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PERFORMANCE OF CONTROL STRUCTURES IN CHANNELS INFESTED BY AQUATIC WEEDS IN EGYPT

أداء منشآت التحكم فى الترع المصابة بالحشائش المائية فى مصر

BY

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خلاصة

تعتبر منشآت التحكم من المنشآت المائية الهامة التي تلعب دورا كبيرا في إتاحة كميات المياه بالتصرفات والمناسيب المطلوبة، والبوابات أحد أهم عناصر منشآت التحكم و يوجد العديد من أشكال البوابات المستخدمة في مصر، لذا كان اهتمام كثير من الباحثين بدراسة الخصائص الهيدروليكية للسريان أسفل البوابات. لقد أثبتت الدراسات أن حوالي ثمانين بالمائة من المجارى المائية فى مصر معوقة بالحشائش المائية بكل أنواعها، وتعتبر الحشائش المغمورة هى أكثر الحشائش إنتشارا حيث انتشرت الحشائش المائية بصورة متزايدة منذ عنتصف السبعينات بعد إنشاء السد العالي. لذا فإن إصابة كثير من الترع المقام عليها منشآت التحكم بالحشائش المائية المغمورة قد يغير خصائصها الهيدروليكية كما قد يسبب عديد من المشاكل مثل زيادة معامل الخشونة للمجاري المائية و تخفيض التصرف التصميمى للقطاع وكذلك سرعة السريان الفعلية. ولقد تبين أنه من الصعب عمليا إزالة الحشائش المائية بصورة كلية فإن تخفيض كثافتها إلى درجة مقبولة يصبح أمرا ضروريا مع الأخذ في الاعتبار وجود بعض هذه الحشائش عند تشغيل بوابات منشآت التحكم. لذا فالهدف الرئيسي من هذا البحث هو دراسة تأثير تغيير كثافة الحشائش المائية على الخواص الهيدروليكية للتدفق المغمور أسفل البوابات الرأسية وعلى كفاءة أداء هذه البوابات وقد تمت الدراسة النظرية باستخدام التحليل البعدي كما تم استنتاج معادلة لإيجاد فاقد الطاقة الناتجة عند البوابات الرأسية نتيجة وجود الحشائش المائية . وقد تمت الدراسة معمليا على نموذج لقنطرة مكونة من فتحتين ذات بوابات رأسية داخل قناة معملية على شكل شبه منحرف ذات قاع أفقي وقد تم تمثيل الحشائش المائية بشرائح من البلاستيك المرن ذات عدة فروع تم تثبيتها على القطاع المائي.

ABSTRACT:

The hydraulic structures play a very important role in controlling the channel discharge and the water levels, but the presence of the hydraulic structures in channels infested by aquatic weeds may cause significant problems for the performance of these structures. In Egypt more than 80% of the canals and the drains are heavily infested by all types of aquatic weeds. This infestation has started shortly after the construction of the High Aswan Dam. The most prevailing type of aquatic weeds is the submerged weeds. This type of weeds decreases the channels hydraulic efficiency as the flow resistance increases. In the present study, the effect of submerged weeds density on the performance of vertical sluice gates was analyzed experimentally. The dimensional

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analysis was employed to derive an expression for the discharge coefficient and an equation for predicting the energy losses on the gates are developed. The experimental modeling was developed for a double vent regulator model with vertical sluice gates constructed in a trapezoidal flume and the branched flexible roughness were used to simulate the submerged weeds. The extensive laboratory measurements concentrated mainly on the discharge coefficient, the energy losses, the variation in the water surface profile, the velocity distribution and the variation in the equivalent roughness coefficient.

KEYWORDS

Experimental modeling, Dimensional analysis, Vertical sluice gates, Submerged weeds, Branched flexible roughness, Discharge coefficient, Energy loss.

1. INTRODUCTION

Due to the practical importance of the sluice gates as control and metering devices, the prediction of the characteristics of the flow under gates has been one of the classical problems of hydraulics. Consequently, many experimental, theoretical and numerical studies of this problem have been achieved. The Irrigation engineers aim to operate the control gates at the highest possible efficiency, but the presence of vegetation in channels causes many problems such as increasing the roughness of channels boundaries, increasing water losses, and increasing water energy losses, which produce a reduction of the hydraulic efficiency for such gates.

During the last thirty years, shortly after the construction of the High Aswan Dam, the aquatic weeds with their various types have flourished and spread all over the Egyptian water courses. The weeds mostly found in the Egyptian irrigation network can be grouped into three main types which are: floating weeds, submerged weeds and ditchbank and emerged weeds. The field monitoring shows that, the submerged weeds represent the major part of the total length of the irrigation network infested by aquatic weeds. To improve the hydraulic efficiency of the irrigation network, aquatic weeds should be controlled to an acceptable low level with minimum costs. Therefore, the presence of weeds has to be taken into consideration in the analysis. The main objective of this research is to study the effect of submerged weeds density on the hydraulic characteristics of submerged flow under sluice gates.

2. THE STATE OF THE ART

The presence of the aquatic weeds reduces seriously the hydraulic efficiency of the irrigation system and large quantities of water are lost. The cultivated area in Egypt is irrigated from the River Nile through 32000 km of canals and drained by a system of drains of a total length 16000 km, (13). It is found that the total lengths of canals and drains infested by all types of weeds were estimated by 32100 km. From which 1900 km were covered by Eichhornia crassipes and 15000 km are infested by submerged weeds mostly Potomogaton spp. and Ceratophyllum demersum. Lengths infested by emergent weeds were estimated by 7200 km, while the channels infested by more than one type are 8000 km. From previous studies, it can be concluded that the major type of aquatic weeds infesting Egyptian canals and drains is the submerged weeds (13,14). The presence of aquatic weeds in irrigation channels causes many problems summarized by El-Samman, (7). At present, three major methods of aquatic weed control are carried out in Egypt which are manual, mechanical, and biological.

Water flowing in open channels is retarded by frictional losses against the boundaries. These frictional losses are described as resistance to flow and can be estimated by many formulae especially the well known Manning formula (4). Simulation of flow characteristics in channels with artificial rigid roughness, small sheet metal roughness or nails, were studied by Robinson and Albertson, (20), Zein et al., (23), and Nagy and Watanabe (19). Simulation of flow characteristics in channels with artificial flexible roughness, plastic strips, were studied by Kouwen and Unny, (15), Salama et. al (21), El-Samman, (7,8) and Gado, (9) . Many Researches were carried out on vegetated natural channels with the purpose of describing their behavior and the effect of vegetation on the flow characteristics. Most of them relate the Manning's roughness coefficient, n, to the retardance of channels, Gwinn and Ree, (10), and Bakry, (2).

The flow under sluice gates can be classified into two types, free flow and submerged flow. Both types have been extensively studied, some of these studies considered the effect of gate shapes on the flow characteristics and others studied the effect of constructed sill under the gate. The flow characteristics under control sluice gates have been studied theoretically by Henderson (11), and Abdel Salam et al. (1) and experimentally by Boiten (3), El Ganaiany (5) and numerically by Isaacs (12). and Montes (17). In 1993, Salama (22) determined experimentally the effect of submerged weeds on the energy loss of sudden transition structures. The branched plastic strips were used to simulate the weeds and were distributed on the wetted perimeter in rows at upstream of the sudden transition structure. In 2000, Mowafy and El-Sayed (18), studied experimentally the effect of weeds accumulation around bridge piers on both the scour depth and the heading up.

