EFFECT OF AQUATIC WEEDS ON VELOCITY PROFILE CHANGES AND ISLAND FORMATION

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ABSTRACT

The existence of aquatic weeds in waterways causes several major problems. Some of them are the obstruction of water flow and navigation, island formation, increase of water losses due to evapotranspiration, and difficulty of water arrival to canal ends. This paper aims to discuss the resulting velocity profile changes due to aquatic weeds. Also, it examines the effect of such weeds on the channel morphology. It is concluded that aquatic weed presence in waterways has significant effects on both water velocity profile and channel morphology. The resulting morphological changes eventually cause island formation.

Keywords: Island Formation – Velocity Profile – Floating Weeds

INTRODUCTION

As an open channel, the River Nile runs through different African countries starting its journey at Lake Victoria at the Equator and ending it at the Mediterranean in the North. It is considered the second longest river in the world with a length of about 6825 km. Its catchment area is about 2.9 million km^2. Its water is considered the main source of fresh water for the countries where it goes through. It is used for different purposes such as drinking, irrigation, navigation and industry. Therefore, it is paramountly important to make its waterway as clear as possible so as to be able to serve these countries in an efficient way.

Aquatic weeds are considered a source of pollution and intervention to the Nile. They cause problems for the ecological and morphological life of the river. They should, therefore, be removed or kept as low as possible. For instance, they affect the river water in different ways. One of these is that they affect the water current velocities significantly. This helps increase the sedimentation process along the river, a matter which directly contributes to island formation. This, in turn, affects the river water course and may cause problems for river-near communities.

HISTORY OF ISLAND FORMATION IN THE RIVER NILE WITHIN EGYPT

A large number of islands that differ in size and age exist in the part of the River Nile that lies within the Egyptian territories. During the French Campaign (1798-1801), these islands were counted to be 215. At the beginning of the 20th century, the number of these islands increased to be 229. A short time before constructing Aswan High Dam (in 1956), the number of islands was 291. After the construction of Aswan High Dam in 1965, the annual Nile flood was fully controlled and the water levels downstream dropped significantly. This drop led to the increase of the total number of islands till they counted 316 in 1982. Today, the number of islands became 492. They cover an area of about 40,000 feddans (16,800 acres). It is worth mentioning that the formation of such islands depends basically on the morphological changes that occur due to the continuous hydraulic and hydrological changes that take place due to natural and human interventions.

EFFECT OF AQUATIC WEEDS ON WATER CURRENT VELOCITIES

The water current velocity profile is largely affected by the presence of aquatic weeds in water. Flow retardation in open channels is always affected by reducing the cross-section of the channel that may result from aquatic weed existence. Guscio et al. (1965) reported the studies which showed that the reduction in designed flow rate for an artificial channel was as much as 97 % due to the presence of aquatic weeds. Many researches studied the velocity distribution profile in channel infested with weeds. Plate and Quraishi (1965) found that the velocity distribution profile above simulated vegetation (submerged weeds) can be represented by logarithmic equation when the bed level is considered at the height of the vegetation.

The velocity distribution profile deviates from the logarithmic distribution curve due to the high turbulence created in the three dimensional field due to vegetation. A power function was suggested for the velocity distribution above the plant cover. Quraishi and Abou-Seida (1975) investigated the velocity distributions inside and above an artificial roughness to get an equation representing the flow in and above model grass. It was concluded that the velocity pattern can not be given by a single curve inside and above the roughness elements. Two equations (power and logarithmic) were developed to represent the velocity distribution above flexible roughness.

Kouwen et al. (1969) found that the logarithmic velocity profile adequately represents flow conditions over the flexible elements. The same conclusion was also noted by Rouse, (1965), Haber, (1982) and Awad (1998).

Awad et al. (1998) carried out an experiment to study the effect of submerged weeds with different heights and densities in a rectangular flume cross section on the velocity distribution profiles. The study showed that the concentration of flow in one part of the channel leads to many problems such as erosion and sedimentation.

OBJECTIVE

This paper aims to study the effect of the floating type of aquatic weeds on water current velocity profile changes in open channels and the consequent effects that may lead to island formation.

THEORETICAL APPROACH

To study the effect of floating weeds on open channel morphology, a theoretical approach together with experimental work is needed. First, a number of parameters which affect the local scour around an obstruction (such as a pier) due to weeds as shown in figure (1) are related below:

$$f\,(d_s\,, Y_a\,, \rho\,, V_a\,, g\,, D_{50}\,, K_w\,, X\,, B, V_s\,, A_s\,) = 0 \qquad (1)$$

where:
f = a function symbol
d_s = the scour depth (L)
V_a = the velocity of approach flow (LT^{-1})
ρ = the fluid density ($M\,L^{-3}$)
Y_a = the depth of approach flow (L)
g = the gravitational acceleration (LT^{-2})
D_{50} = the mean sediment diameter of channel bed at which 50% of sediment is finer (L)
k_w = the roughness height of floating weeds (L)
X = the distance between floating weeds and the obstruction (pier) (L)
B = the maximum width of the scour hole (L)
V_s = the volume of the scour hole (L^3)
A_s = the projected area of the scour hole (L^2)

By applying the theory of dimensional analysis, the relationship between the above different parameters can be presented as follows:

$$ds = f\,(V_a\,, \rho\,, Y_a\,, g\,, D_{50}\,, K_w\,, X\,, B, V_s\,, A_s\,) = 0 \qquad (2)$$

$$\frac{d_s}{Y_a} = f\left(F_r\ ,\frac{V_s}{{Y_a}^3},\frac{A_s}{{Y_a}^2},\frac{k_w}{Y_a},\frac{x}{Y_a},\frac{B}{Y_a}\right) \tag{3}$$

EXPERIMENTAL PROCEDURE

The experimental works and measurements were carried out at the laboratory of the Hydraulic Research Institute (HRI), National Water Research Center (NWRC), Ministry of Water Resources and Irrigation, Egypt. The used flume is a rectangular circulating flume with inner dimensions of 22.70 m long, 0.74 m wide, and 1.0 m deep. The bed is constructed from concrete with a thickness of 0.12 m. All the surrounding walls are cured to prevent seepage losses. The flume walls are provided with two clear glass windows with dimensions of 2.0 m x 0.6 m. The inlet part of the flume consists of a well with dimensions 0.5 m x 0.74 m x 2.0 m. The well is provided with a heavy screen and filled with 60 cm gravel with different grading to dissipate any excessive energy coming from the inlet pipes.

