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Effect of Entrance Froude Number on Vertical Distribution Velocity and Concentration in Turbidity Current Using Experimental Study

EFFECT OF ENTRANCE FROUDE NUMBER ON VERTICAL DISTRIBUTION VELOCITY AND CONCENTRATION IN TURBIDITY CURRENT USING EXPERIMENTAL STUDY

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ABSTRACT

Sedimentation process and accumulation of a reservoir due to turbidity current hazards economical life of the associated dam gradually. Hence, sediment removing management from the reservoir by turbidity current hydrodynamic force through understanding of turbidity current's properties can play an important role in increasing the economical life of dams. In the present study, the effect of entrance Froude number of turbidity current in sub and super critical conditions (Fr =0.6-3.5) have been tested through effect of change related to opening entrance valve, bottom slope of the reservoir, and entrance turbidity current's concentration on vertical distribution velocity and concentration under two dimensional flow conditions. The examined parameters are vertical distribution of flow velocity and concentration measured by two Acoustic Doppler Velocitimeters (ADV). The effect of channel slope changing is tested in two cases of 1% and 2%. The results show that value of vertical distribution concentration increases by decreasing of reservoir bottom slope and decreases in the longitudinal direction. In addition, the value of velocity is decreased longitudinally, whereas depth of turbidity current is increased. furthermore, a reduction in entrance concentration influence value of densimetric Fr number to increase.

Keywords: turbidity current, vertical distribution velocity and concentration, experimental study, densimetric Froude number.

1. INTRODUCTION

Gravity and density current are flows driven by density differences Turbidity currents are types of gravity currents where the driving force is gained from suspended sediments and turbid water made heavier than the clear water above it. Turbidity currents in dam reservoir usually are produced during a flood in a reservoir of high bottom slope (greater than 0.001) and low width As the river entered the reservoir, the muddy water plunged on the foreset, forming a turbidity current. The turbidity current deposits, in turn, formed a bottomset (Toniolo and Schultz., 2005). Recognition of deposition process, the value of monthly entrance sediment, sediment distribution in reservoir can help us to operate and utilize dams optimally and sediment emission in pattern of turbidity current hydrodynamic. Geological observations show turbidity currents to be a common form of sediment transport in many sedimentary basins (Hay, 1987). Therefore, survey and study of turbidity current in dam's reservoir can gives us useful information.

Density current or gravity current is the current with different density from ambient flow. This current is created due to different density on gravity acceleration, until g is changed by R=dρ/ρ in which $d\rho=\rho_t-\rho_a$ and ρ_a is the density of ambient flow, ρ_t is the density of gravity current. This difference between the density of gravity current fluid and static ambient fluid can stimulate by different in temperature, salinity and existence of the suspended sediment in gravity current (Altinakar *et al,* 1990). So the density current receptacle of solid particle is entitled turbidity current (Turner, 1973):

$$g' = g\left[\frac{\rho_s - \rho_a}{\rho_a}\right].C_s = g.R.C_s \quad (1)$$

where g' is reduced gravity acceleration and C is layer-averaged current volumetric concentration.

