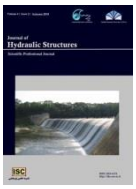
Journal of Hydraulic Structures
J. Hydraul. Struct., 2020; 6(4): 16-32
DOI: 10.22055/jhs.2021.36477.1159



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Laboratory Investigation of the Parameters of the Submerged Plates on the Turbidity Currents Characteristics

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Abstract

In dam reservoirs, the turbidity current is usually the cause of sediment transfer and deposition. Therefore, it is necessary to study this phenomenon. Here, experiments were made on the effects of the impermeable submerged plates on turbidity current head. In order to investigate the effects of the impermeable submerged plates, some parameters of the plates were changed, such as shape, angle of mounting of the plates with respect to the current axis, location and the dimensions of the plates. The results showed that the flow velocity of the turbidity current decreased by 25 to 27.1% compared to the control state in case of different shapes of plates mounted. The analysis of the position of the plates showed that in different conditions, the flow velocity decreases 45.1% relative to the control state. Various mounting angles also resulted in 8.6 to 27.1% lower velocity relative to the control. Changing the width and height of the plates reduced the head velocity from 21.8 to 43.9% and 10 to 45.2%.

Keywords: Impermeable submerged plates, Turbidity current, Velocity.

Received: 25 January 2021; Accepted: 14 February 2021

1. Introduction

Today, the construction of dams is one of the most important solutions for the storage of surface water. Due to fresh water limitations, the construction of reservoir dams to control the surface water resources in Iran is inevitable and necessary. The major cause of sediment movement in the reservoirs of the dam is a phenomenon known as “turbidity current”. Generally, the turbidity flow can be described as the introduction of a fluid of a specific mass to a fluid of different specific mass resulted by the effect of gravity on the mass difference. The difference in specific mass can be due to the presence of suspended matters, soluble matters, temperature

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difference or a combination of them [9]. The acceleration of gravity affecting the current, which is considered as a driving force in the turbidity current is expressed as Eq. (1):

$$g' = g(\frac{\rho_d - \rho_a}{\rho_a}) = g(\frac{\Delta\rho}{\rho_a}) \quad (1)$$

Where g' is the reduced gravitational acceleration, g is the gravity acceleration (9.81 m/s^2), ρ_a and ρ_d are the mass of the around fluid and the turbidity fluid, respectively [9]. Like the current in the open channels, in the turbidity current also the effect of gravity force is very important; such that the Densimetric Froude Number is expressed as follows for the turbidity current:

$$Fr_d = \frac{U}{\sqrt{g'h\cos\theta}} \quad (2)$$

This dimensionless parameter is called the Densimetric number. U is the average velocity; h is the flow depth and θ is the angle of the bed with the horizon [19]. One of the most important issues in the dynamics of turbidity current is the current head section (Fig. 1) [2].

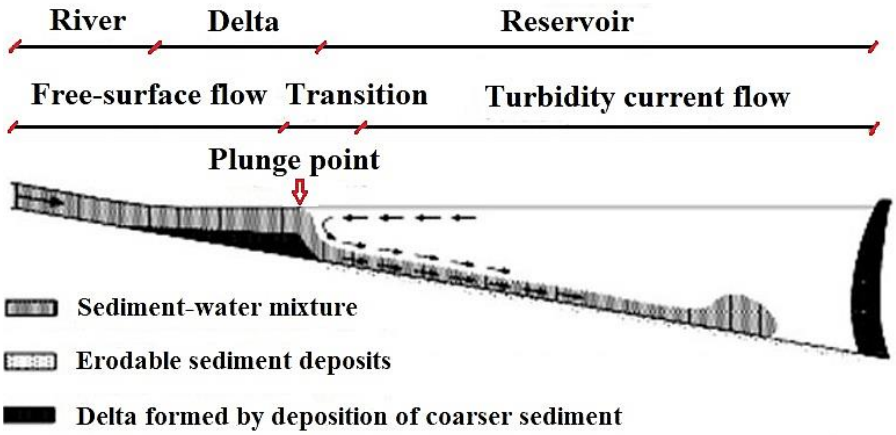


Figure 1. Schematic of the turbidity current process in the dam reservoir [14]

Several studies have been carried out in relation to the collision of two-phase current with the barrier. By creating two-dimensional roughness (6, 13, 19, 25 mm) along a horizontal laboratory flume, Peters [15] studied the current velocity of concentrated salt on rough surfaces. Ghorban Moghadam et al. [7] investigated the effects of cylindrical barriers in the bed slopes of 0.5, 1.25, 2.0% and salt concentrations of 10 and 20 g/l, on the turbidity current head. A laboratory investigation was made by Varjavand et al. [20] to analyze the salt concentration streams on beds with synthetic roughness, and two cylindrical and conical roughness states were used with three roughness heights. Tabatabaei [18] investigated the effects of six types of vegetation arrangements on the flow of the salty turbidity current head, and he performed his experiments on three slopes and two concentrations. Pourkayd et al. [16] investigated the concurrent effects of roughness, bed slope and concentration on the average speed of the body of the turbidity current. Asghari Pari and Mohagheghiyan [3] examined the numerical effect of using plate barrier and column barriers with zigzag arrangement and low height at 45, 60 and 90-degree

body angles on controlling the current. By carrying out some experiments, Khalili naftchali et al. [12] investigated the effects of vegetation density on the reduction of the velocity of the turbidity current head. Their experiments were carried out at concentrations of 10, 20, 30 and 40 g/l at two heights of 15 and 20 cm and densities of 0.6, 0.8, 1, 1.2, and 1.4. A literature review shows that no research has been done on the effects of the impermeable submerged plates on the turbidity current. In the present study, the effect of these types of plates on the conditions of turbidity current was investigated. In order to investigate the effects of gradient and concentration, two concentrations of 20 and 40 g/l and two bed slopes of 1 and 2% were investigated.

2. Materials and methods

The experiments for the present study were carried out at the Hydraulic Lab of the Faculty of Agriculture, University of Birjand. A flume with a length of 10m, a width of 0.3m, and a height of 0.46m was used to perform the experiments. A sliding gate is fitted at a 2m distance from the head of the flume. In order to make the uniform current conditions possible, a 5cm opening was considered for the gate, and the distance of the mounted plates from the head of the gate is 2.5m. Fig. 2 shows an overview of the flume, the tank of mixing and the head tank.