To simulate the natural floating weeds in the physical model, artificial floating weeds were used in the experiment. They consisted of 32 strips of Foam with Aluminum nails. Each strip was 100 cm long, 18 cm wide, 2 cm thick and weighed 500 gm. The strips were used to cover an area of 400 cm long by 72 cm wide. Each Aluminum nail had a diameter of 2.5 mm with an average length of 13 cm. The submerged length of the Aluminum nails was 10 cm. A sand layer of thickness 30 cm was placed at the flume bed to study the scour depth around the pier. The selected pier was a well-rounded wood nose with 32 cm length and 7 cm width. It was placed and fixed in the bed of the flume with a 5 cm thick wood strip.

During the experiment, the measured parameters were the flow rate, flow depth, flow velocity, distance between weeds and the obstruction (pier), scour data in (X, Y, Z directions). The time was kept constant for each run of the experiment. Before the experiment was started, an intensive calibration program was made for all the equipment and flume parts. An accurate leveling of the flume bed was made to check that the bed is completely horizontal. Another accurate leveling was made to the wood angles on which the manual carriage used to run. A Foam mattress (0.72 m x 0.05 m) was laid on the water surface at a distance of 0.5 m from the inlet well to absorb the surface waves and to ensure smooth water surfaces. The depth of water was adjusted by means of a revolving gate which was installed at the downstream end of the flume. The circulating system consisted of an electrically-driven centrifugal pump located at the upstream of the flume, and a pipe line of 6 inches in diameter to accommodate different flow rates. The maximum capacity of the pump was 55 Litre/sec.

Five discharges were selected to run the experiment namely; 20 L/sec; 25 L/sec, 30 L/sec, 35 L/sec, and 40 L/sec. The five different depths which corresponded to the selected discharges were 15 cm, 18.87 cm, 23.95 cm, 25.45 cm, and 31 cm respectively to satisfy the sub-critical and turbulent conditions. For each discharge and depth, a certain gate opening was allocated. The weed distributions attempted were: distribution (U) (weeds covering all of the flume surface width with uniform distribution), distribution (T_1) (weeds covering the flume surface width as a triangular shape where the base of the triangle is close to the pier), distribution (T_2) (weeds covering the flume surface width as a triangular shape where the base of the triangle is far from the pier), and a case without weeds as a comparison reference for the other distributions. Each of the first 3 cases of weed distributions had five different positions with respect to the pier referred as (x_1 , x_2 , x_3 , x_4 ,and x_5) where x was the distance between the pier front and the weeds which was taken equal to 10 cm, 40 cm, 80 cm, 120 cm and 150 cm respectively.

RESULTS AND ANALYSES

1- Effect of Floating Weeds on the Scour around the Pier

Seventy five experimental runs were carried out to investigate the behavior of scour around the pier due to the presence of 3 different distributions of floating weeds at 5 different distances upstream the pier for 5 different discharges. Five more runs were carried out on the smooth case where no weeds were used for the 5 different discharges used. The results of the experiments showed - see figure (2) - that the presence of any distribution of floating weeds increases the scour around the pier because of the consequent change in the vertical distribution of water current velocity over the water depth. The current velocity at the surface decreases while it increases at the lower layers causing such scour. The resulting scour shape and geometry are found to be larger than those in the smooth case. Also, the shape of the scour changes according to the change in the shape of floating weed distribution. The uniform distribution of floating weeds causes a uniform scour while the triangular distribution causes a triangular shape of scour.

It is concluded that the scour shape is a function of the shape of floating weed distribution. For a uniform distribution of floating weeds, the shape of the scour around the pier is nearly uniform but larger than that in the smooth case. Also, the resulting scour shape around the pier due to the presence of floating weeds in a triangular distribution (where the base of this triangle is near the pier) is a triangular shape. This means that the shape of scour hole around the pier follows the shape of floating weeds distribution. The change in the triangular distribution shape of floating weeds (where the base of this triangle is far from the obstruction) leads to a change in the shape of the scour hole.

Computations of the Maximum Scour Depth (d_s) around the Pier

With respect to the distance (X) between the near edge of the floating weed area and the pier

The experimental input data (discharges and water depths) have been used to obtain the relation which describes the effect of floating weeds on the maximum scour depth around the pier (d_s) and the distance between the near edge of the floating weed area and the pier (X). The different longitudinal sections of the scour hole across the center line of the pier for different cases were plotted as shown in figure (3). The analysis of the experimental results showed that for the same discharge, water depth, and weed distribution, the scour depth (d_s) is inversely proportional to the distance (X). Regression analyses were used to obtain linear equations that link the scour depth (d_s) with the distance (X) for the same discharge and water depth. Here are the equations deduced for a discharge (Q) of 20 L/sec:

1- For a uniform distribution of floating weeds:

$$d_s/Y_a = -0.013(X/Y_a) + 0.33 \qquad r^2 = 0.90 \qquad Q = 20 \text{ L/sec} \qquad (4)$$

2- For the triangular distribution (T1) of floating weeds:

$$d_s/Y_a = -0.010(X/Y_a) + 0.20 \qquad r^2 = 0.86 \qquad Q = 20 \text{ L/sec} \qquad (5)$$

3- For the triangular distribution (T2) of floating weeds:

$$d_s/Y_a = -0.002(X/Y_a) + 0.05 \qquad r^2 = 0.94 \qquad Q = 20 \text{ L/sec} \qquad (6)$$

4- The general form is:

$$d_s/Y_a = -C1(X/Y_a) + C2 \qquad (7)$$

where:

Y_a = the approach flow depth corresponding to discharge Q = 20 L/sec, and
C1 & C2 are constants

Table (1): Values of Constants C1 and C2

C1	C2	Case of Weed Distribution
- 0.013	0.33	Uniform
- 0.010	0.20	Triangular (T_1)
- 0.002	0.05	Triangular (T_2)

It can be observed from table (1) that the linear relation between the term (d_s/Y_a) and the term (X/Y_a) is inverse. This is explained by the negative values of constant (C1). As for constant (C2), it changes from (0.33) for the uniform distribution of floating weeds to (0.20) for the triangular distribution (T_1). Then, it decreases to (0.05) for the triangular distribution (T_2). This means that the minimal value of pier scour due to the presence of different distributions of floating weeds is the distribution (T_2).