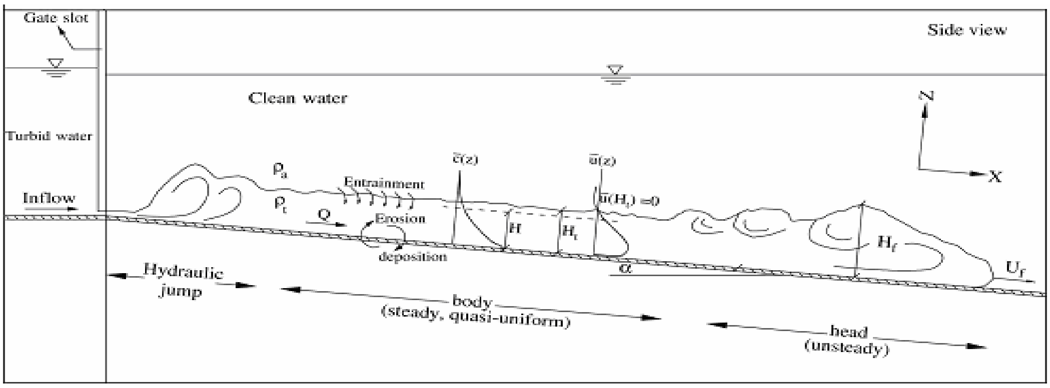


Figure 1 A schematic diagram of turbidity current

Oldest observation in turbidity current in nutural-scale was carried out by Forel in 1892 on GENEVA river (De Cesare *et al*, 2001). Generally, turbidity current's study in natural-scale under the heavy bulk water is too difficult and expensive. Also due to much access that is exerted in result analysis, using of them is not categorical (Bradford & Katopodes, 1999). Thus most the available studies on turbidity currents are due to experimental or mathematical model studies. Most of these surveys are in 2-D form. For example, we can refer to survey by (Bonnecase et al, 1993), (Altinaker et al, 1996), (Lee & Yu, 1997), (Yu et al, 2000). A 3-D survey was done by (Alavian, 1986) and it was extracted the trait of turbidity current. In another study the plunge point's Froude number was notify by (Lee & Yu., 1997). The role of fine-grain sediment in turbidity current and increasing in conveyance capacity of coarse-grain sediment was studied by (Salaheldin et al, 2000). One numerical model of turbidity current was proposed and compared by (De Cesare *et al*, 2001) with observation result of experimental model and natural-scale in LOZZON. Kubo and Nakajima studied in both experimental model and numerical simulation on sediment wave array due to turbidity current (Kubo & Nakajima, 2002). Felix studied Combined measurements of velocity and concentration in experimental turbidity currents. The similarity of changes in velocity and concentration at the same measurement heights are described and it is shown that the similarity depends on flow concentration and position in the flow (Felix *et al*, 2005). In another survey, water and sediment's exchange in the harbor through a 3-D experimental model was studied by (Stoschek & Zimmermann, 2006). In addition, Parker and Toniolo found Froude number just correlated with ambient flow entrainment coefficient during their study on height of turbidity current and plunge point Froude number (Parker & Toniolo, 2006). Also Fukushima did study on turbidity current motion. His result shows that entrance concentration increasing redounds to increase in horizontal extension but in great slope this concentration increasing does not affect. In addition, an increment in both bottom slope and concentration cause head velocity to increase (Fukushima & Hayakawa, 1995).

In the present research, the effect of reservoir bottom slope, opening height of entrance underneath valve and entrance concentration on hydrodynamic of turbidity current are studied by a 2-D experimental frame work. Any alteration in each of the control parameters influenced the entrance densimetric Froude number to change. Hence, the vertical distribution of velocity and concentration are objectives to analyze through measurements made by Acoustic Doppler Velocimeter (ADV).

2. EXPERIMENTAL SETUP AND PROCEDURE

The experiments were run in a channel with 12 m-long, 0.2 m-wide and 0.5 m-high that is limited by wall glass in the one side and marble stone wall in the other side. One step by 0.5 m-high and 0.35 m-wide constructed in downstream of the channel, prevent the back water to develop in the up stream channel. In each test, turbidity current is introduced from underneath valve into tap water of resource and continues it's motion as underflow longitudinally. The effect of channel slope changing is tested in two cases of 1% and 2%. Opening of underneath valve in the height of 4 and 7 cm and changing of entrance concentration flow could change dense metric Froude number. The flume was filled with tap water before each experiment. There is a tank with a total volume of 2 m^3 in 2.5 m from bottom laboratory of water and sediment mixture. On the mixing tank, there is a cubic tank with 0.5m height and 0.8 width in the stable distance from bottom of laboratory that water and sediment mixture is entered to it by a pump from sustenance tank. In this way, the current could be in a quasi-steady condition. The turbid water is released from a gate valve on the supply pipe into the inlet box. In channel upstream there is a lacuna (inlet box) with 10 cm length that is segregated by metal wall. Metal wall butt was setup in 4 cm and 7cm from the bottom of channel as underneath valve in different experiments. Prior to each experiment, the lacuna was blocked by a gate that segregates water and sediment mixture from tap water in the flume. In start of each experiment, this gate voids from channel and lets to turbidity current that enter to tap water of channel under the metal wall butt. When the sediment was thoroughly mixed with water in the mixing tank, a gate valve on the supply pipe was opened and the experiment was started by allowing the dense fluid (suspension) to flow into the main tank and the turbidity current generated. At the end of the tank the turbid water was drained out thorough the drain bottom in downstream step. The experimental set-up is illustrated in Figure 2.