3. STATEMENT OF THE PROBLEM

The flow under the vertical sluice gates of a double vent reinforced concrete regulator constructed in a trapezoidal channel infested by submerged weeds was considered in the present study and figure (1) presents the definition sketch for the problem. The orifice equation and the energy equation were used to deduce the theoretical relations between the involved variables. The submerged flow under a sluice gate was considered as a submerged flow through a sharp rectangular orifice given by, (4):

$$Q = C_d\, a\, b \sqrt{2 g \Delta y} \qquad (1)$$

in which :

Q: the discharge passing through the sluice gate;
C_d: the discharge coefficient;
a: the gate opening height;
b: the gate opening width;

Δy: the difference between upstream and downstream water levels; and
g: gravitational acceleration.

The following assumptions were considered for the theoretical approach : i) the flow was ideal and steady, ii) the flow was incompressible, irrotational and non viscous, iii) the bed and the sides of the channel were frictionless, vi) no effect of internal force and outside temperature, v) no resistance effect of wind fraction, and iv) the pressure distribution is hydrostatic.

To calculate the energy loss through the regulator due to the existence of submerged weeds, the specific energy equation could be applied between section (o) in the upstream and section (t) in the downstream, Fig. (1). It can be written as ;

$$y_o + \frac{Q^2}{2gA_o^2} = y_t + \frac{Q^2}{2gA_t^2} + \Delta E \tag{2}$$

in which ΔE is the energy loss between sections (o) and (t). Eq. (2) can be written as, (9), Fig.(1):

$$\Delta E = \frac{Q^2}{2gA_o^2}\left[1 - \left(\frac{A_o}{A_t}\right)^2 + \left(\frac{2y_o}{F_{ra}^2\, y_{ho}}\right)\left(1 - \frac{y_t}{y_o}\right)\right] \tag{3}$$

in which :

A_o	cross sectional area of the flow U.S. the vegetated reach;
A_t	cross sectional area of the flow at the tail water depth;
F_{ra}	Froude's number under the gate;
y_o	depth of flow upstream the vegetated reach, Fig.(1);
y_t	tail water depth;

y_{ho} is the hydraulic mean depth at section (o) ($y_{ho}= A_o/T_o$); and
T_o is the top width at section (o).

From Eq. (3) , it can be deduced that;

$$\Delta E = C_L \frac{Q^2}{2gA_o^2} \tag{4}$$

in which,

$$C_L = \left[1 - \left(\frac{A_o}{A_t}\right)^2 + \left(\frac{-2y_o}{F_{ro}^2\, y_{ho}}\right)\left(1 - \frac{y_t}{y_o}\right)\right] \tag{5}$$

Equation (4) is a general equation for calculating the energy loss due to the regulator and submerged weeds simulteneously. The coefficient C_L depends on the shape of the inlet and the exit wing wall, the height of gate opening, the type, density and distribution of weeds and the flow conditions.

4. DIMENSIONAL ANALYSIS APPROACH

The dimensional analysis was employed to drive an expression for the discharge coefficient. The variables affecting discharge characteristics can be classified into three groups as follows :

Fluid characteristics: g; gravitational acceleration (LT^{-2}), ρ; fluid density (ML^{-3}). μ; dynamic viscosity of fluid ($ML^{-1}T^{-1}$).
Flow characteristics : Q; the discharge (L^3T^{-1}), V_a the velocity of water under the sluice gate (LT^{-1}), y_u; the water depth upstream the sluice gate (L), y_d; the water depth downstream the sluice gate (L), y_t; the tail water depth (L), Δy; the difference between upstream and downstream water levels (L).
Boundary characteristics: b; gate opening width (L), a; gate opening height (L), D; density of vegetation (L^{-2}), H; original vegetation height (L), n; Manning's roughness coefficient ($L^{-1/3}T$).
The general relationship among these variables may be written as :

$$f(Q, g, \rho, \mu, V_a, y_u, y_t, \Delta y, b, a, D, H, n) = 0 \tag{6}$$

By using Backingham's π-theory to develop a proper correlation between these variables, the following equations can be obtained, (9) :

$$\Phi 1\,(1/F_{ra}^2,\ 1/R_{Na},\ y_u/a,\ y_t/a,\ \Delta y/a,\ b/a,\ a^2D,\ H/a,\ nV_a/a^{2/3}) = 0 \tag{7}$$

in which :

$$F_{ra} = \frac{V_a}{\sqrt{g\,a}} = \frac{Q}{b\,a\sqrt{g\,a}} = \frac{C_d\,a\,b\sqrt{2\,g\,\Delta y}}{a\,b\sqrt{g\,a}} = C_d\sqrt{\frac{2\,\Delta y}{a}} \tag{8}$$

By solving for C_d, then :

$$C_d = \Phi_2\,(F_{ra},\ R_{Na},\ a/y_u,\ y_t/a,\ \Delta y/a,\ b/a,\ a^2D,\ H/a,\ nV_a/a^{2/3})\ \frac{1}{\sqrt{2\,(\Delta y/a)}} \tag{9}$$

then:

$$C_d = \Phi_3\,(F_{ra},\ R_{Na},\ a/y_u,\ y_t/a,\ \sqrt{\Delta y/a},\ b/a,\ a^2D,\ H/a,\ nV_a/a^{2/3}) \tag{10}$$

Neglecting the effect of Reynold's number R_{Na} as the fluid viscosity has a negligible effect, one reaches, (9):

$$C_d = \Phi_4\,(F_{ra},\ a/y_u,\ y_t/a,\ \sqrt{\Delta y/a},\ b/a,\ a^2D,\ H/a,\ nV_a/a^{2/3}) \tag{11}$$

5. EXPERIMENTAL MODELING

The problem of submerged flow under sluice gates in channels infested by submerged weeds was simulated experimentally in the present study. The channel was simulated using a trapezoidal flume, the sluice gates were simulated using vertical gates in a regulator model and the submerged weeds were simulated using branched plastic sheets. The flume used in the present study had a total length of 22.10 m. The trapezoidal cross section was of 0.60 m wide, 0.42 m maximum depth, 16.22 m long, and 1:1 side slope. The regulator model consists of one pier, two wing walls, and two sluice gates. The pier was 80 cm long, 10 cm wide, and 42 cm high. The pier had a circular upstream and downstream nose with 5 cm radius. Each wing wall was 80 cm long and 42 cm high. The clear distance between the pier and each wing wall was 25 cm. Each sluice gate was 26 cm wide, 30 cm high, and 0.80 cm thick. The sluice gates were made of Perspex, Fig. (2).

To represent the submerged weeds in nature, the artificial branched flexible roughness elements were cut out from a 2 mm plastic sheets. The type of plastic sheets was selected to float in waterway to simulate the submerged aquatic weeds in nature. The dimensions of branched roughness element was 1.00 cm wide, 0.20 cm thick, and 10.00 cm high, the height was divided into three parts. The weeds were distributed on trapezoidal cross section in stagger as shown in Fig (3). The flexible roughness elements were fastened to the bed and sides along the selected tested length upstream the gates. A movable carriage was constructed for the purpose of measuring water surface levels and velocity. It could be moved along the whole length of the working section, and was provided with a point gauge. It could carry a velocity meter. A scale was fixed on the carriage transverse direction to allocate the longitudinal cross section required. An electronic flow meter was connected to the model to measure the discharge automatically in l/s. The accuracy of reading with this electronic flow meter was found to be ± 0.02 l/s. The point gauge was used to measure the depth of the flow at different sections. The vernier of the point gauge could read to the nearest 0.01 cm. The velocity profiles at different verticals and different cross sections were measured by means of electromagnetic liquid velocity meter, Model P-EMS, WL/Delft Hydraulics. The current sensor accuracy is equal to or less than ± 0.002 m/s.

The water was supplied to the flume from underground reservoir through 5 inch diameter pipe fitted with a regulating sluice valve. The flow was uniformly distributed by using two vertical plates to eliminate the turbulence due to the inlet transition. Water was drained from two 8 inch diameter pipes to the underground reservoir and the flow was re-circulated by using two pumps. The required discharge was adjusted by the sluice valve and the electronic flow meter. Water levels were adopted using the tilted tail gate.