With respect to Froude Number

The experimental input data (discharges and water depths) have been also used to obtain the relation between the maximum scour depth around the pier (d_s) and the Froude Number (Fr) where the latter is a function of the water current velocity (V). It is equal to $(V/(gY_a))^{0.5}$. The analysis of results showed that for the same relative distance and the same weed distribution, the scour depth (d_s) is directly proportional to Froude Number (Fr) as shown in figure (4) where the governing equations are:

1- For the uniform distribution of floating weeds:

$d_s/Y_a = 0.20(F_r) +0.29 \qquad r^2 = 0.60$ (8)

2- For the triangular distribution (T1) of floating weeds:

$d_s/Y_a =0.60(F_r) +0.14 \qquad r^2 = 0.96$ (9)

3- For the triangular distribution (T2) of floating weeds:

$d_s/Y_a =0.18(F_r) +0.029 \qquad r^2 = 0.97$ (10)

4- The general form is:

$d_s/Y_a =C3(F_r) +C4$ (11)

Table (2): Values of Constants C3 and C4

C3	C4	Case of Weed Distribution
0.20	0.290	Uniform
0.60	0.140	Triangular (T_1)
0.18	0.029	Triangular (T_2)

It can be observed from the positive values of constant (C3) in table (2) and figure (4) that the term (Fr) is directly proportional to the term (d_s/Y_a). The changes in the values of constant (C4) are from (0.29) for the uniform distribution of floating weeds to (0.14) for triangular distribution (T_1). Then, it decreased to (0.029) for triangular distribution (T_2). This explains the reason for the small scour values of triangular distribution (T_2). It is clear that the change in flow velocity affects (Fr) as the latter is a function of the former. Therefore, it can be said that the change in (Fr) due to the presence of different distributions of floating weeds is attributed to the change in velocity values. Consequently, the change in scour values is directly affected by the change in velocity values.

Effect of Floating Weeds on Water Current Velocity Profiles

In order to study the effect of floating weeds on water current velocity profiles through the area of weed distribution, experimental results were plotted for the different distributions of the weeds. Four equally-spaced cross sections along the distribution area with five points (verticals) along each were appointed for measuring the velocity profiles. For the same discharge (Q = 20 L/sec in our case), water depth, and weed distribution, the results showed that the velocity distribution profile undergoes changes due to the presence of floating weeds as shown in figure (5). The difference in velocity values from surface to bed and from the beginning of weed distribution to end leads to a change in channel morphology especially channel bed scour.

Case of Triangular Weed Distribution (T1)

It was noted that the velocity distribution profile due to the presence of floating weeds in triangular distribution (T1) did not change at the beginning of weeds compared with the smooth case. But the velocity near the bed of the channel inversely changed with respect to the velocity at the surface. At the middle of the longitudinal section of floating weeds, the velocity decreased at the surface compared with the smooth case, but increased at the channel bed. The velocity at the end of weeds changed dramatically compared with the smooth case. This means that the change in distribution shape of floating weeds leads to a great change in velocity distribution profile through the longitudinal section of vegetation.

Case of Triangular Weed Distribution (T2)

For the same discharge and depth, the results of triangular weed distribution (T2) were also plotted. The results showed that the velocity decreased at the surface compared with the smooth case but remained unchanged at the bottom. The velocity at the end of weeds increased at the water surface while it decreased at some verticals and increased at others. This means that the change in distribution shape of floating weeds leads to a change in velocity distribution profile through the longitudinal section of vegetation.

Case of Uniform Weed Distribution

The velocity values due to the uniform distribution of floating weeds are found to be bigger than those due to the application of triangular distribution (T1) and (T2). It is noted that the values of triangular distribution (T2) are the lowest among the results of the different distributions. The predicted velocity profile curves due to the presence of floating weeds in uniform distribution are shown in figure (6).

Computations of Flow Velocity Profile under the Weed Distribution Area

From the experimental results, an equation which can be used to compute the velocity values in the vertical zone between the floating weeds and the channel bed could be deduced. The final form of the equation is shown below:

$$(Y/h) = m_i * Ln(V/V_{max}) + \qquad (12)$$

where the subscript (i) denotes the shape of distribution of floating weeds. The constant (m_i) is equal to (- 1.84) for the uniform distribution, (-1.44) for triangular distribution (T1), and (+ 0.14) for triangular distribution (T2).

(C_i) is also a constant equal to (0.49) for the uniform distribution, (0.744) for triangular distribution (T1), and (0.94) for triangular distribution (T2). The variations in the constants (m_i) and (C_i) indicate the validity of equation (12), where the regression analysis showed that the R-squared values for both triangular distributions (T1) and (T2) were 0.12 and 0.002 respectively. These values of R-squared indicate that the equation is not valid for either triangular distribution (T1) or (T2).

Effect of Floating Weeds on the Velocity Profiles at the diagonal section

The velocity distribution profile through the diagonal section due to the presence of floating weeds in triangular distribution (T1) upstream the pier increased from vertical 1 to vertical 5 as shown in figure (7). This means that the velocity below vegetation for the triangular distribution (T1) increases in the diagonal direction.

The velocity distribution profile at the diagonal section due to the presence of floating weeds in triangular distribution (T2) changed as shown in figure (8), where the bed velocity values at verticals 1 and 3 are bigger than those in vertical 2. But for vertical 3, the bed velocity values are bigger than those in vertical 2. This means that the velocity below vegetation for triangular distribution (T2) decreases in the diagonal section.

For different discharges, the same results were obtained. These changes in the velocity profiles are the mainly responsible for bed scour changes and hence the morphological changes in the channel cross section.

CONCLUSIONS

From the above results and analyses, it can be concluded that:

1. The resulting scour shape and geometry around an obstruction (such as a pier) increases due to the presence of floating weeds upstream it. Here, the geometry

means the dimensions of the scour hole formed such as the scour depth, width, and projected area while the shape means the resulting layout of the scour which may be circular, triangular or polygonal.

2. The shape of the scour also changes according to the shape of the floating weeds distribution. This means that the scour shape is a function of the floating weeds distribution shape.
3. The relation which describes the effect of the floating weeds on the maximum scour depth (d_s) around an obstruction and the distance (X) between the near edge of the floating weed distribution and the obstruction front could be formulated.
4. For the same relative distance (X), and the same weed distribution, the scour depth (d_s) is directly proportional to Froude number.
5. The presence of floating weeds in different shapes upstream an obstruction leads to a change in velocity distribution profiles in longitudinal and transverse sections throughout the weed distribution zone and the downstream zone. This change results in new sediment distribution downstream which, in turn, leads to aggradation/degradation processes that eventually cause both bed scour and island formation.
6. The presence of floating weeds in triangular shapes leads to a change in surface velocities and bed velocities. The change in surface currents values is balanced by a counter change in bed currents values. This means that the increase in surface currents values leads to a decrease in bed currents and vice versa.
7. The directions of surface currents and bed currents velocities tend to deviate to the zones free from vegetation because of the presence of floating weeds in different shapes.