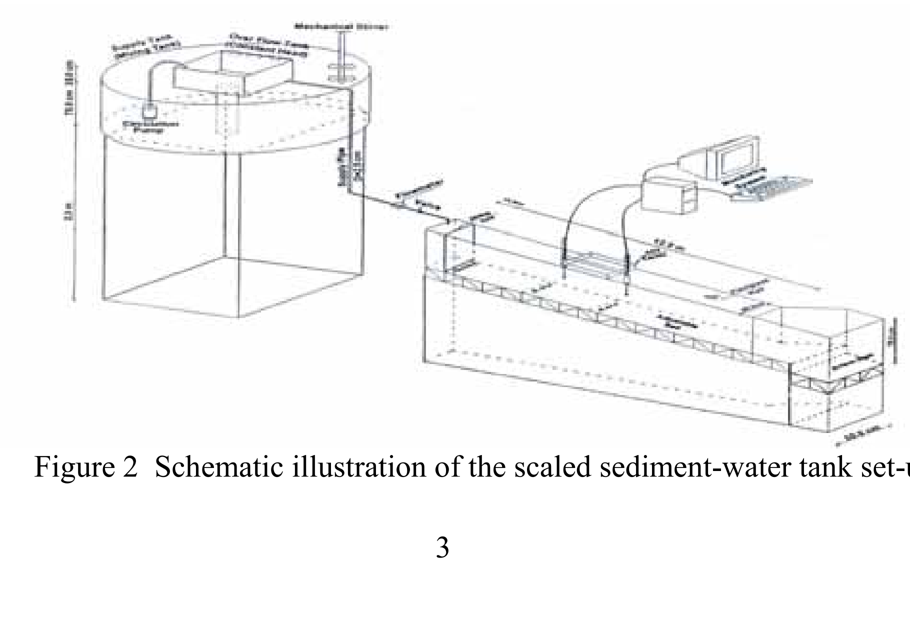


Figure 2 Schematic illustration of the scaled sediment-water tank set-up.

Kaolin with the specific gravity of 2.65 was used as the adhesive suspended material. The mean particle diameter is D_{50} = 0.02 mm. A constant water discharge of 35 L/sec used in all tests.

The initial bulk density of the dense fluid is alterable but always less than 1008 kg/m^3. The mixture is assumed to be a Newtonian fluid. A total of 13 successful experiments are carried out. The experimental conditions and some test properties are summarized in Table1. Vertical velocities were measured in this station in the centre of the insert channel by using 2 Acoustic Doppler Velocimeter (ADV). ADV is a useful tool for measuring all three components of velocity in laboratory and field environments. This instrument is commercially available and in recent years it has been replacing the previously developed flow meters. For a further description see Hosseini et al (2006), who also used this technique in turbidity currents. These ADV's are mounted on the carrier, used for velocity measurement. Also one of the most widely measured parameters of turbidity currents is the concentration. In present study the profile of concentration were measured by ABS method that needs to calibration by measuring with siphon-sampling of concentration in vertical axes.

In each experiment ADV's measure 20-22 point of vertical profile in center line of channel and this measurement was done from top to down of vertical profile. After 20–30 s of data acquisition, the probes are moved downward to the next measurement position until the profile is completed. The total duration of each experiment is about 60 min. All of these measuring were done in center line of the experimental channel.

Table 1 Summary of test's Characteristic

Exp. No	Q (lit/min)	a (m)	Slop (%)	C_0 (g/lit)	ρ_t (kg/m3)	Fr_0	Ri_0	Re_0
TS2A4C65	35	0.04	2	6.5	1004.05	1.86	0.29	2751.91
TS2A4C25	35	0.04	2	2.5	1001.56	3	0.11	2759.13
TS2A4C175	35	0.04	2	1.75	1001.09	3.6	0.08	2760.49
TS1A4C65	35	0.04	1	6.5	1004.05	1.86	0.29	2751.91
TS1A4C25	35	0.04	1	2.5	1001.56	3	0.11	2759.13
TS1A4C175	35	0.04	1	1.75	1001.09	3.6	0.08	2760.49
TS1A7C25	35	0.07	1	2.5	1001.56	1.3	0.59	2759.13
TS1A7C175	35	0.07	1	1.75	1001.09	1.55	0.42	2760.49
TS1A7C1	35	0.07	1	1	1000.62	2	0.25	2761.84
TS1A7C1175	35	0.07	1	11.75	1007.32	0.6	2.78	2742.38
TS1A7C85	35	0.07	1	8.5	1005.29	0.7	2.04	2748.28
TS1A7C65	35	0.07	1	6.5	1004.05	0.8	1.56	2751.91
TS1A7C42	35	0.07	1	4.2	1002.62	1	1.00	2756.08