6. EXPERIMENTAL PROGRAM

Before starting the experimental work, an intensive calibration program is made for all the equipment and the flume parts. After the calibration is made, the bed is completely covered with plastic sheets with a thickness of 3 mm to allow for the weeds fastening. Five discharges were selected and for each discharge a test is carried out for five heights of gate openings for the case of no vegetation on the cross section (smooth case). The five discharges are 37, 34, 31, 28, and 25 l/sec. The five gate openings are 5, 7, 9, 11,and 13 cm. For each discharge and each gate opening, the depth at the upstream reach to be infested by vegetation is measured and is stored to be used in the different study densities. For each depth, discharge, and gate opening a certain tail gate opening is allocated. Two densities were used in the present study; $D_1 = 0.25$, $D_2 = 0.\ 0625$ (stem/cm^2). There were three cases of experimental work which were used according to the upstream depth of vegetated reach. The three cases were : i) smooth case where no weeds on the cross section., ii) case A where the upstream depth was increased compared to the depth of smooth case, iii) case B where the upstream depth of the reach infested by weed was decreased with partially closing the sluice valve until the upstream depth is equal to the depth in smooth case. The smooth case, case A, and case B are described in Fig. (4). The following procedures were followed to conduct each test :

1) The density weeds required were prepared and fixed in the flume, 2) the required sluice gate opening was adjusted, 3) the required tilted gate opening was adjusted, 4) the flume was filled to a suitable level, 5) the flow was re-circulated by the pump, 6) the sluice valve was opened and adjusted to provide the required discharge, 7) after attaining the steady condition the following measurements were recorded; the water

surface profiles were recorded for cases A and B, the upstream water depth y_u, the downstream water depth y_d, the tail water depth y_t, 8) the discharge was measured for case B and adjusted for case A, 9) the velocity for two dimension flow was vertically measured every 1.0 cm. The details of experimental data were given by Gado, (9).

7. COMPARATIVE STUDY ANALYSIS

The comparison between the present study and the previous studies of El-Saiad (6) and Mohamed (16) as for the relationship between the Froude's number under the gate and ($\sqrt{\Delta y/a}$) is shown in Fig.(6). The present results agree favorably with the previous results. The curves give nearly the same ($\sqrt{\Delta y/a}$) for lower values of (F_{ra}) (subcritical flow) and the difference increases as (F_{ra}) increases, and the maximum percentage of difference between the present results and previous results for($\sqrt{\Delta y/a}$) was about 15.3 % at (F_{ra})= 1.9. This was due to the difference in the shape and the dimensions of the flume used in each study. The relationship between the theoretical and the experimental (F_{ra}) is shown in Fig.(7). This figure indicates that the experimental (F_{ra}) is higher than the theoretical (F_{ra}) covering all values of ($\sqrt{\Delta y/a}$). The difference increases as ($\sqrt{\Delta y/a}$) increases and the percentage of difference is constant (about 20%). This is due to the approximation in the theoretical equation, $F_{ra} = 0.863\sqrt{\Delta y/a}$.

8. ANALYSIS AND DISCUSSION OF RESULTS

The experimental data described previously for the case of no weeds and the two weeds densities were presented and analyzed. The effect of weeds density on the hydraulic characteristics of submerged flow under sluice gates was studied. The experimental data were used to calculate the basic parameters derived in the theoretical approach. The analysis of the experimental results show the effect of submerged vegetation on: water surface profiles; velocity profiles; flow parameters; energy losses; discharge; and equivalent Manning's roughness coefficient.

8.1. Effect of Submerged Vegetation on the Water Surface Profiles

Water surface profiles were measured for five heights of gate opening, two weeds densities, two cases A and B and the smooth case. Water surface profiles for cases A, B and the smooth were plotted together to show clearly the heading up due to vegetation. For example, the water surface profile for the gate height a = 13 cm is shown in Fig. (8a) for density 1 and Fig. (8b) for density 2 respectively. It can be noticed that the slope of water surface in the zone infested by submerged vegetation is a function of the height of gate opening, vegetation density and discharge. Also, the slope of water surface increases with the increase of the height of gate opening and weeds density. It could be concluded that the heading up was increased with the increase of weeds density. The heading up was the difference in water levels between case A and the smooth case at a reference place 1 m upstream the vegetation. It's clear from these figures that the presence of submerged vegetation upstream the regulator model nearly has no effect in the water surface profile downstream the regulator model.

8.2. Effect of Submerged Vegetation on the Velocity Profiles

The vertical velocity profiles were measured at three different cross sections for the smooth case, density 1 and density 2 and three heights of gate opening (5, 9 and 13 cm). The three different velocity profiles were at the beginning of the infested length, in the middle of the infested length (upstream the regulator model) and finally downstream the regulator model. For each run, the profiles were measured at five vertical sections, Figs.(5a) and (5b). All vertical velocity profiles were drawn for maximum discharge and for case A, Gado, (21). For examples Fig.(9) shows the vertical velocity distribution for the height of gate opening, a = 13 cm for cases of smooth, weeds density 1 and density 2. The analysis of the experimental data of vertical velocity profiles upstream the regulator model shows that : i) the velocity profiles were symmetrical in case of no weeds on cross section (smooth case), ii) the velocity profiles were not symmetrical in case of weeds density 1 and density 2. This phenomena was observed by El-Samman, (7) and defined as swinging flow. The flow increases in one side of the stream than the other causing a non-uniform bed shear stress distribution resulting in more bed erosion, this was due to warping of the flow axis in plan, iii) the main part of the flow was over the vegetation zone while the flow through the vegetation was very small.

The vertical velocity profiles downstream the regulator model were prepared and drawn for all the carried out tests. For example Fig.(10) for the height of gate opening a = 13 cm for cases of smooth, weeds density 1 and density 2. The analysis of the experimental data of vertical velocity profiles downstream the regulator model shows that : i) the velocity profiles were symmetrical in cases of smooth, weeds density 1 and density 2, ii) the presence of weeds slightly decreased the velocity about average 13.5%.

8.3. Effect of Submerged Vegetation on the Flow Characteristics

In this section, the relationships between the different flow parameters were plotted to show the effect of weeds density on the characteristics of submerged flow under the sluice gates. The charts were drawn for the case of no weeds (smooth), weeds density 1 (D1), and weeds density 2 (D2).

8.3.1. Relationship between (y_t) and (y_u)

The general relationship between the tail water depth (y_t) and the upstream water depth (y_u) is a direct proportion as shown in Fig. (11). From this figure, it can be observed that: i) any increase in the tail water depth leads to an increase in the upstream water depth, ii) the weeds density do not affect the relationship between y_t and y_u, iii) the relationship between (y_u/a) and (y_t/a) for different weeds densities can be expressed by;

$(y_u/a) = 0.553\ e^{0.69\ (y_t/a)}$ (12)

in which the determination coefficient (R^2) = 0.99.

8.3.2 Relationship between (y_t) and (y_d)

Figure (12) shows the relationship between the tail water depth (y_t/a) and the downstream water depth (y_d/a). From this figure, it can be observed that: i) any increase in the tail water depth leads to an increase in the downstream water depth, ii) the weeds density do not affect the relationship between y_t and y_u, iii) the relationship between (y_d/a) and (y_t/a) for different weeds densities is a straight line and can be expressed by:

$(y_d/a) = 0.8\ (y_t/a) + 0.225$ (13)

in which the determination coefficient (R^2) = 0.99.

8.3.3 Relationship between (C_d) and (a/y_u)

The relationship between the discharge coefficient (C_d) and the ratio of gate opening to upstream water depth (a/y_u) was plotted as shown in Fig. (13). This figure indicates that the discharge coefficient increases as the ratio (a/y_u) increases. The relationship between (C_d) and (a/y_u) can be expressed by;

$C_d = a_1\ (a/y_u)^2 + a_2\ (a/y_u) + a_3$ (14)

in which a_1, a_2 and a_3 are constants. These constants were estimated by the least squares technique and given by Table (1).