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ABBREVIATIONS

T1 = The triangular distribution of floating weeds of shape T1
T2 = The triangular distribution of floating weeds of shape T2
U = The uniform distribution of floating weeds
S = The distribution without floating weeds
Q = The flow discharge *L/s*
X = The distance of floating weeds from the hydr. structure pier
X_{10} = The distance of floating weeds from the pier equal 10*cm*
X_{80} = The distance of floating weeds from the pier equal 80*cm*
V.S = Velocity at water surface level *m/s*
V_b = Velocity at bed level *m/s*
V_m = Mean velocity at bed level *m/s*
W.dep. = Water depth cm

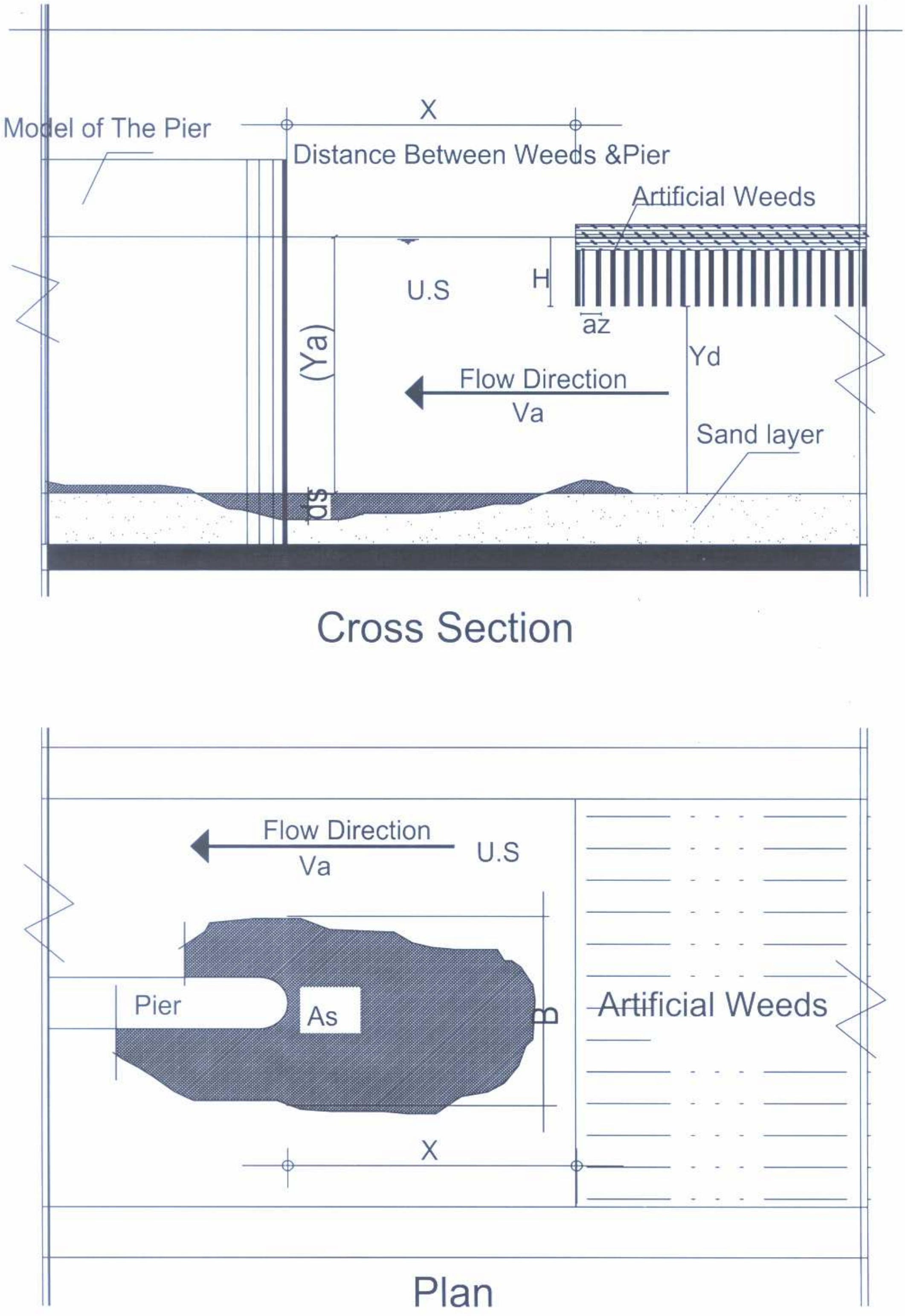
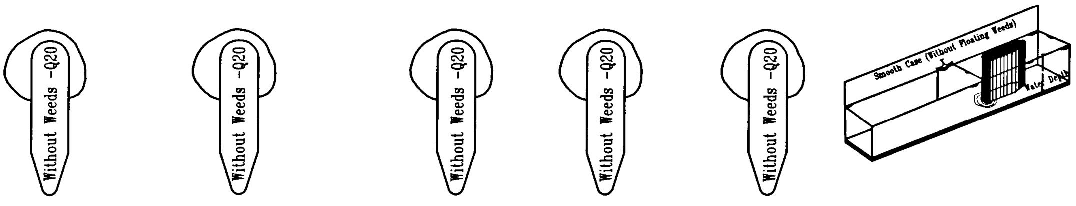
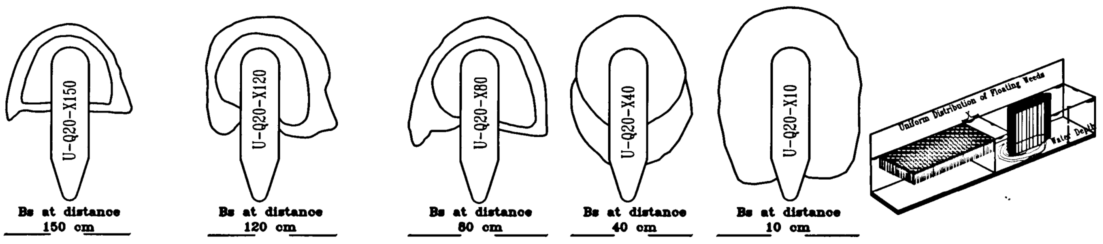


