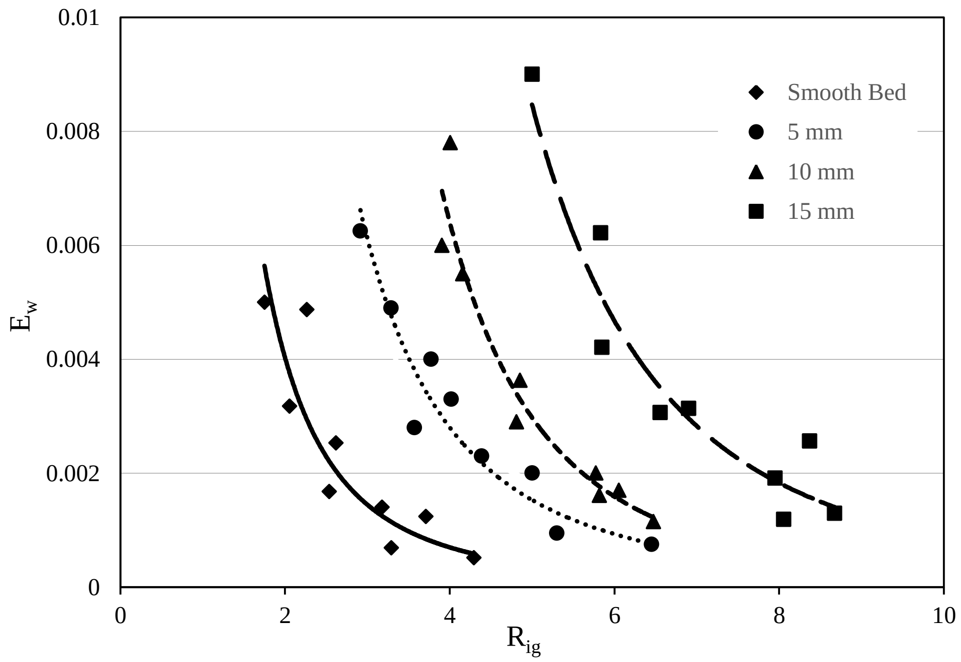

Fig 1- Water entrainment coefficient for different Richardson Number and bed roughness

An equation was developed using regression analysis and SPSS statistical model describing the relationship between water entrainment coefficient and the parameters considered. This equation may be written as:

$$E_w = \left[\frac{-0.009 + 0.036\dfrac{q_0}{Uh} + 0.046\dfrac{k_s}{h}}{R_i^{1.88}} \right] \tag{2}$$

Conclusions

Density current and its characteristics are always affected by hydraulic and geometric parameters. One of the main properties of density current is water entrainment which causes to decrease the concentration of density current when the current progresses in dam reservoir towards the body of dam. In this study a series of experiments were designed and conducted with the main variables affecting water entrainment coefficient being inlet density current discharge, bed slope and bed roughness. It was found that by increasing bed slope from 0% to 3.4% water entrainment coefficient increases in average of 36%. Also with increasing inlet density current discharge from 0.6 to 1.2lit/s the average of water entrainment coefficients for all bed slopes and bed roughness heights shows an increasing about 51%. For the same Richardson number increasing bed roughness height from 0 to 15mm shows an increase of about 42%.

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