3. EXPERIMENTAL RESULTS

3.1. Velocity profiles

In this study, the experiments were formed in terms of densimetric Froude number of entrance turbidity current yielding sub and super critical flow conditions. Generally, reservoir bottom slope does not have important effect on densemetric Froude number. However, concentration and opening height of underneath valve's entrance may strongly affect on densemetric Froude number of entrance turbidity current.

Figure 3 shows vertical distribution of velocity in 5.5 m downstream from the upstream end of the reservoir. This comparison is made between height of entrance underneath valve opening in constant reservoir bottom slope and entrance concentration. As seen in the legend of the Figure, Fr decreases when opening height of underneath valve increased and vise versa. In low concentration, i.e. up to 2.5 g/L, when Fr is large, i.e. the opening height of underneath valve is 4cm, the maximum velocity reduced by a factor of 15 to 20% once compared with the case of 7cm valve opening height. These effects are not significant in the case of denser concentration, i.e. C=6.5 g/L.

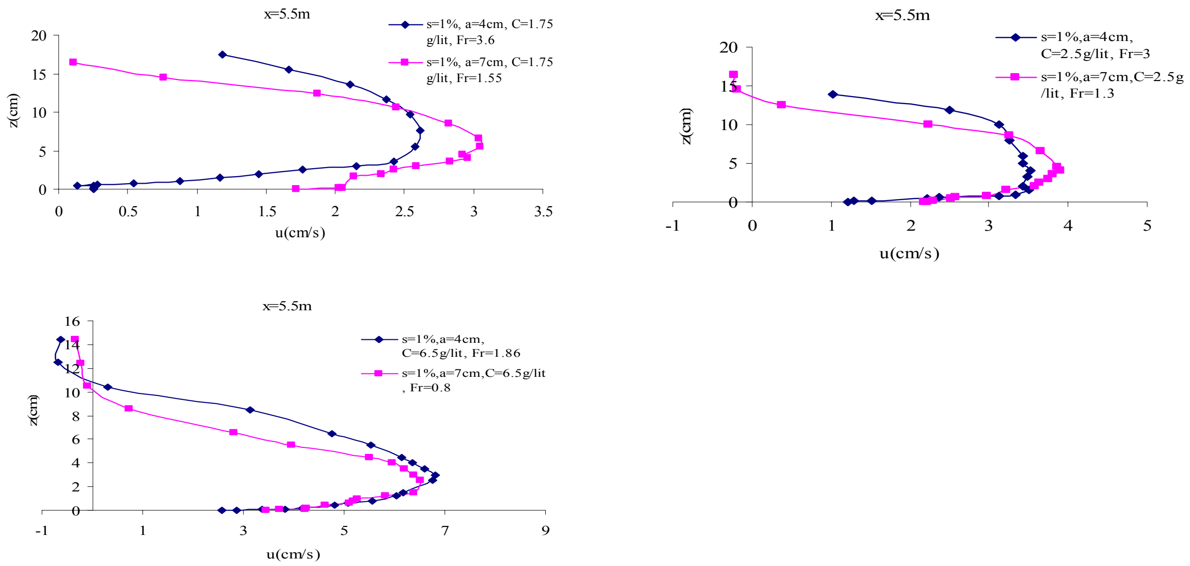


Figure 3 Effect of opening height of entrance valve on vertical current velocity distribution.

The effect of entrance concentration on vertical velocity profile is shown in Figure 4. As seen in the Figure, the effect of entrance concentration in super-critical condition are more obvious than sub critical entrance current. In this condition, the vertical velocity profiles are in recumbent form and the maximum velocity is increased by a factor of nearly 25 to 40% depending on the entrance current Fr. All of these profiles are measured in 5.5m downstream the entrance underneath valve, since the profiles become stable in this section. In super critical conditions, the form of velocity profiles are influenced by entrance current concentrations. When entrance current concentration are changed from 2.5 to 1 g/L in 7cm opening height, (i.e. Fr=1.3 to 2), the maximum velocity decreases from 4 to 2.5m/s (reduction of about 60%). Also, in 4cm opening height (i.e. Fr=1.86-3.6, 3.7) increasing in entrance concentration redound to a significant factor of reduction in maximum current velocity, i.e. a factor of about 1.8.