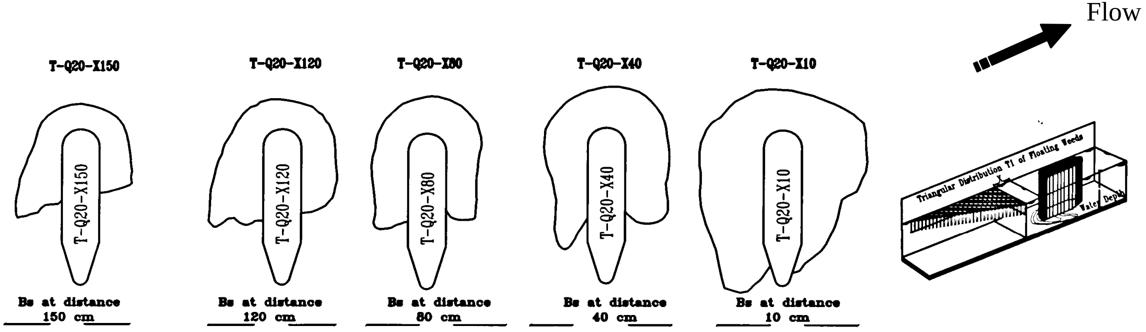
Figure (1) Definition Sketch Showing Dimensional Analysis Parameters



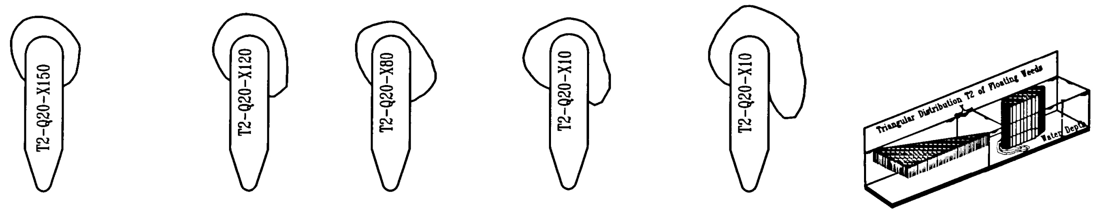
Scour Geometry Due to The Smooth Case



Scour Geometry Due to The Uniform Distribution of Weeds



Scour Geometry Due to The Triangular Distribution of Weeds T1



Scour Geometry Due to The Triangular Distribution of Weeds T2

Figure (2) Scour Geometry for Different Distributions of Floating Weeds

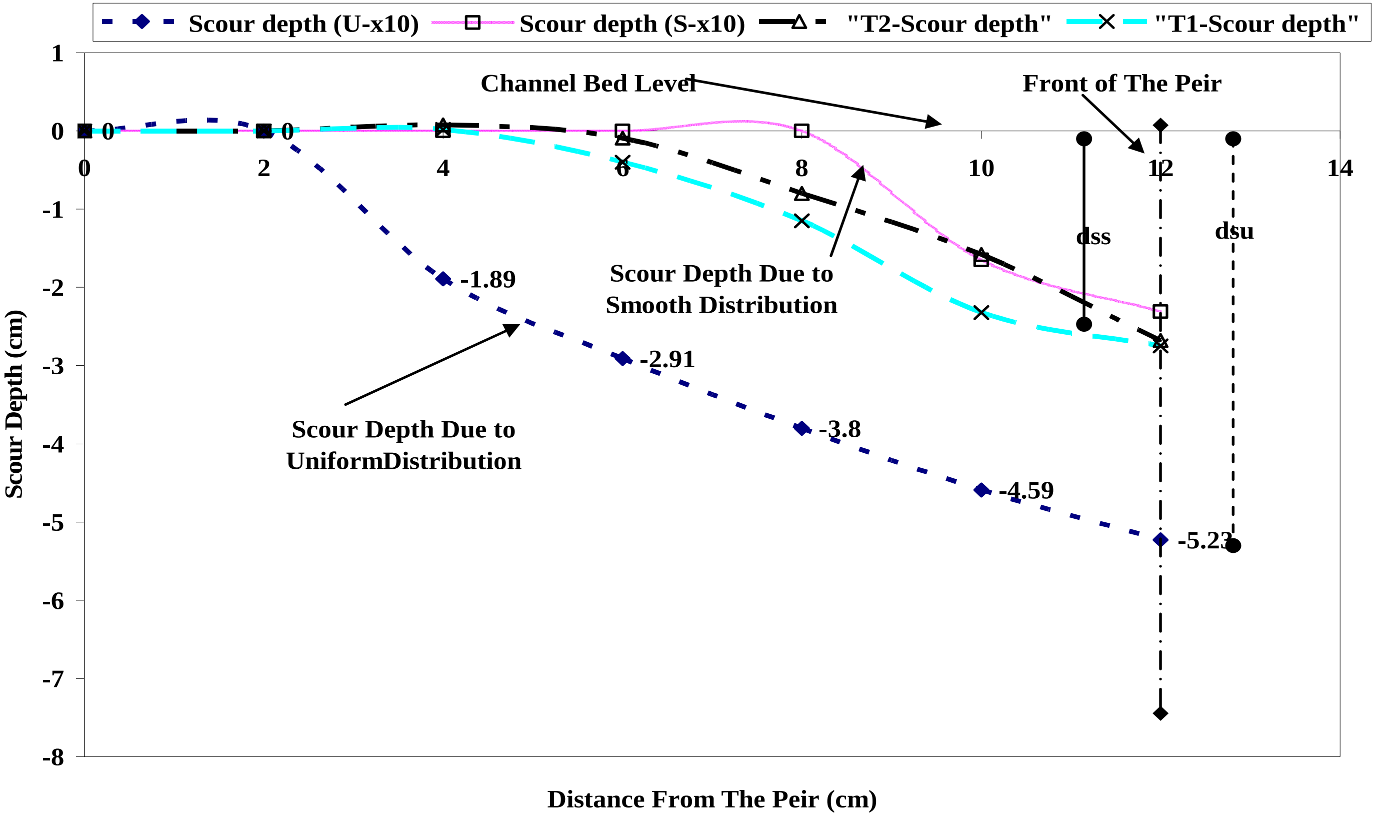


Figure (3): The Scour Depth Profile due to Different Distributions of Floating Weeds