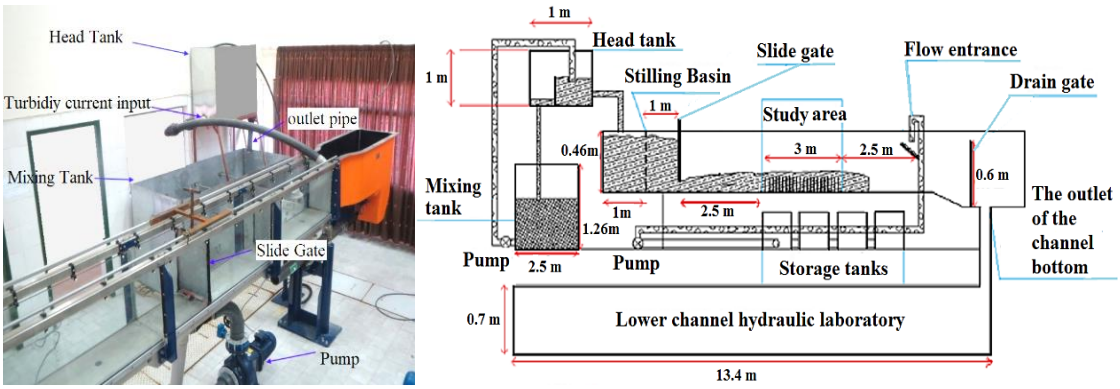


Figure 2. Experimental set-up

To conduct experiments, salt powder was used to create a salt turbidity current. The concentrated fluid with an appropriate concentration was dissolved in the mixing tank, and it could be distinguishable from the surrounding fluid by solving a stain matter. By using a pump, the prepared solution was transferred to the fixed-head tank. The fixed load tank was divided into two parts to allow the overflow of the excess fluid and the turbidity current to enter the flume by gravity. In order to ensure that the concentrated fluid only enters the around fluid by concentration difference, the gate was opened when the level of the around fluid and surrounding fluid are equal. Fig. 3 shows a sample of formed turbidity current.

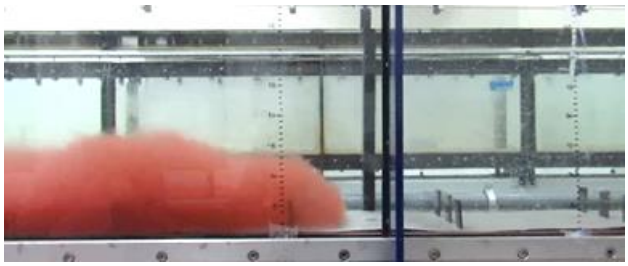


Figure 3. A sample of the formed turbidity current

The total number of plates was 30 and fixed. Square, Rectangular, Triangle, Trapezius, and Rhombus were used to study the effect of plate shapes on turbidity current. Also, the initial angle of the plates relative to the current axis was investigated by the angles of 0, 15, 30, 45, 60, 75 and 90 degree. The positioning of the plates is shown in Fig. 4. Also, in order to analyze the effects of the length and width of the plates the five length and the five width of 2, 3, 4, 5 and 6cm were used. The experiments were carried out for two concentrations of 20 and 40 g/l and two slopes 1 and 2%.

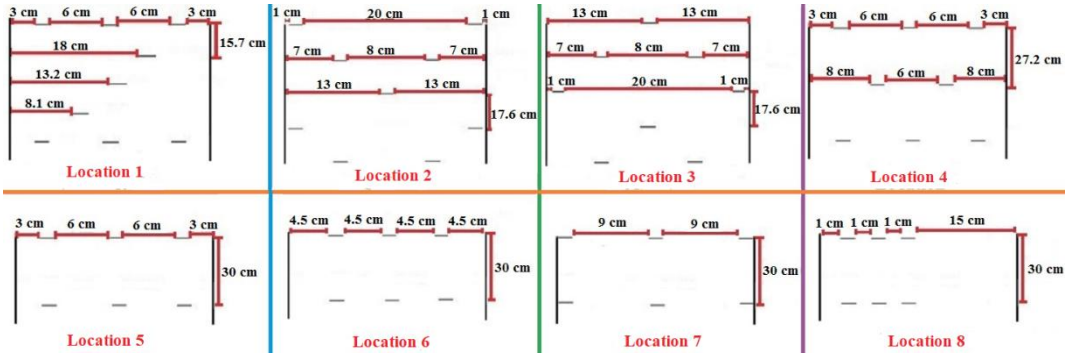


Figure 4. Schematic diagram of various mounting positions of the plates

In Fig. 5, a sample of a Plexiglas plates with submerged plates is shown. Table 1 summarizes the experimental conditions and the range of the laboratory data.



Figure 5. a. Triangular Plates



b. Plates with dimensions of 3×4

Table 1. List of the performed experiments

Group	L	F	W	H	α	S	C	Re (×10^4)	No. of exp
A	-	-	-	-	-	1,2	20,40	1.28-2.3	4
B	5	Total F	different	different	90	1	20	0.96-1.35	4
D	5	Square	4	4	Total α	1	20	0.77-1.41	6
E	Total L	Square	4	4	90	1,2	20,40	0.71-2.2	32
G	5	Rectangular	4	2,3,5,6	90	1,2	20,40	0.67-1.77	16
I	5	Rectangular	2,3,5,6	4	90	1	20	0.7-1.11	4

Note: L = position of the plates; S = slope of the flume (%); C = concentration of the turbidity current (gl^{-1}); F = shape of the impermeable submerged plates; α = mounting angle of the plates relative to the current axis (degree); H = height of the impermeable submerged plates (cm); W = width of the impermeable submerged plates (cm); Re = Reynolds number.