The effect of reservoir bottom slope on velocity vertical profiles is illustrated in Figure 5 in a constant entrance concentration, opening height and entrance Fr current. The effect of slope on a current with greater Fr due to less entrance concentration is vatly. When entrance concentration is 6.5 g/L and Fr is 1.86, slope changing does not have some effect (about 20% decreasing due to 1% slope reduction) but in less entrance concentration (2.5-1.75g/lit) or greater entrance current Fr (3-3.6), 1% slope reduction redounds to sequence 50-100% decreasing in maximum current velocity.

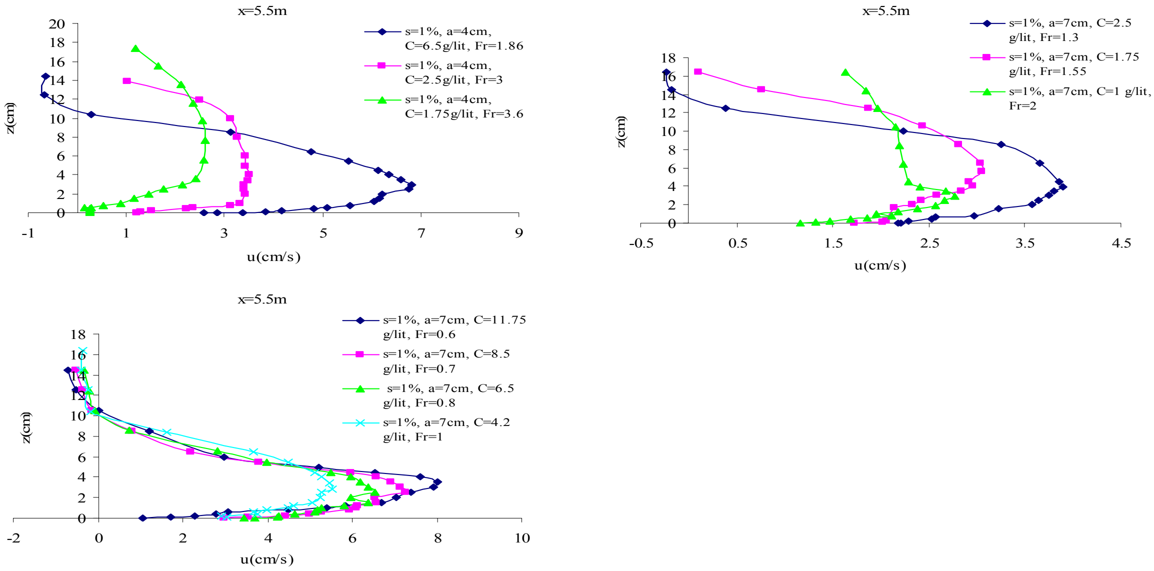


Figure 4 Effect of entrance concentration on vertical current velocity distribution in constant reservoir bottom slope of 1%.