8.3.4 Relationship between (C_d) and (y_t/a)

The relationship between the discharge coefficient (C_d) and the ratio of tail water depth to gate opening (y_t/a) was plotted as shown in Fig. (14). This figure indicates that the discharge coefficient decreases as the ratio (y_t/a) increases (increasing the submergency of the gate opening). For smaller values of (y_t/a) (case close to free flow), the discharge coefficient decreases rapidly with increasing (y_t/a), while for larger values of (y_t/a) and for completely submerged flow, C_d is not affected much by increasing (y_t/a). The relationship between (C_d) and (y_t/a) can be expressed by

$C_d = a_4\ (y_t/a)^2 + a_5\ (y_t/a) + a_6$ (15)

in which a_4, a_5 and a_6 are constants given by Table (1).

8.3.5 Relationship between (C_d) and ($\sqrt{\Delta y/a}$)

The relationship between the discharge coefficient (C_d) and the ratio ($\sqrt{\Delta y/a}$) in which Δy which representd the change in depth of flow U.S. & D.S. the sluice gate] was plotted as shown in Fig. (15). This figure indicates that the discharge coefficient decreases as ($\sqrt{\Delta y/a}$) increases. The rate of decreases in C_d value is high for $\sqrt{\Delta y/a}$ <

1.3 and is slightly affected for $\sqrt{\Delta y/a} > 1.3$. The relationship between (C_d) and ($\sqrt{\Delta y/a}$) can be expressed by the following equation:

$$C_d = a_7 (\Delta y/a) + a_8 (\sqrt{\Delta y/a}) + a_9 \tag{16}$$

The values of the deduced constants (a_7, a_8 and a_9) for the two weeds densities and the smooth case were estimated by the least squares technique, given by Table (1)..

8.3.6 Relationship between (C_d) and (F_{ra})

The relationship between the discharge coefficient (C_d) and Froude's number under the gate (F_{ra}) was plotted as shown in Fig. (16). This figure indicates that the discharge coefficient decreases as the gated Froude's number increases. The discharge coefficient decreases significantly for subcritical flow under the gate ($F_{ra}<1$) while it is slightly affected by supercritical flow ($F_{ra}>1$). The relationship between (C_d) and (F_{ra}) can be expressed by;

$$C_d = a_{10} (F_{ra})^2 + a_{11} (F_{ra}) + a_{12} \tag{17}$$

in which a_{10}, a_{11} and a_{12} are constants given by Table (1). From the four previous figures (13, 14, 15, and 16), it can be noticed that the weeds of density 1 gives the lowest discharge coefficient comparing with the case of no weeds, smooth case, and that of density 2. In other words, it can be said that increasing the density of vegetation will reduce the discharge coefficient that could be due to increase the differential head on the gate. For the same discharge (Q) and gate opening (a), Froude's number under the gate (F_{ra}) has a constant value given by the following expression;

$$F_{ra} = C_d \sqrt{2} \sqrt{\Delta y / a} = \text{constant}, \quad \text{then} \quad C_d \; \alpha \; \frac{1}{\sqrt{\Delta y / a}} \tag{18}$$

8.3.7 Relationship between (F_{ra}) and ($\sqrt{\Delta y/a}$)

The relationship between Froude's number under the gate (F_{ra}) and ($\sqrt{\Delta y/a}$) was plotted as shown in Fig. (17). This figure indicates that the relationship between (F_{ra}) and ($\sqrt{\Delta y/a}$) is a straight line and when extended, it nearly passes through the origin. This relationship can be expressed by;

$$F_{ra} = a_{13} + a_{14} \sqrt{\Delta y/a} \tag{19}$$

in which a_{13} and a_{14} are constants estimated by the least squares technique for the two weeds densities and the smooth case given by Table (1). The deduced relationship between (F_{ra}) and $\sqrt{\Delta y/a}$ was proposed to predict the Froude's number under the gate and consequently the corresponding discharge for given upstream and downstream water depths, as well as, the gate opening. The curves show that $\sqrt{\Delta y/a}$ increases slightly by increasing the weeds density at constant (F_{ra}).

8.4 Effect of Submerged Vegetation on the Energy Losses

The coefficient of the energy losses (C_L) given by Eq. (5) was calculated for each experimental run. The relationships between it and the various flow parameters were plotted to show the effect of weeds density on the energy losses in the submerged flow under sluice gates. The relationships were studied for the case of no weeds (smooth), weeds density 1 (D1), and weed density 2 (D2).

8.4.1 Relationship between (C_L) and (a/y_u)

The relationship between the coefficient of the energy losses (C_L) and the ratio of gate opening to upstream water depth (a/y_u) was plotted as shown in Fig. (18). From this relationship, it can be concluded that the coefficient of the energy losses decreases as the ratio (a/y_u) increases. For smaller values of (a/y_u), the coefficient of the energy losses decreases rapidly with increasing (a/y_u), while for larger values of (a/y_u), C_L is not affected significantly by increasing (a/y_u). The relationship between (C_L) and (a/y_u) can be expressed by the following equation,

$$C_L = a_{15} (a/y_u)^{b1} \qquad (20)$$

in which a_{15} and b1 are constants given by Table (1). The curves show that, the coefficient of the energy losses increases due to the presence of vegetation and it increases with the weeds density increase. It could be concluded that the presence of vegetation had a great effect on the energy losses.

8.4.2 Relationship between (C_L) and (y_t/a)

The relationship between the coefficient of the energy losses (C_L) and the ratio of tail water depth to gate opening (y_t/a) was plotted as shown in Fig. (19). This figure indicates that the coefficient of the energy losses increases as the ratio (y_t/a) increases. As when the tail water depth (y_t) increases or the height of gate opening (a) decreases the velocity of flow under the gate (V_a) increases then the energy losses increase. For smaller values of (y_t/a), the coefficient of the energy losses increases gradually with increasing (y_t/a), while for larger values of (y_t/a), C_L increases rapidly with increasing (y_t/a). The relationship between (C_L) and (y_t/a) is deduced as

$$C_L = a_{16} (y_t/a)^2 + a_{17} (y_t/a) + a_{18} \qquad (21)$$

in which a_{16}, a_{17}, and a_{18} are constants estimated by the least squares technique given by Table (1). The curves show also that, the coefficient of the energy losses increases due to the presence of vegetation and it increases with the weeds density increase. It could be concluded that the presence of vegetation had a great effect on the energy losses.

8.4.3 Relationship between (C_L) and (F_{ra})

The relationship between the coefficient of the energy losses (C_L) and Froude's number under the gate (F_{ra}) is shown in Fig.(20). The results indicate that the coefficient of the energy losses increases as (F_{ra}) increases due to the increase in the energy losses. The relationship between (C_L) and (F_{ra}) can be expressed by;

$$C_L = a_{19}\, e^{b_2 F_{ra}} \tag{22}$$

in which a_{19} and b_2 are constants, Table1. The curves show also that the coefficient of the energy losses increases due to the presence of vegetation and it increases with the weeds density. It could be concluded that the presence of vegetation had a great effect on the energy losses. However the vegetation had slightly effect on the energy losses at $F_{ra} > 2$.

8.5 Effect of Submerged Vegetation on the Discharge

From the analysis of data, it was found that the presence of vegetation led to a reduction in the discharge. The discharge reductions were calculated as a percentage ratio between the difference of discharges in the smooth case, Q_s, and the case of presence of vegetation (case B), Q_B, to the discharge in the smooth case $(Q_s-Q_B)/Q_s$. The effect of the ratio (a/y_u) on the discharge reduction is given by Fig. (21). This figure shows that the increase of the ratio (a/y_u) leads to an increase in the discharge reduction percentage. Moreover, it can also be concluded that the density of vegetation has a great effect on the discharge reduction. In other words, it can be said that the higher the density, the more the discharge reduction is. The maximum discharge reduction was found to be 48% in the case of weeds density (D1) at (a/y_u= 0.88), while the minimum discharge reduction was found to be 2.97% in the case of weeds density 2 (D2) at (a/y_u= 0.17).