2.1. Dimensional Analysis

The effective variables in relation to impermeable submerged plates and their effect on the flow of the turbidity current in this study can be illustrated by using Eq. (3):

$$f(F, H, W, \alpha, L, S, C, \rho_a, h_f, U_f, \mu_{d.c}, g' cos\theta)=0 \quad (3)$$

where, F is the shape of the impermeable submerged plates, H is the height of the impermeable submerged plates, W is the width of the impermeable submerged plates, α the angle of the plates relative to the current axis, L is the position of the plates, S is the slope of the flume, C is the concentration of the turbidity current), h_f is the height of the turbidity current head, U_f is the velocity of the turbidity current head, ρ_a is the specific mass of the around fluid, $\mu_{d.c}$ is the dynamic viscosity of the turbidity current, θ is the bed angle relative to the horizon, g' is the reduced gravity acceleration. Taking into account the three recurrent parameters of h_f, U_f and ρ_a, the dimensional analysis was done by Buckingham's method. Also, considering that the experiments of this study were carried out in flume and in free flow conditions, and that the Reynolds Number of the turbidity current $\frac{\rho_a \times U_f \times h_f}{\mu_{d.c}}$ is always within the turbulent current range, its effects are neglected. Therefore, the Densimetric Froude Number of the turbidity current and its effective parameters are in accordance with Eq. (4):

$$Fr_d = \frac{U_f}{\sqrt{g' \times cos\,\theta \times h_f}} = f^*(F, \frac{H}{h_f}, \frac{W}{h_f}, \alpha, L, S, \frac{C}{\rho_a}) \quad (4)$$

3. Results and discussion

In the graphs, h_f and U_f are the height and velocity of the turbidity current head in a bed with plates, h and U are the height and velocity of the turbidity current head in a smooth bed (control), U/U_f is the ability of the plates to control the turbidity current relative to the smooth bed. Also, X is the distances of the data measurement from the beginning of the mounted plates to the desired section and X_a is the total length of the mounting of the plates (3m). Finally, after analysis of the graphs, the coefficients of the velocity of the turbidity current head and the empirical equations obtained from the experiments are summarized.

3.1. The effect of the shape plates on turbidity currents

Fig. 6 shows the range of non-dimensional velocity variations of a continuous current in 6 sections at intervals of 50cm and 5 plate shapes with a surface area of 16cm^2. As shown in Fig. 6, due to the collision of the turbidity current with the plates, the non-dimensional velocity is greatly reduced in the mounting route. Also, the results of Ghorban Moghadam et al. [7] showed that the flow velocity of the turbidity current reduces by positioning the barriers. This is due to the collision of the turbidity current and the plate, creation of fraction and also the increased inflow of the around fluid into the turbidity current head, as a result of which, the concentration difference between the turbidity current and the around current. This is consistent with the results of Oehy [14], which indicated the construction of a barrier to be an appropriate solution to control the current flow. For various shapes, as shown in Fig. 6, one of the shapes has the highest rate of deceleration at each section. However, by averaging the percentage of the deceleration rate along a 3m section, the Square shape has highest rate of deceleration with 27.1%. Thereafter, the Rectangular and Triangle shapes ranked second with 26.4 and 26.2% deceleration, and the Rhombus and Trapezius shapes ranked third with 25.8 and 25%. This is due to the fact that when the turbidity current flows along the flume, the resistive (drag) force is applied to the plates and all of the parameters of this force, like density, area, an collision velocity are the same and the only difference is in the C_d coefficient of the shapes (empirical coefficient in the drag force relation).

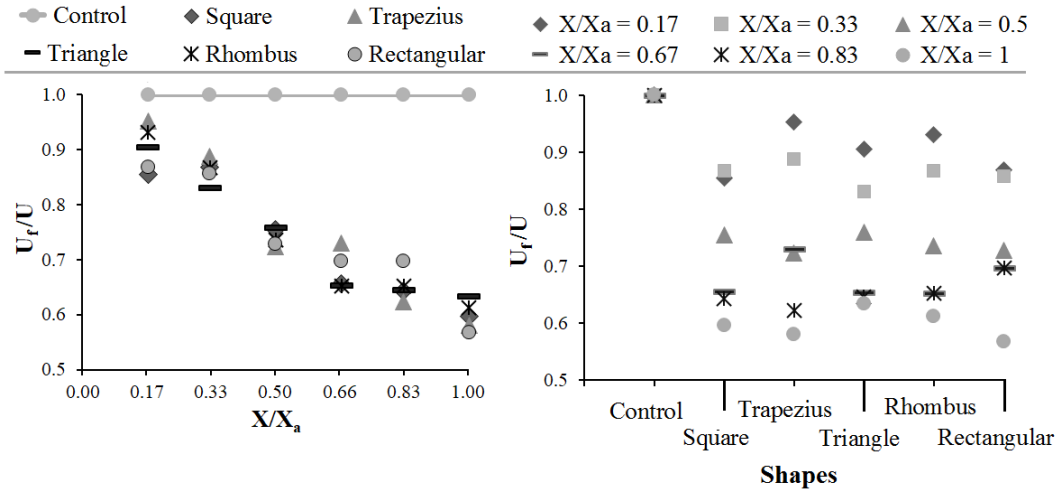


Figure 6. Changes in the non-dimensional velocity of the turbidity current head relative to a smooth bed in different shapes at a bed slope of 1% and a concentration of 20 gr/l

Investigation of the height of the turbidity current head along the route (Fig. 7) shows that at the beginning of the route, the plates reduced the height of the turbidity current head, which is consistent with the result of Ghorban Moghadam et al. [7], but gradually, and at the end of the route, it increased the height of the turbidity current head. Because, at the end of the route, the velocity of the turbidity current has the greatest decrease, and the current passes the barriers at low speeds and high current head. Also, the results revealed that the Densimetric Froude Number has an increasing trend in the control experiment, which is due to the increasing trend of velocity along the flow current route. It is also observed that with the mounting of plates in all

shapes, the Densimetric Froude Number has a decreasing trend along the route, which is the same for all types of barriers.