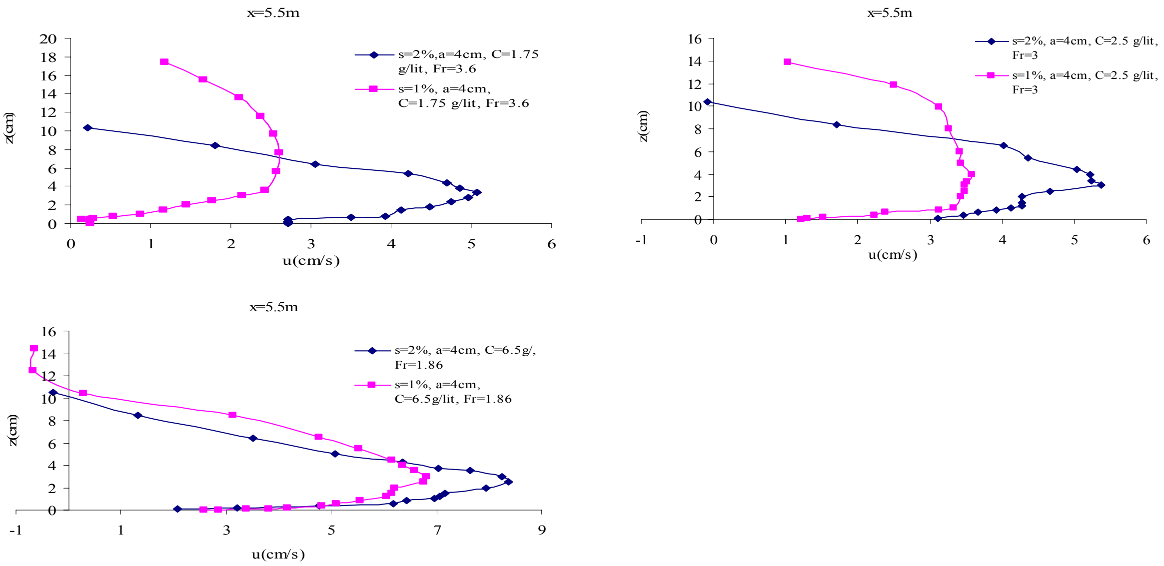


Figure 5 Effect of reservoir bottom slope on vertical current velocity distribution.

3.2. Concentration profiles

ADV works by measuring the reflection of an acoustic signal from particulate matter in water. While ADV is primarily used to measure the velocity of the particles. Also it can give us information about the sediment that is present. This information is measured in the form of the intensity of the reflections received, sometimes referred as the backscattering strength or signal amplitude. In ADV's output record a signal amplitude is provided, which is measured with the same frequency and in the same sampling volume as the velocities. The Signal Amplitude (SA) value obtained by the ADV is proportional to the logarithm of the intensity of the acoustic signal that is backscattered from small particles within the sampling volume. The intensity backscattered by particles in the sampling volume, I, is calculated by ($I \;\alpha 10^{0.0434SA}$) (Nikora and Goring, 2002). In low concentration there is a nearly linear correlation between the concentration, c, and intensity, I. General experience indicates that the linear region corresponds to a sediment concentration of about 10 g/L. In this experimental study, the entrance sediment concentrations have values up to 12 g/L but through water entrainment, the concentration reduces and in the working section it would be below the limit. Collected samples prove that the concentration values are less than 10 g/L after the spreading of turbid water. So, based on the above illustrations, the intensity of the acoustic signal, I, from sediment particles within the ADV sampling volume can be used as a surrogate measurement of suspended sediment concentration in experiments. The acoustic backscattering intensity of the ADV had been calibrated in the laboratory, by the siphon sampling of sediment concentration by Hosseini et al, (2006). The measured concentration has been used for producing a calibration curve, Equation 2, relating backscattering intensity and sediment concentration:

$$c=0.01092*0.00003*10^{0.0434SA} \tag{2}$$

where c is the mean sediment concentration at different heights above the bed in terms of g/L. The effect of opening height of entrance valve is shown in Figure 6. As seen in the Figure, the effect of opening height on the concentration profiles is remarkable. In constant entrance concentration and channel slope, an increase in opening height causes a reduction in both entrance densimetric Froude number of turbidity current and vertical sediment concentration in vertical profile. A comparison between Figure 3 and 6 reveals that by increasing in vertical profile of velocity, the value of sediment concentration decreases.