Different densities of flexible roughness elements upstream the sluice gate causes a reduction in the discharge and at the same time causes a reduction in the coefficient of the discharge. The relationship between the ratio of discharge with vegetation to without vegetation (Q_B/Q_s) and the ratio of discharge coefficient with vegetation to without vegetation (C_{dB}/C_{ds}) was presented in Fig. (22). It can be shown that the maximum reduction in the discharge appears in the case of high density (D1). Also, it is concluded that discharge is reduced when the discharge coefficient decreases.

8.6 Effect of Submerged Vegetation on Equivalent Manning's Roughness Coefficient

The relationship between ($n_{eq}V_a/a^{2/3}$) [in which n_{eq} is the equivalent Manning's roughness coefficient, V_a is the velocity of flow under the sluice gate, and (a) is the height of gate opening] and the different flow parameters were plotted to show the effect of weeds density on the equivalent Manning's roughness coefficient. The curves were drawn for the case of no weeds (smooth), weeds density 1 (D1), and weeds density 2 (D2). The relationship between ($n_{eq}V_a/a^{2/3}$) and the ratio of gate opening to upstream water depth (a/y_u) was plotted as shown in Fig. (23). The figure was proposed to estimate the velocity of flow under the gate and consequently the discharge passing through the gate for a given upstream water depth and the gate opening as well as the equivalent Manning's roughness coefficient.

The relationship between ($n_{eq}V_a/a^{2/3}$) and the ratio of tail water depth to gate opening (y_t/a) was plotted as shown in Fig. (24). The figure was proposed to estimate the velocity of flow under the gate and consequently the discharge passing underneath the gate for a given tail water depth for certain gate opening, as well as the equivalent Manning's roughness coefficient. The relationship between ($n_{eq}V_a/a^{2/3}$) and Froude's number under the gate (F_{ra}) was plotted as shown in Fig. (25). From the three figures (23, 24, and 25), it can be concluded that the equivalent Manning's roughness coefficient increases due to the presence of vegetation along with the increase of weeds density.

9. CONCLUSIONS

In Egypt more than 80% of the canals and the drains are heavily infested by all types of aquatic weed. The most prevailing type of aquatic weeds is the submerged weeds type. This type of weeds decreases the channels hydraulic efficiency as the flow resistance increases. In the present study, the effect of submerged weeds density on the performance of vertical sluice gates was analyzed. The dimensional analysis was employed to derive an expression for the discharge coefficient. A general equation for predicting the energy losses was developed. The experimental program was developed for a regulator model in a trapezoidal flume and the branched flexible elements were used to simulate the submerged weeds. From the analysis and discussion of the experimental results, the following conclusions can be listed:

1. The presence of submerged vegetation upstream the regulators increases the water surface slope upstream.
2. The presence of submerged vegetation upstream the regulators has nearly no effect on the water surface profile downstream the regulators.
3. The presence of submerged vegetation upstream the regulators leads to non-uniformity of the velocity profiles distribution.
4. The presence of submerged vegetation upstream the regulators slightly decreases the velocity downstream the regulators.
5. The dimensional analysis is employed to derive an expression for the discharge coefficient.
6. The discharge coefficient increases as the gate opening ratio (a/y_u) increases.
7. The presence of vegetation decreases the discharge coefficient.
8. The increase of weeds density leads to a significant decrease in the discharge coefficient.
9. The coefficient of the energy loss decreases as the gate opening ratio (a/y_u) increases.
10. The increase of weeds density leads to a considerable increase in the energy loss.
11. The presence of the submerged vegetation upstream the regulators leads to a reduction in its discharge. The percentage of the discharge reduction depends mainly on the weeds density and the height of gate opening.
12. The presence of submerged vegetation increases the equivalent Manning's roughness coefficient and this increases with the increase of weeds density.

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Table(1): Constants of Equations (14) to (22).

Variable	D1	D2	smooth
a_1	0.596	0.829	0.125
a_2	-0.447	-0.664	0.085
a_3	0.768	0.829	0.718
a_4	0.029	0.048	0.021
a_5	-0.171	-0.262	-0.151
a_6	0.943	1.064	1.005
a_7	0.052	0.044	0.046
a_8	-0.162	-0.113	-0.146
a_9	0.881	0.785	0.855
a_{10}	0.035	0.042	0.043
a_{11}	-0.115	-0.112	-0.144
a_{12}	0.785	0.787	0.859
a_{13}	-0.003	-0.014	0.023
a_{14}	1.009	1.025	1.038
a_{15}	9.132	5.960	1.578
b_1	-1.377	-1.648	-2.479
a_{16}	35.57	32.98	31.04
a_{17}	-121.41	-108.84	-101.51
a_{18}	122.14	103.31	87.74
a_{19}	12.067	8.719	2.854
b_2	1.196	1.359	1.896

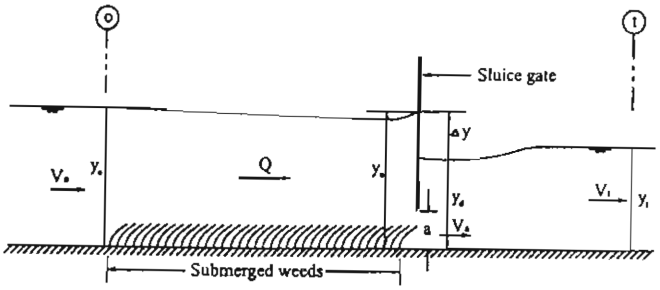
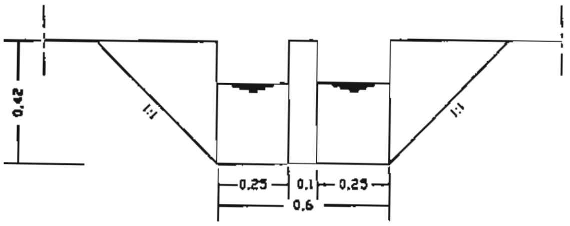


Fig. (3-1) Definition sketch for submerged flow under sluice gate in a channel infested by submerged weeds.



Dimensions in meters.

Fig. (2) Cross Section for the Regulator Model.

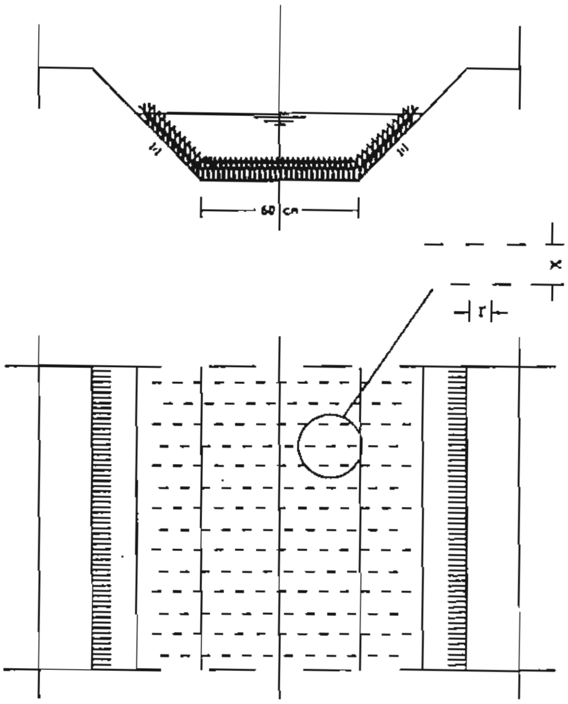


Fig. (3) Distribution of Weeds on Cross Section & Plan.