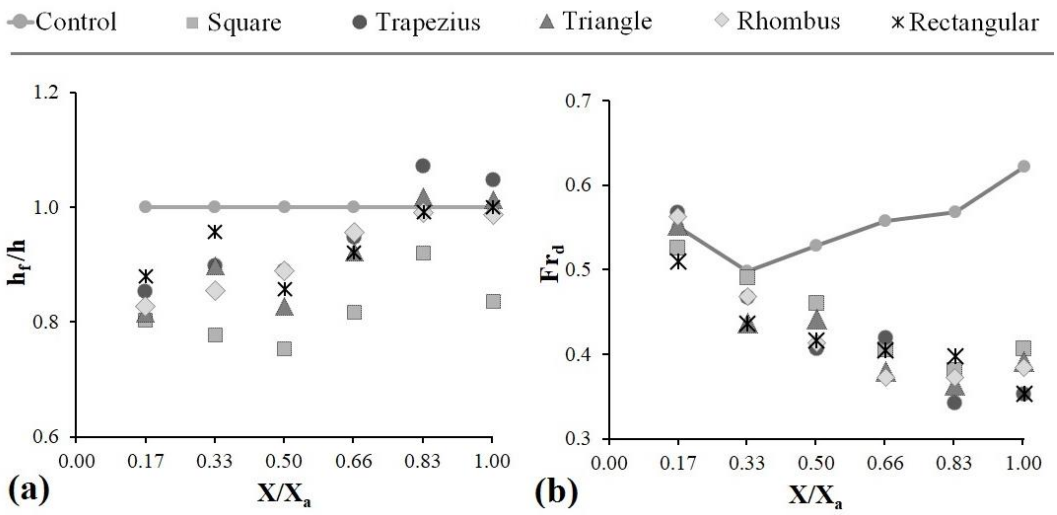


Figure 7. Changes in the non-dimensional height and Densimetric Froude Number in plates with different shapes on a bed slope of 1% and a concentration of 20 gr/l

3.2. The effect of the angle of plates on the flow characteristics

With regard to the highest rate of deceleration relative the smooth bed in Square plates, this shape was used to investigate the effect of the angle of the impermeable submerged plates. Fig. 8 shows the range of dimensionless velocity variations of the current flow at 7 mounting angles, with the concentration of 20 g/l and slope of 1%. As it is evident in this figure, with the turbidity current flow along the mounting route of the plates, the dimensionless velocity decreases significantly, which is more pronounced with the increase in the angle of the plates, because with increasing the angles of plate relative to the current axis, the area of the collision increases between the plates and the turbidity current head, the collision-induced drag force increases and then, the flow velocity decreases. With increasing the angle of the plates, the decreasing gradient of the dimensionless velocity increases along the dimensionless route. In addition, considering the Fig. 8, the 75- and 90-degrees positioning angles indicate the most deceleration compared to the control with 26.4% and 27.1%, respectively. Therefore, the plates with angles of 75° and 90° which are in the vertical and near-vertical position relative to the current axis, are affecting the current flow velocity more than plates at other angles. This is Similar to the results of Asghari Pari and Mohagheghiyan [3] on the angle of the plate barriers.

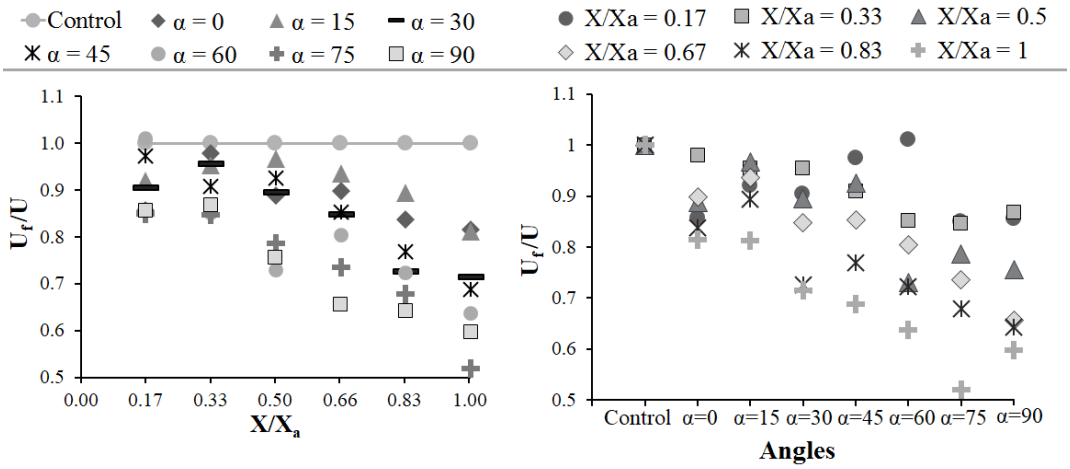


Figure 8. Changes in the non-dimensional velocity of the turbidity current head relative to the smooth bed at different angles of the plates at a 1% slope and a concentration of 20 gr/l

Fig. 9 shows the variation in the height and Densimetric Froude Number of the turbidity current head at different angles of mounted plates along the route, at the concentration of 20 g/l and a slope of 1%. By increasing the angle of the impermeable plates, the height of the turbidity current head increases; because, the more the plates resist the turbidity current flow, the higher viscous shear stresses at the top boundary of the current head, and after the failure of the Kelvin – Helmholtz instabilities, the mixing of turbidity fluid with the around fluid increases and the height of the mixing zone between the turbidity and around fluids increases, thereby increasing the current head [1, 18]. Also, in Fig. 9, the mounting angles of less than 45° do not affect the reduction of the Densimetric Froude Number. The 45-degree angle had a slight effect on the reduction of the Densimetric Froude Number with 3.9%, but the mounting angles of 75° and 90° had the most effect on reducing the Densimetric Froude Number relative to the control with 20.4% and 19%. Therefore, the increase in the mounting angle of the plates has a positive effect on the reduction of the Densimetric Froude Number.