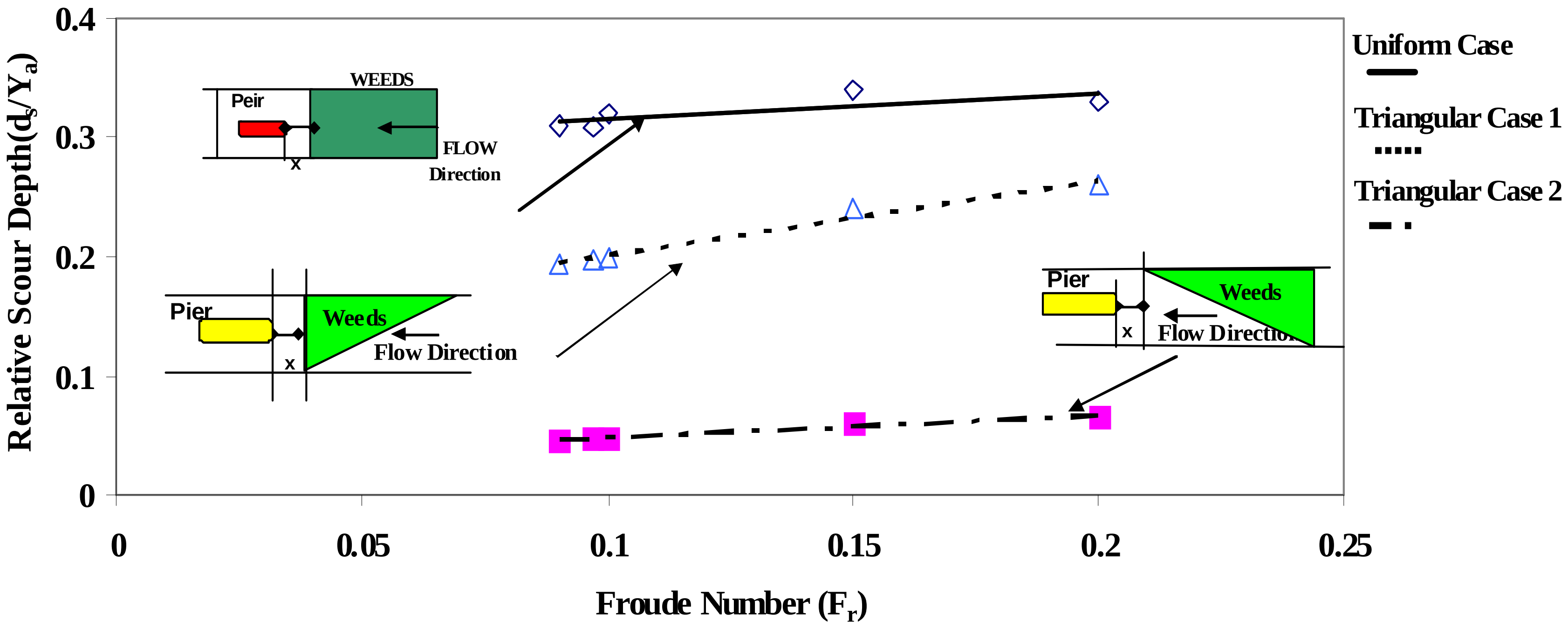


Figure (4): The Relation between Froude No. and Scour Depth for Different Distributions of Floating Weeds

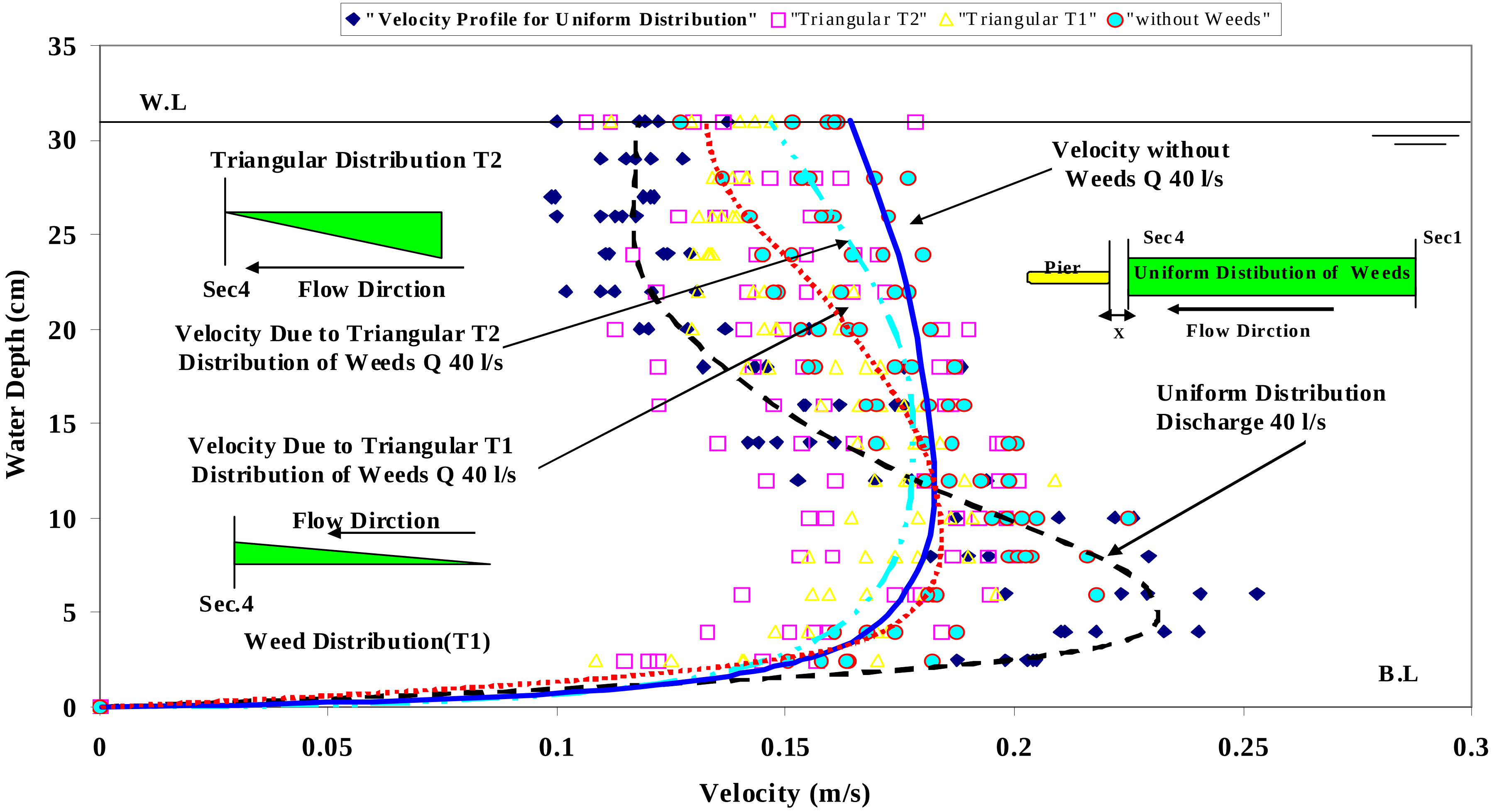


Figure (5): Approach Velocity Profiles for Different Distributions of Floating Weeds at (Sec4) for Discharge 20L/s