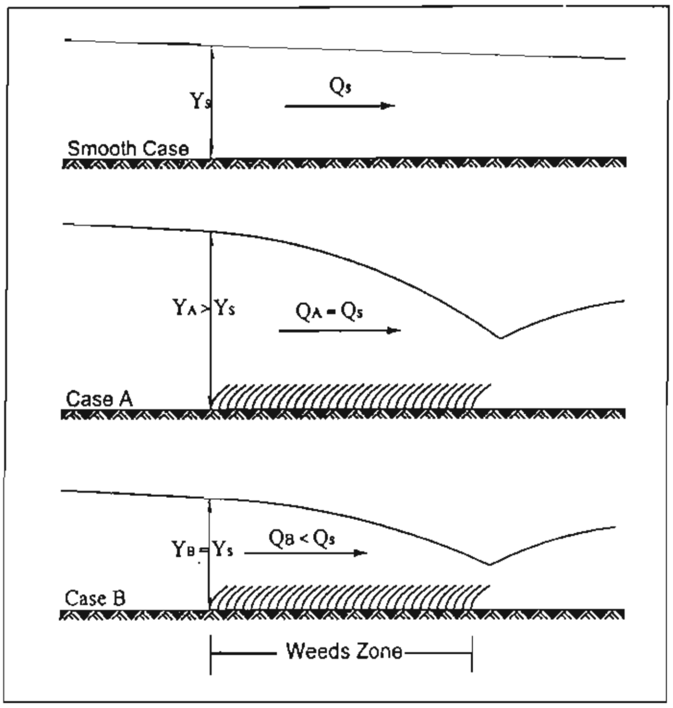


Fig. (4) Description of the Flow Cases (Smooth, Case A, and Case B).

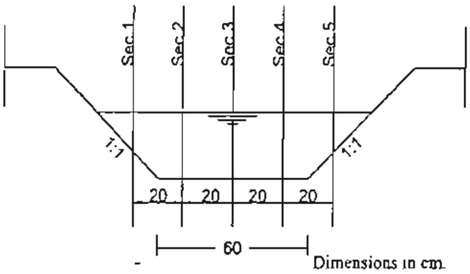


Fig. (5-a) Vertical sections for velocity profile measured U.S. the sluice gate.

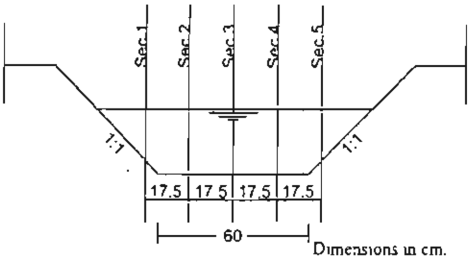


Fig. (5-b) Vertical sections for velocity profile measured D.S. the sluice gate.

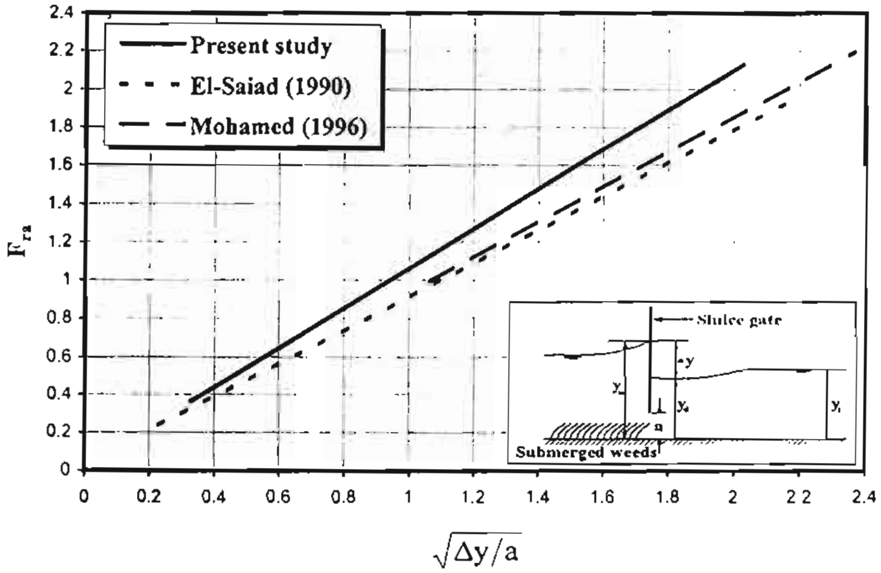


Fig. (6) Comarison between the present study and previous studies as for the relationship between (F_{ra}) and $\sqrt{\Delta y/a}$

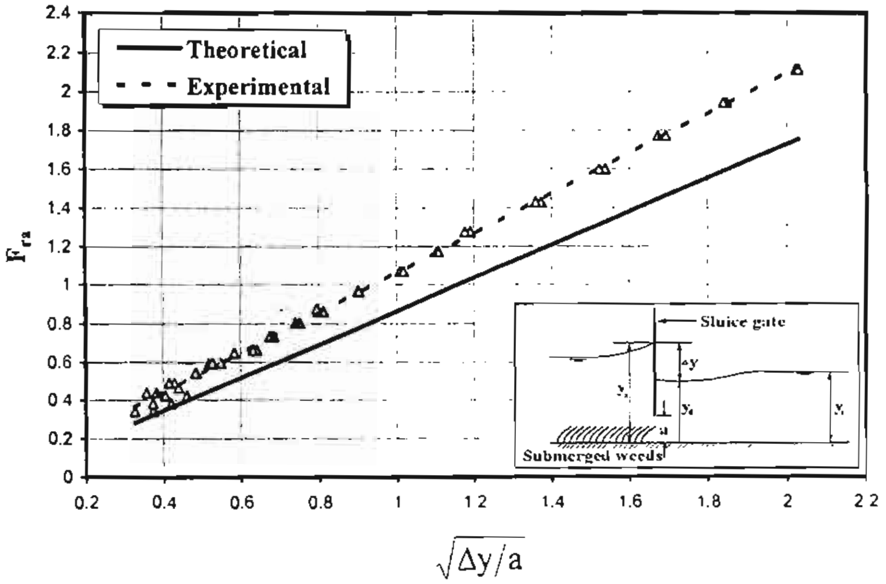


Fig. (7) Comarison between the theoretical and the experimental results of the present study as for the relationship between (F_{ra}) and $\sqrt{\Delta y/a}$

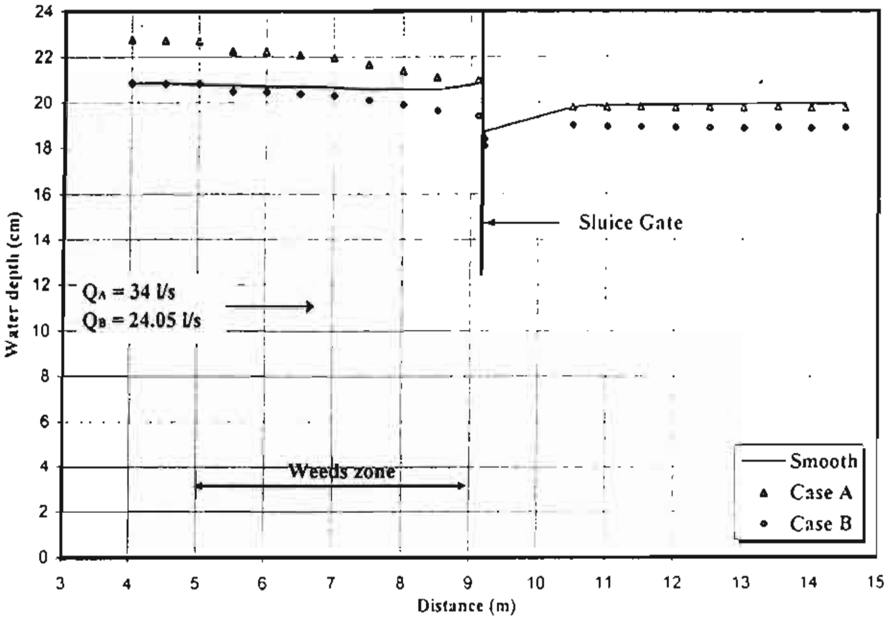


Fig. (8.a) Water surface profile for weeds density 1 (a = 13 cm)