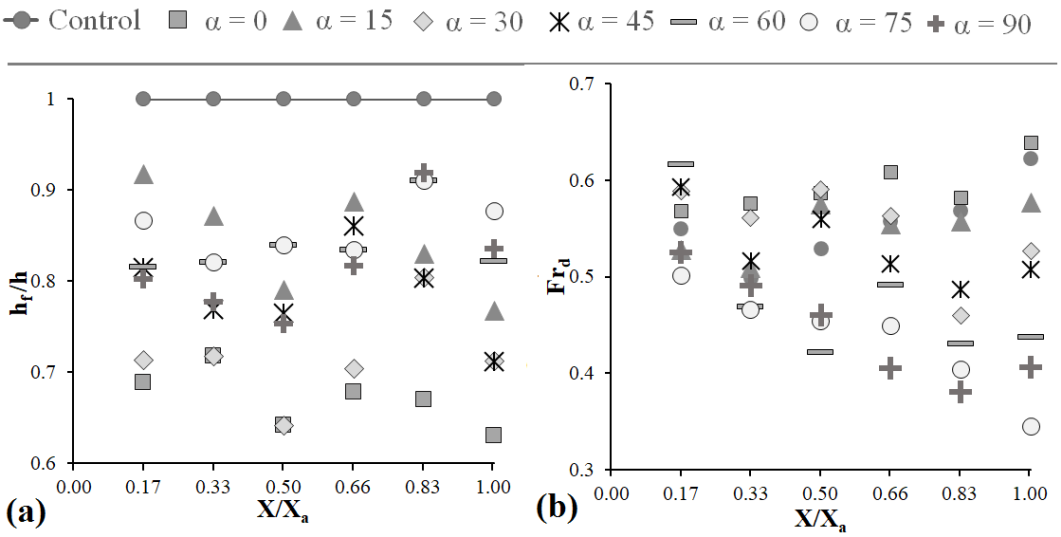


Figure 9. Changes in the non-dimensional height and Densimetric Froude Number of the turbidity current head on a bed slope of 1% and a concentration of 20 gr/l

3.3. The effect of positioning plates on turbidity current

In order to investigate the effect of the position of the plates, and considering that the Square shape with a 90 degree angle has the greatest effect on the decrease of the turbidity current relative to the control. This shape and mounting angle were used for these experiments. Fig. 10 shows the non-dimensional variations of the velocity when mounting plates in different positions relative to the control. As can be seen, the non-dimensional velocity of the turbidity current head is decreased along the route; and all positions, except position 8, the velocity decreased in the whole route compared to the control test. Position 8 to have no effects on the velocity decrease trend due to its bias to another direction and velocity increase in the empty area of the plates. It increased the velocity of the turbidity current with respect to the control in some sections. Any increase in the slope and the concentration will reduce the effects of the plates on the velocity decrease and the velocity decreasing slope is less in the concentration of 40 g/l than the concentration of 20 g/l. At constant sections, the concentration increase made an increase in the density difference between the turbidity current and the around fluid; and then, the current accelerates and the gravity acceleration (driving force of the movement of turbidity current) decrease significantly; and the fresh water integrates more into the turbidity current. On the other hand, due to the barrier in the current way and the fraction increase because of collision with the plate and, therefore, lower driving force of the current, the velocity of the current head is affected more by the submerged plates and indicates a higher decrease. Similarly, Pourkayd et al. [16] reported the same results for the average velocity of the turbidity current body. Also, at the concentration of 20 g/l, position 2 had a higher influence on the flow velocity if the current at an average velocity decrease of 45.1% at the slope of 1% and 29.5% at the slope of 2% with respect to other positions. Also, the concentration of 40 g/l, the position 5 has the best conditions for decreasing the velocity with 33.9% at the slope of 1% and 38.3% at the slope of 2%, which is consistent with the results provided by Ghorbani et al. [8]. On the other hand, at both concentrations, with an increase in the bed slope, the current flow velocity is increased and the effects of barrier on the flow velocity increases, which is consistent with the study of Asghari

Pari et al. [4] on the velocity of the turbidity current head, and the study of Pourkayd et al. [16] on the average velocity of the body of turbidity current. This way, the effects of barrier resistance, and the mixing intensity of the around fluid and the turbidity current decrease, and the current stability increases.

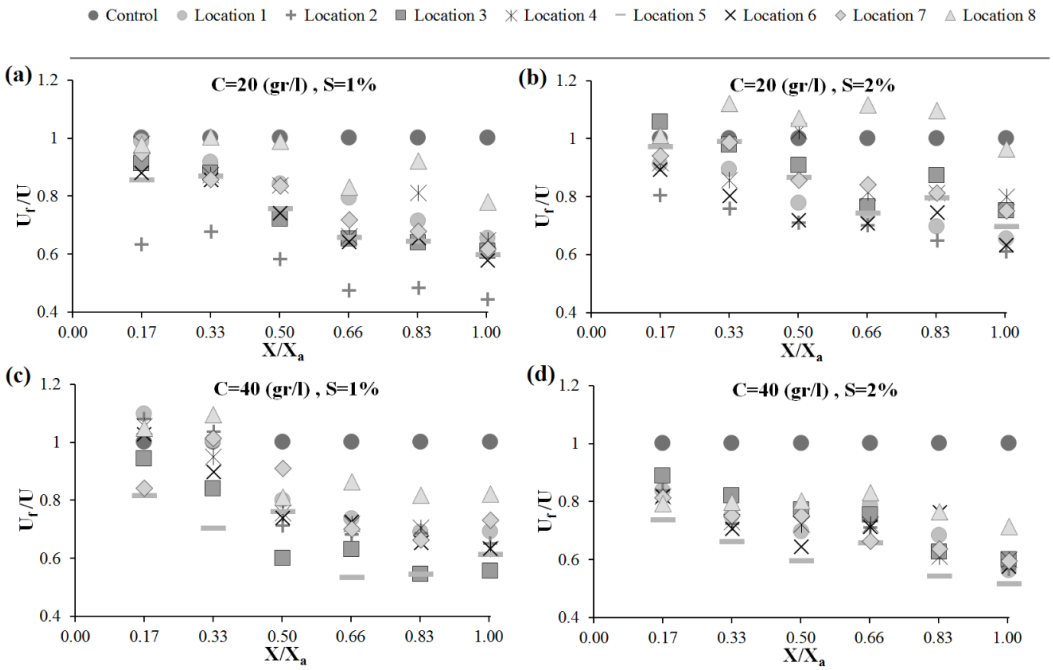


Figure 10. Non-dimensional variations of the velocity with respect to changes in the bed slope and concentration