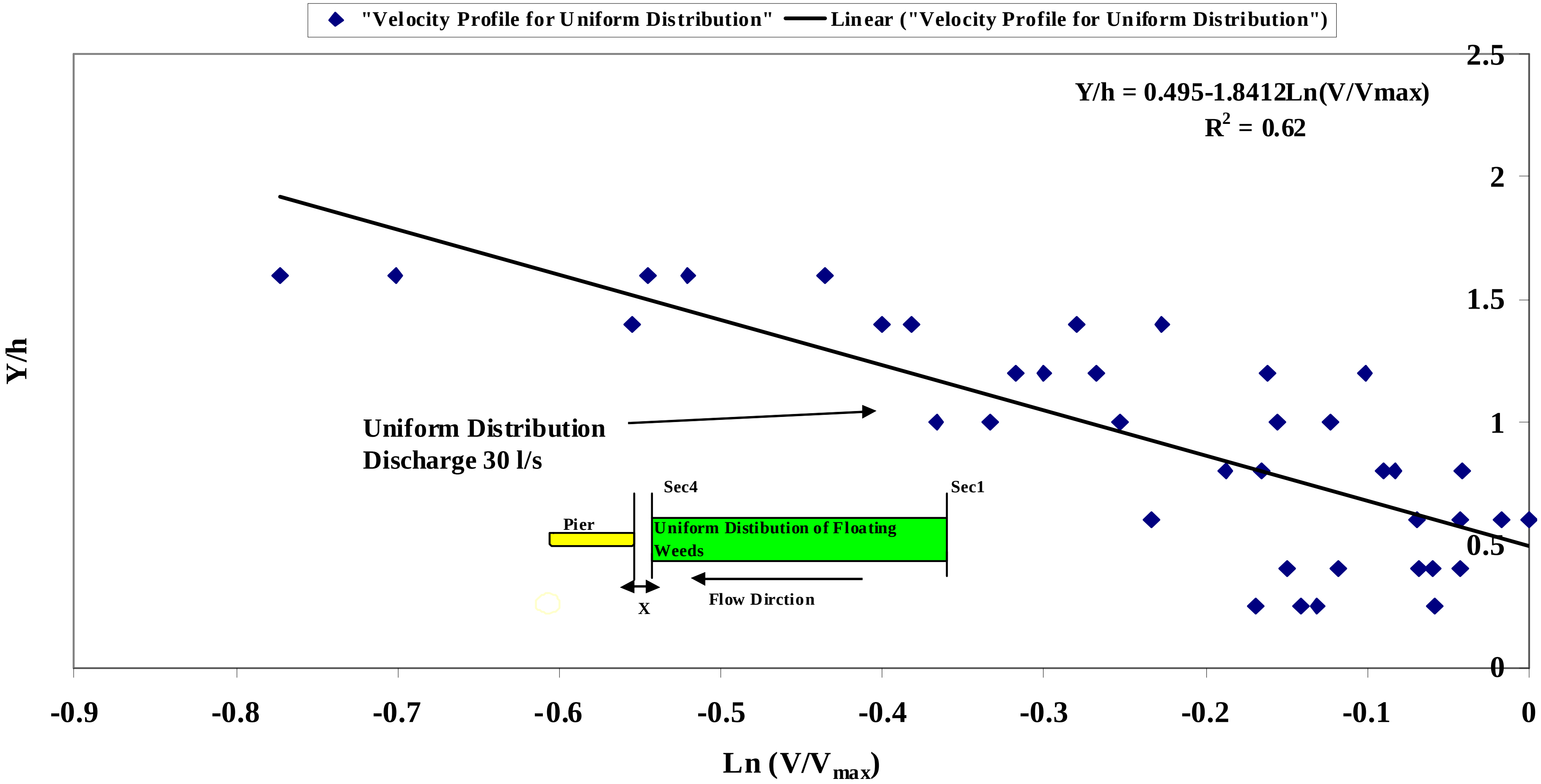


Figure (6): The Predicted Velocity Curve below Weeds for Uniform Distribution of Floating Weeds