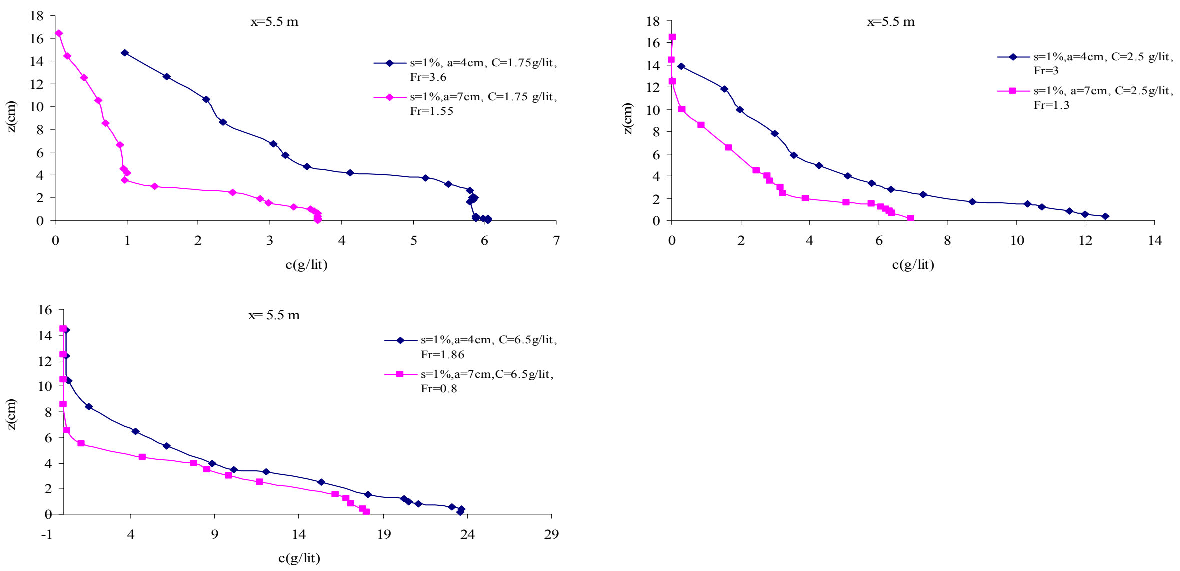


Figure 6 Effect of entrance underneath valve opening height on vertical profile of concentration in 5.5m after entrance valve.

The effect of entrance concentration in constant opening height and reservoir bottom slope, is exhibited in Figure 7. Based on this Figure, when entrance concentration is increased, the value of sediment concentration along the channel for most part of the profile is also increased accordingly. Furthermore, when the entrance densimetric Froude number is large, turbidity current profiles extended in greater height but with less maximum concentration at the bed than those in subcritical entrance turbidity current. In subcritical entrance turbidity current, concentration profiles have greater gradient in turbidity current height limit. Thus, by comparison between the results shown in Figures 4 and 7, it can be realized that in a constant opening height , the value of entrance Froude number reduced whereas the value of velocity increases as the entrance concentration increased. On the other hand, an increment in current velocity redounds to increase in water entrainment but to reduce in current concentration, in spite of the fact that the effect of increasing in entrance concentration is more highlighted than those of increment in water entrainment.

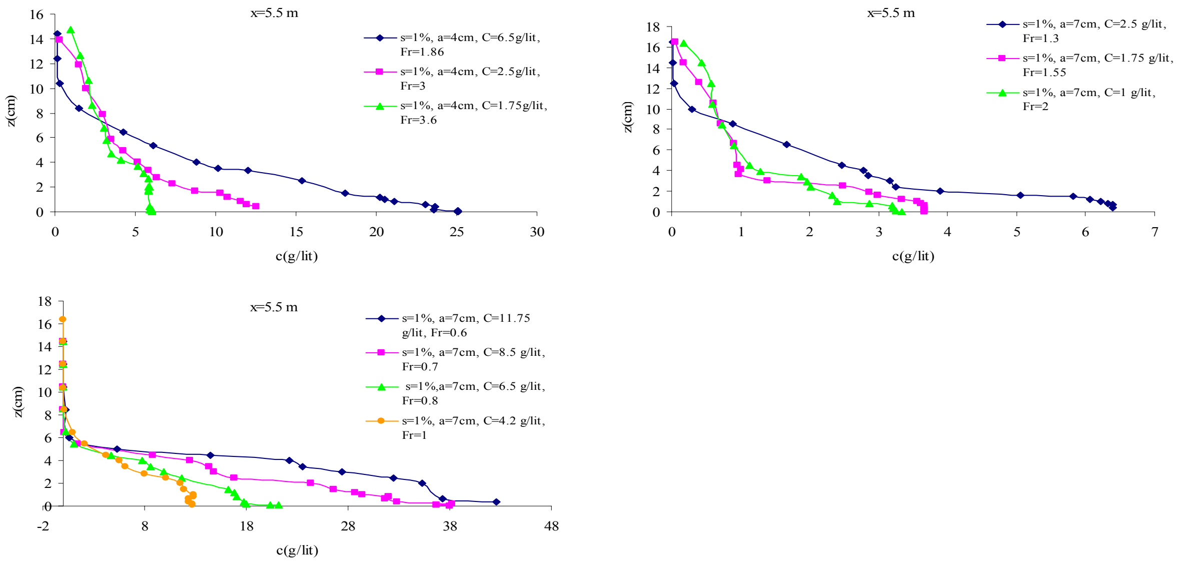
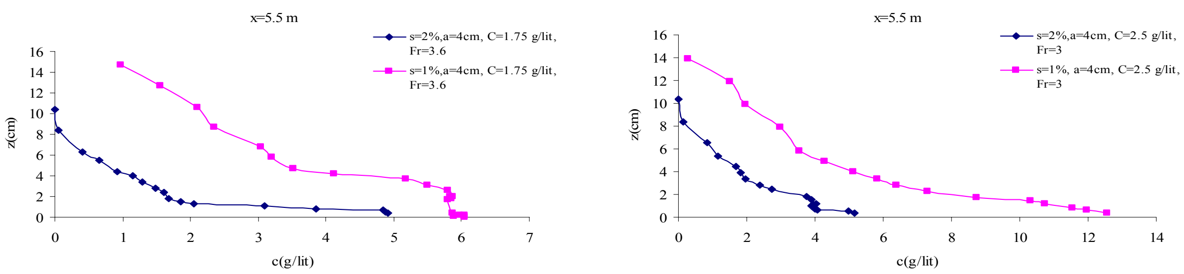