Fig. 11 shows the trend of non-dimensional height and Densimetric Froude Number changes in different positions relative to the control. According to this Fig. 11, at all mounting positions of the plates increased the height of the current head relative to the control. Since the discharge of the turbidity current is almost constant along the route, increase in height and the area occupied by the turbidity current head will necessarily reduce the velocity of the current head. Also, as can be seen, all mounting positions except the position 8, decrease the Densimetric Froude Number along the route, and, finally, it reaches equilibrium at the final stages. In the concentration 20 g/l, position 2 has the highest effect on reducing the Densimetric Froude Number with 42.2% at the slope of 1% and 31.5% at the slope of 2%, which is consistent with the results of Tabatabaei [18]. In the concentration of 40 g/l, position 5 has the highest effect on reducing the Densimetric Froude Number with 33.6% and 36.3% at the slopes of 1 and 2%.

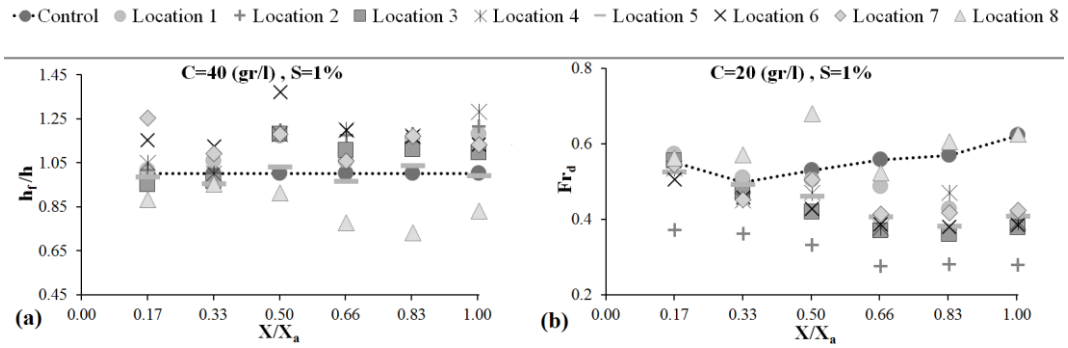


Figure 11. Changing the non-dimensional height and Densimetric Froude Number of the turbidity current head

3.4. The effects of plates height on turbidity current

Two different positions in two concentrations showed a more significant decrease in the velocity than other positions. In nature, turbidity current occurs with so many currents, so in this section, we used the position 5. That was taken to be more suitable to analyze the effects of the height of the plates. Also, in order to investigate the effects of the plate height, the constant width was taken to be 4cm. Fig. 12 shows the non-dimensional velocity in the plates mounting conditions with various heights relative to the control. The presence of barriers against the turbidity current will increase the resistive force and the increased depreciation of the current energy, to intensify the mixing of the around fluid with the turbidity fluid. Therefore, with a decrease in the density, the flow velocity of the current head decreases more significantly in proportion to the status without impermeable plates [13]. With an increase in the density and the bed slope, the velocity of the current flow will increase and the resistive effect of barriers will reduce, which is consistent with the study of Daryaee et al. [5] on the depositional turbidity flow. Also, as observed in the Fig. 12, the increase in the height of the plates will decrease the velocity of the current head compared to the control, which is consistent with the study of Khalili [11], Pourkayd et al. [17] and Daryaee et al. [5, 6]. The plates with the height of 6cm have the most significant effect on the decrease in the velocity of the turbidity current head compared to the control.

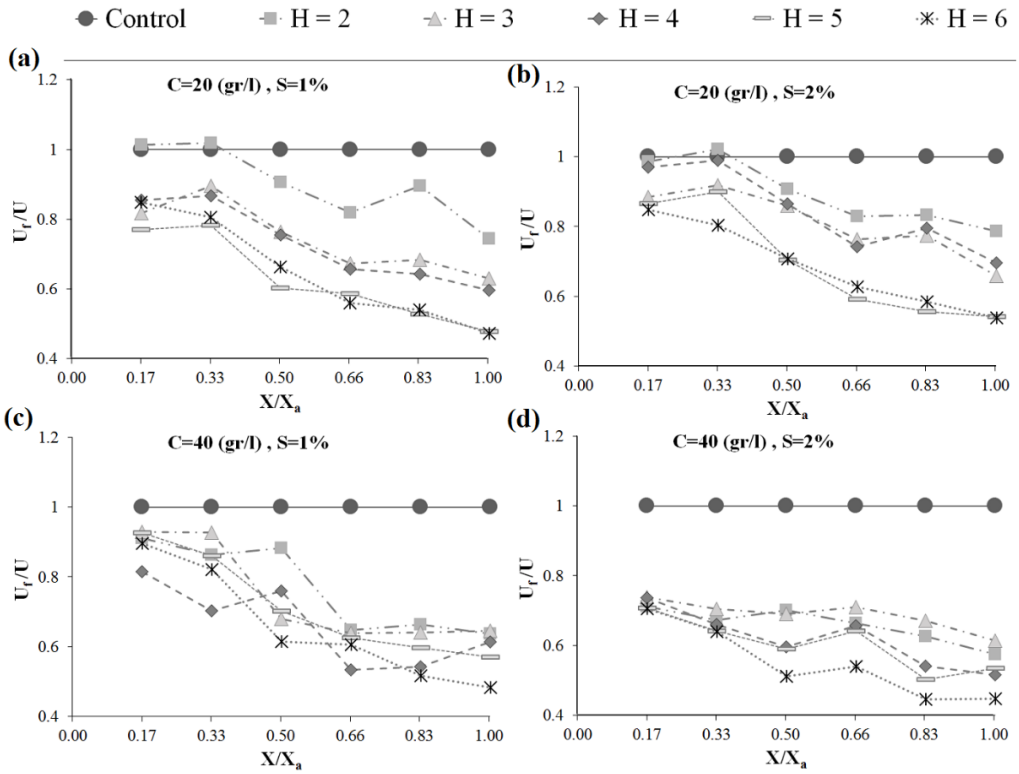


Figure 12. Non-dimensional velocity variation of the turbidity current at various heights of the plates

Fig. 13 shows the variation trend of the non-dimensional height and Densimetric Froude Number at various heights of the plates compared to the control. According to Fig. 13, at all of the states, the height of the current head has increased compared to the control. Also, the increase in the height of the plates would increase the height of the turbidity current head, which is consistent with the study of Pourkayd et al. [17]. As observed, in all states, the plates reduce the Densimetric Froude Number along the route, but at the final stages, it comes to equilibrium. Also, with an increase in the height of the plates, the decrease in the Densimetric Froude Number would be more significant than the control.