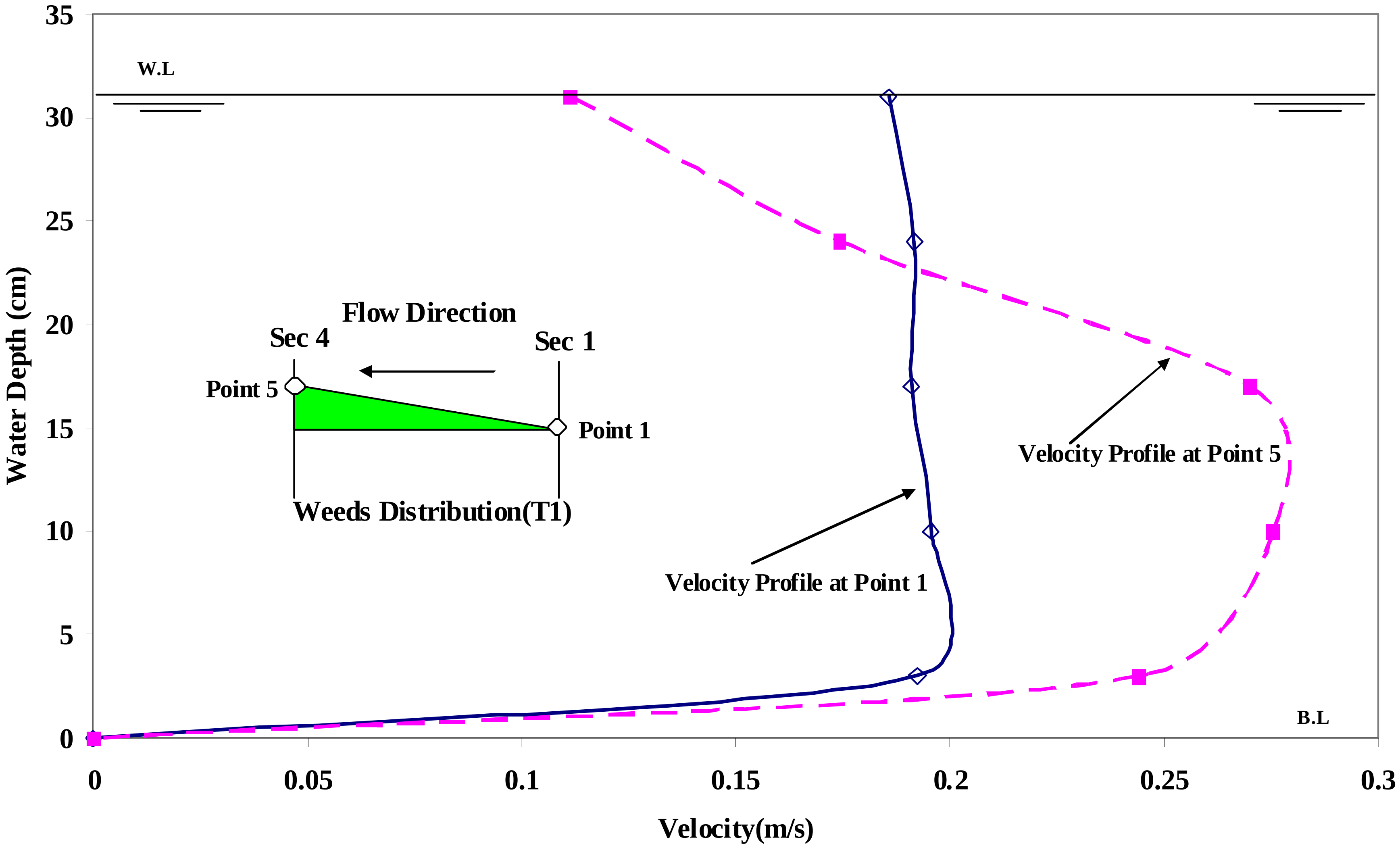


Figure (7): The Velocity Profile in the Diagonal Direction for Distribution (T1) for Discharge 20 L/s

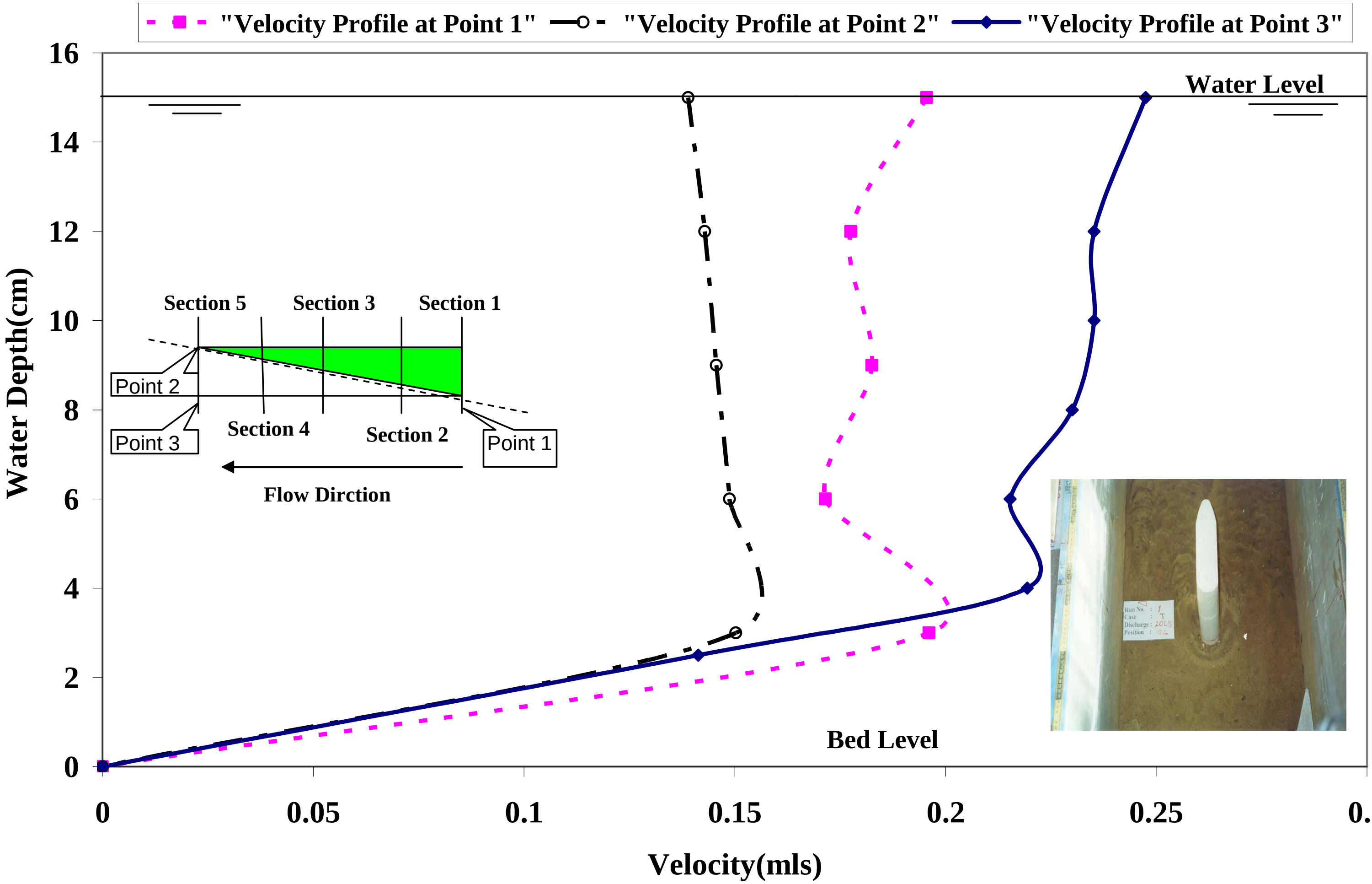


Figure (8): The Velocity Profile in the Diagonal Direction for Distribution (T2) for Discharge 20 L/s