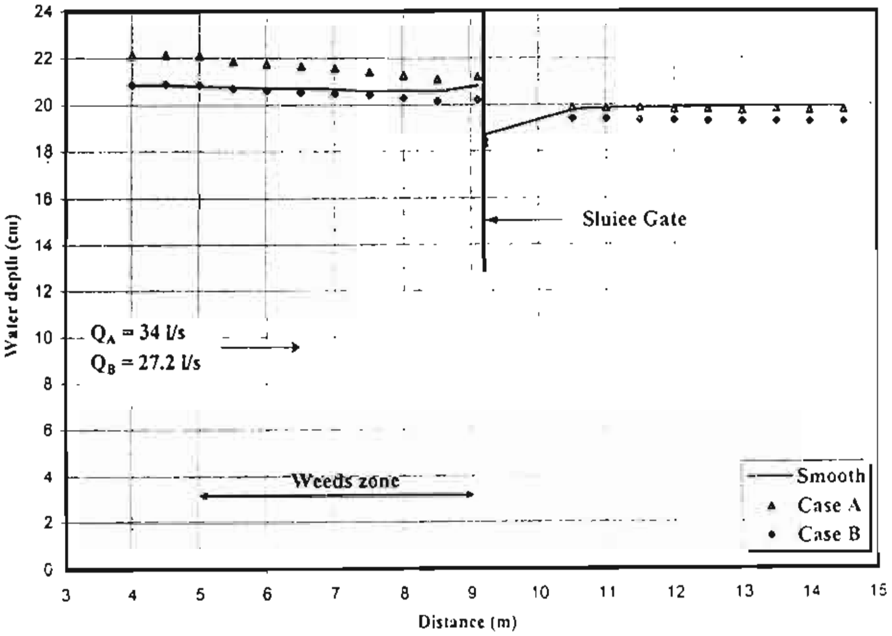


Fig. (8.b) Water surface profile for weeds density 2 (a = 13 cm)

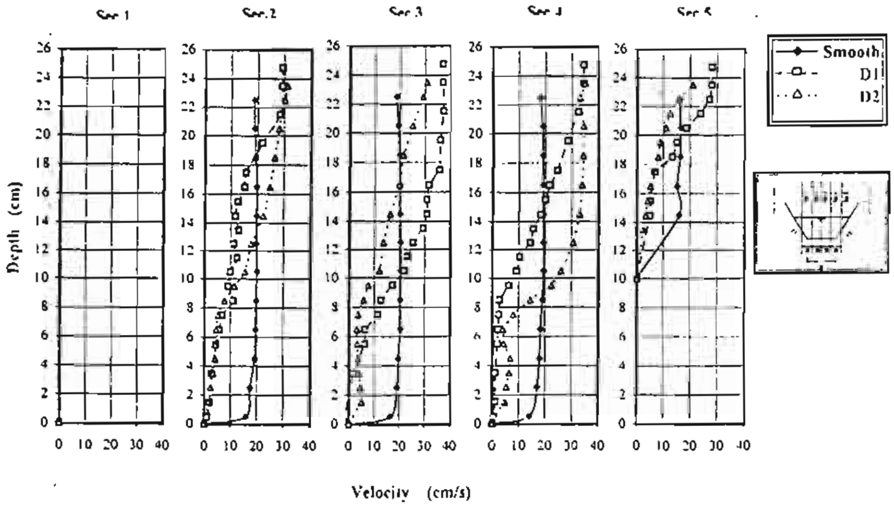


Fig. (9) Vertical velocity profiles U. S. the Regulator model for the smooth case and the two weeds densities (a = 13 cm)

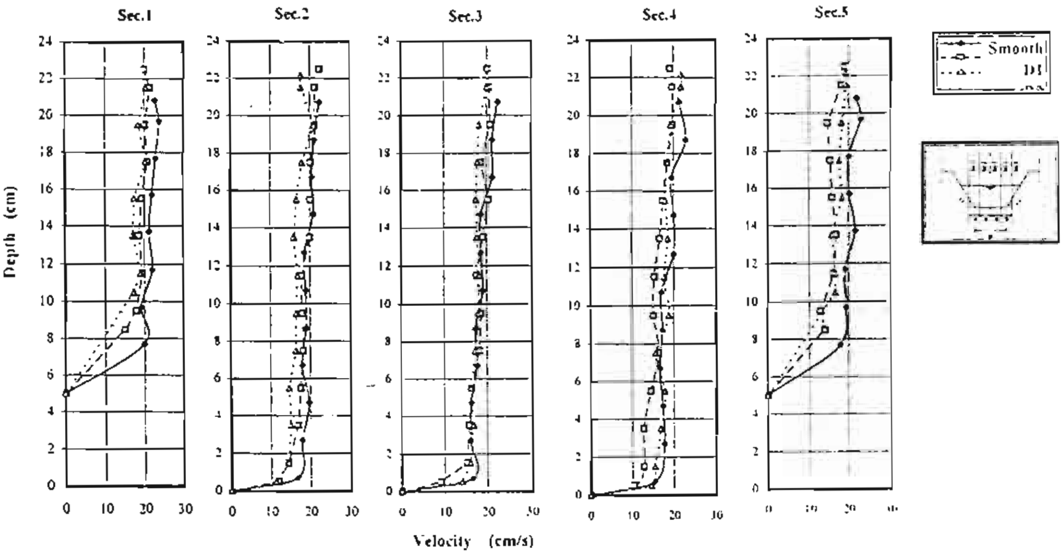


Fig. (5-10) Vertical velocity profiles D. S. the Regulator model for the smooth case and the two weeds densities (a = 13 cm)

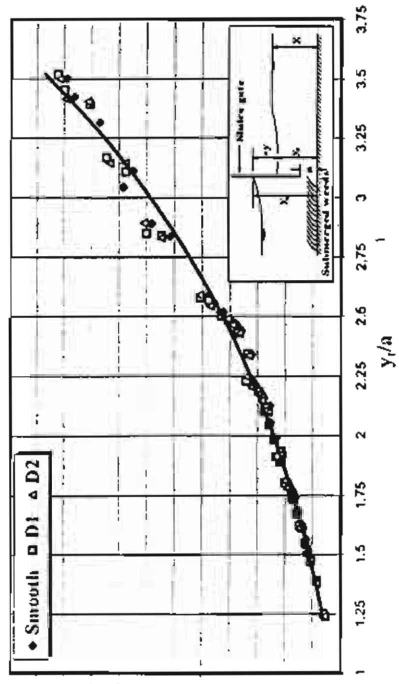


Fig. (11) Relationship between (y_u/a) and (y_t/a) for the smooth case and the two weeds densities

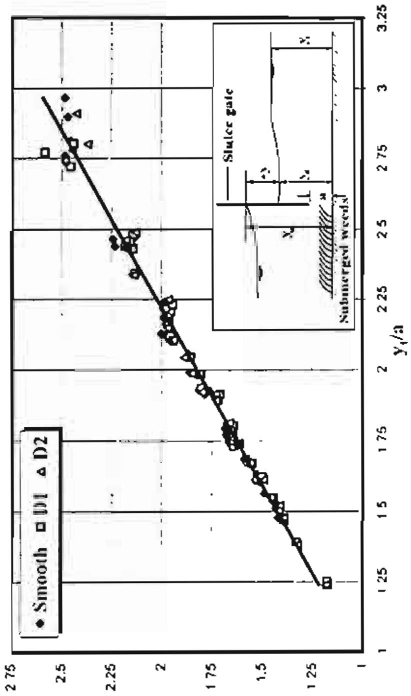


Fig. (12) Relationship between (y_d/a) and (y_t/a) for the smooth case and the two weeds densities