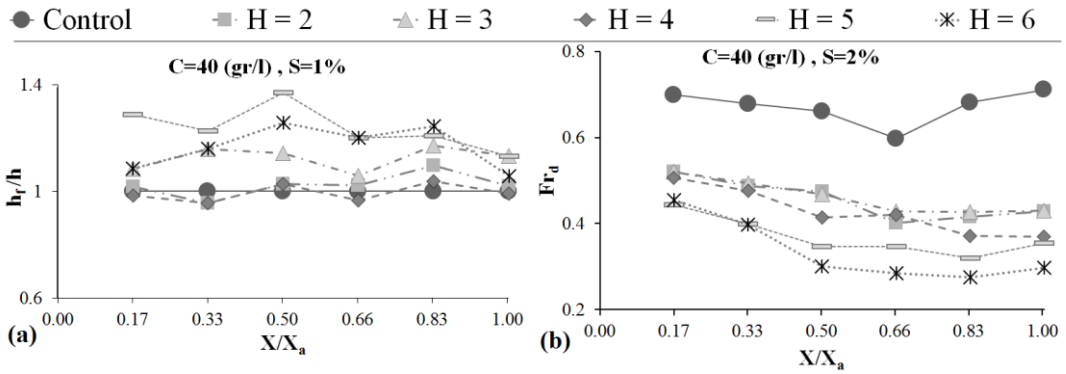


Figure 13. Non-dimensional height and Densimetric Froude Number variation of the turbidity current in the various heights of the plates

3.5. The effects of plates width on turbidity current

In order to investigate the effects of the width of the plates, the constant height of 4cm was considered. Fig. 14 show the range of non-dimensional velocity variations of the current flow for the 5 different widths of the impermeable plates. As shown in the Fig. 14, with an increase in the width of the plates, the non-dimensional velocity decreases. Because, this will limit the route of the turbidity current along the canal, and the collision and fraction of the current with the plates increases. This is consistent with the study of Hosseini [10] on the diameter of the vegetation.

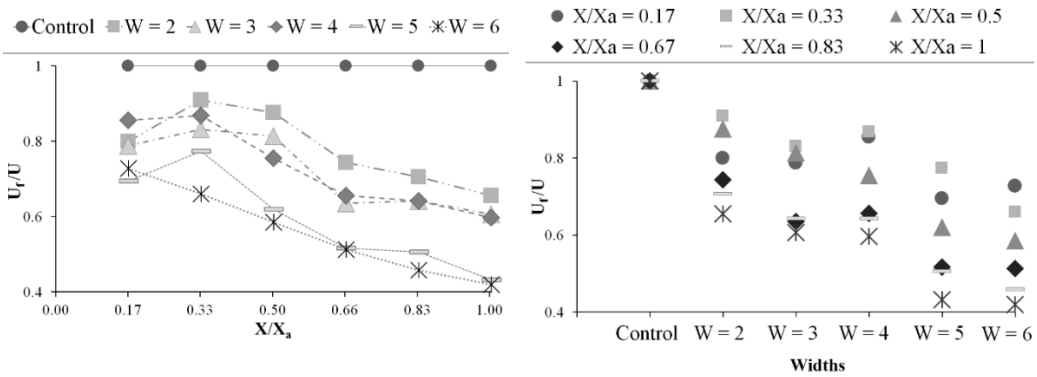


Figure 14. Non-dimensional velocity variations of the turbidity current flow compared to the smooth bed at various widths of the plates with the concentration of 20 gr/l and the slope of 1%

Fig. 15 shows the variations of the current head and the Densimetric Froude Number of the turbidity current head when mounting plates with various widths. As observed in the figure, plates with the widths of 5 and 6 have the most effect on the increase the height of the turbidity current. With increasing the width of the plates would increase the height of the turbidity current head. In addition, the graph of the Densimetric Froude Number reveals that when the width of the plates increases, the Densimetric Froude Number decreases, which is similar to the study of Hosseini et al. [10] on the diameter of the vegetation which concluded that with an increase in the diameter of the vegetation, the height of the salty turbidity current increases and the Densimetric Froude Number decreases.

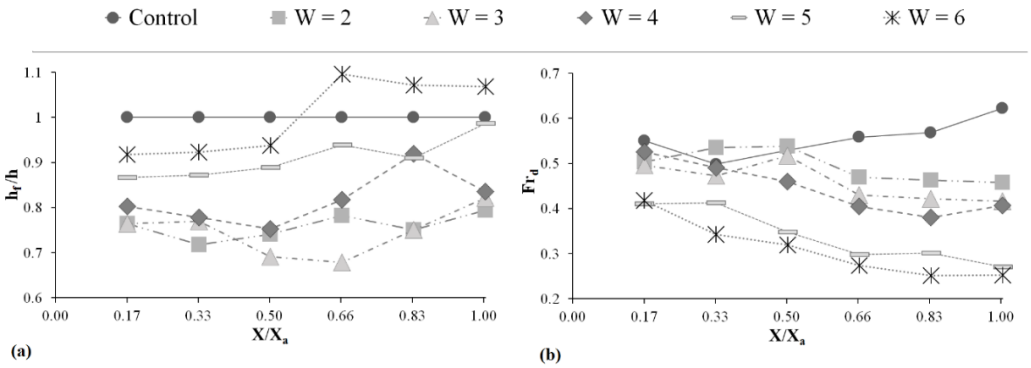


Figure 15. Non-dimensional height variations and the Densimetric Froude Number of the turbidity current head compared to the smooth bed at various widths of the plates

3.6. Coefficients of vertex velocity of the turbidity current

The coefficient of vertex velocity of the turbidity current (C_c) was calculated separately for all experiments at any slopes and concentrations. As can be seen in Table 2, the coefficient of velocity is of the highest magnitude in the equation of velocity as compared to the control, and when the plates are mounted, the coefficient reduces. With an increase in the angle, the velocity coefficient of the current vertex decreases and, because the area of the collision of current and plates is increased with mounting wider plates, so the velocity decreases and the coefficient of velocity will be lower. Also, with an increase in the width of the plates, the coefficient of the vertex velocity decreases. The lowest coefficient of the velocity is related to the plates with the width of 6cm, which has the most effect on the velocity decrease of the turbidity current.