Figure 7 Effect of entrance concentration on vertical profile of sediment concentration in last section (5.5m after the entrance underneath valve).

The effect of reservoir bottom slope on sediment concentration profiles is demostrated in Figure 8. In constant opening height, entrance concentration and Froude number of entrance current, increasing in the slope causes sediment concentration to reduce. Comparison between Figures 5 and 8 indicates an increment in the slope redound to increase in turbidity current velocity and water entrainment. Hence by entering water of ambient flow into the turbidity current, the value of sediment concentration decreases along the channel.



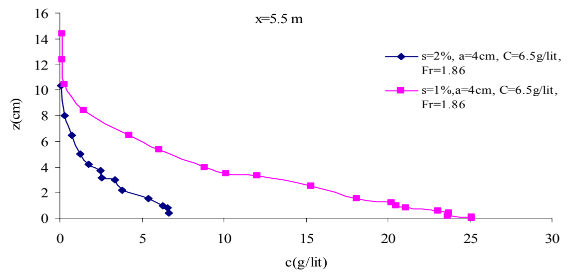


Figure 8 Effect of channel slope on vertical profile of sediment concentration in 5.5m after the entrance underneath valve.

5. CONCLUSIONS

1-In sub-critical entrance current, vertical velocity profiles advance along the channel until in 5.5 m downstream of the channel entrance become stable.

2- In a=4 cm and Fr=1.86 to 3.6 the height of turbidity current is 2.5 to 5 times greater than that of a=7 cm. However in a=7cm, Fr= 0.8-1.55, the height growth toward the height of entrance valve opening is about 1.5-2.5. By increasing in entrance Fr, in super-critical entrance current, the maximum velocity is smaller than the entrance current velocity. In sub-critical entrance current, the maximum velocity is about 50% greater than entrance current. Furthermore, by increasing in opening height of entrance valve and consequently reducing in Fr of entrance current, the current velocity and water entrainment are increased and under this condition, the sediment concentration reduced due to increasing in water entrainment.

3- The experimental results show that in sub critical entrance current, the velocity vertical profiles are in recumbent form and maximum velocity is increased by decreasing in entrance current Fr due to increasing in entrance concentration. In super-critical current, the effect of entrance concentration is more obvious than that under sub-critical condition. An increment in entrance concentration redounds to increase in the value of velocity profile. So both values of water entrainment and sediment concentration along the channel are increased, since the effect of increasing in entrance concentration effect is greater that that of water entrainment effect.

4- In greater entrance current Fr, the effect of reservoir bottom slope on current velocity distribution is remarkable, i.e. a reducting factor of 50 to 100% in maximum current velocity due to 1% reduction in bottom slope but in smaller Fr, the alteration in slope does not have any considerable effect, i.e. a reduction factor is nearly 20% .

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TECHNICAL CONTRIBUTIONS

Multiphase Flow