Table 2. Coefficients of vertex velocity of the turbidity current at the bed slope of 1% and concentration of 20 gr/l

W	C_c	α	C_c	F	C_c
Control	0.553	Control	0.553	Control	0.553
2	0.494	0	0.59	Square	0.443
3	0.459	15	0.549	Rectangular	0.419
4	0.443	30	0.547	Trapezius	0.421
5	0.339	45	0.53	Triangle	0.424
6	0.307	60	0.477	Rhombus	0.426
-	-	75	0.437	-	-
-	-	90	0.433	-	-

Note: W = width of the impermeable submerged plates (cm); α = mounting angle of the plates relative to the current axis (degree); F = shape of the impermeable submerged plates; C_c = Coefficients of vertex velocity.

In Table 3, the coefficients of the position and height experiments of the plates, which were made at two slopes and two concentrations, are shown separately for the slopes and concentrations. As shown in Table 3, with an increase in the bed slope, the coefficient C_c increases. Also, the magnitude of the coefficient will be higher than when the plates are present, except for the position 8, which is due to the empty space in the width of the canal in position 8. Also, due to the simultaneous effect of the velocity and the height of the turbidity current head, this coefficient is different for every situation. With an increase in the height of the plates, the coefficient of the vertex velocity of the current will decrease.

Table 3. Coefficient of the vertex velocity of turbidity current in various conditions

H	C=40 S=2%	C=40 S=1%	C=20 S=2%	C=20 S=1%	L	C=40 S=2%	C=40 S=1%	C=20 S=2%	C=20 S=1%
Control	0.671	0.543	0.584	0.553	Control	0.671	0.543	0.584	0.553
2	0.453	0.411	0.557	0.527	1	0.447	0.429	0.498	0.485
3	0.46	0.377	0.49	0.454	2	0.432	0.409	0.398	0.316
4	0.426	0.36	0.505	0.443	3	0.432	0.357	0.496	0.421
5	0.368	0.358	0.4	0.37	4	0.437	0.404	0.463	0.45

H	C=40 S=2%	C=40 S=1%	C=20 S=2%	C=20 S=1%	L	C=40 S=2%	C=40 S=1%	C=20 S=2%	C=20 S=1%
6	0.332	0.328	0.392	0.369	5	0.425	0.36	0.505	0.443
-	-	-	-	-	6	0.433	0.387	0.426	0.424
-	-	-	-	-	7	0.431	0.407	0.512	0.458
-	-	-	-	-	8	0.553	0.535	0.636	0.588

Note: L = position of the plates; S = slope of the flume (%); C = concentration of the turbidity current (gl^{-1}); H = height of the impermeable submerged plates (cm).

Finally, by using the software SPSS, the relationships between the variables of the turbidity current are provided in the following (Table 4.):

Table 4. Empirical relations in various conditions

Relations	Concentration	Bed slope	No. of relations
$U_f = 0.042 + (0.276 \times \sqrt{g'h_f}) - (0.012 \times \alpha)$, $R^2 = 0.917$	C=20 gr/l	S=1%	(5)
$U_f = -0.036 + (0.854 \times \sqrt{g'h_f}) - (0.649 \times H)$. $R^2 = 0.94$	C=20 gr/l	S=1%	(6)
$U_f = 0.795 - (4.965 \times \sqrt{g'h_f}) + (1.055 \times H)$, $R^2 = 0.967$	C=20 gr/l	S=2%	(7)
$U_f = 0.012 + (0.384 \times \sqrt{g'h_f}) - (0.408 \times H)$, $R^2 = 0.968$	C=40 gr/l	S=1%	(8)
$U_f = 0.089 + (0.079 \times \sqrt{g'h_f}) - (0.481 \times H)$, $R^2 = 0.818$	C=40 gr/l	S=2%	(9)
$U_f = 0.118 - (0.316 \times \sqrt{g'h_f}) - (0.326 \times W)$, $R^2 = 0.904$	C=20 gr/l	S=1%	(10)

Note: U_f = turbidity current head velocity (m/s); g'= decreased gravity acceleration (m/s^2); h_f = height of the turbidity current head (m); α= mounting angle of the plates relative to the current axis in radians; H= height of the impermeable submerged plates (m); W= width of the impermeable submerged plates (m).

4. Conclusion

In general, in this study the results showed that:

1. With an area of 16 cm^2, the square shape was the best shape to reduce the velocity of the turbidity current head with 27.1%.
2. The plates with the mounting angles of 75 and 90° relative to the horizontal axis of the turbidity current flow provided the most significant decrease in the velocity compared to the control, with 26.4% and 27.1%.
3. Investigation of the plate positions showed that when the plates are mounted across the total width of the canal, they provided the most significant reduction in the velocity compared to the control. The slope increase will reduce the effect of the plates on the velocity.
4. With the concentration of 20 g/l at the slope of 1%, the plates with the height of 6cm, with 37.6%, and at the slope of 2% with 31.5%, had the biggest effect on the decrease of the current head velocity compared to the control. Also, with the concentration of 40 g/l, at the slopes of 1 and 2%, the plates with the height of 6cm had the highest effect on the decrease of the current head velocity with 34.3% and 45.2%.

5. With the concentration of 20 g/l and the slope of 1%, the plates with the width of 6cm made the biggest decrease by 43.9% in the velocity.

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