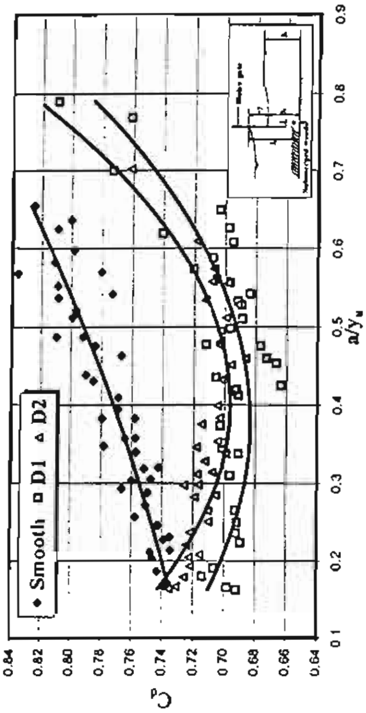


Fig. (13) Relationship between (Cd) and (a/y_u) for the smooth case and the two weeds densities

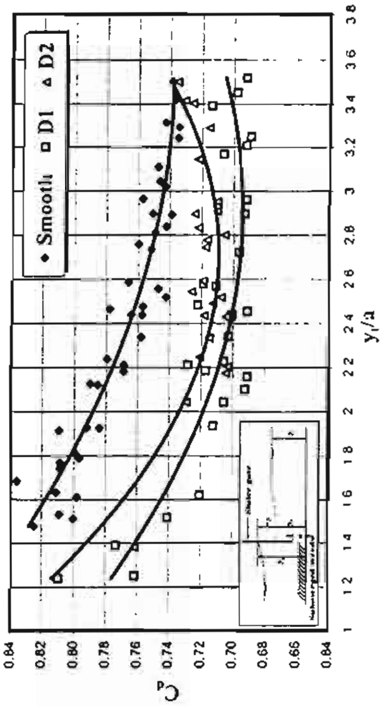


Fig. (14) Relationship between (Cd) and (y_t/a) for the smooth case and the two weeds densities

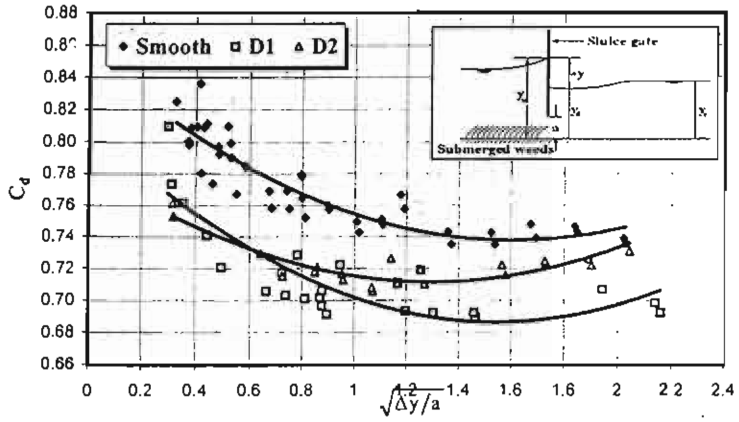


Fig. (15) Relationship between (C_d) and $\sqrt{\Delta y/a}$ for the smooth case and the two weeds densities

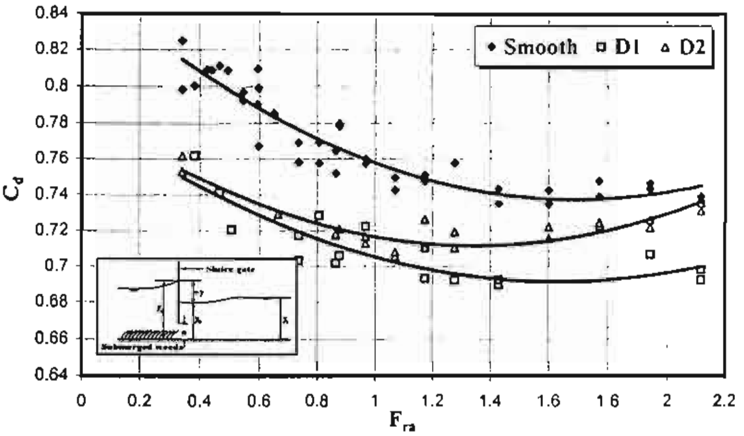


Fig. (16) Relationship between (C_d) and (F_{ra}) for the smooth case and the two weeds densities

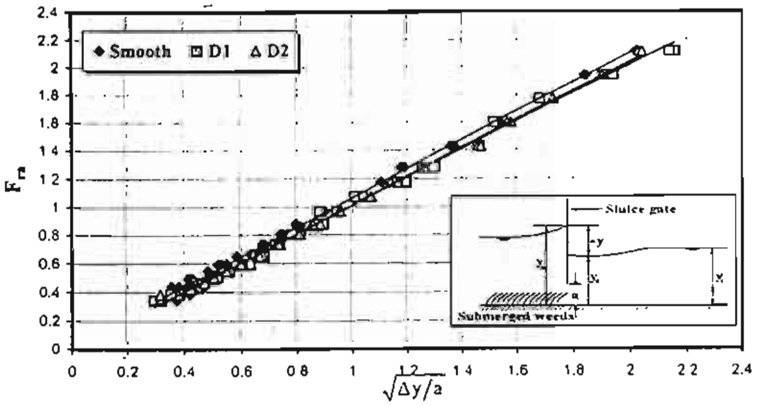


Fig. (17) Relationship between (F_{ra}) and $\sqrt{\Delta y/a}$ for the smooth case and the two weeds desities

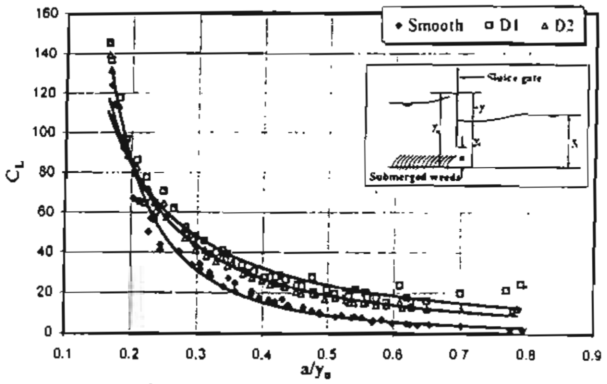


Fig. (18) Relationship between (C_L)and (a/y_o) for the smooth case and the two weeds densities

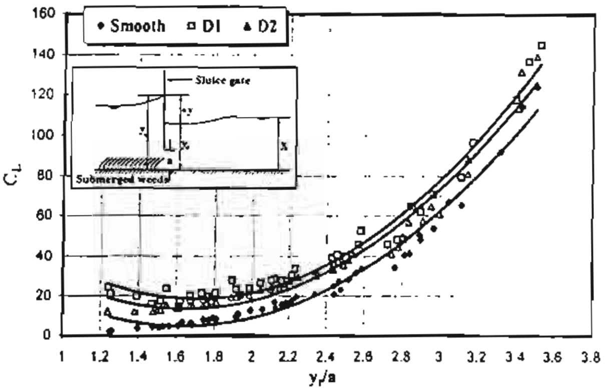


Fig. (19) Relationship between (C_L)and (y_o/a) for the smooth case and the two weeds densities

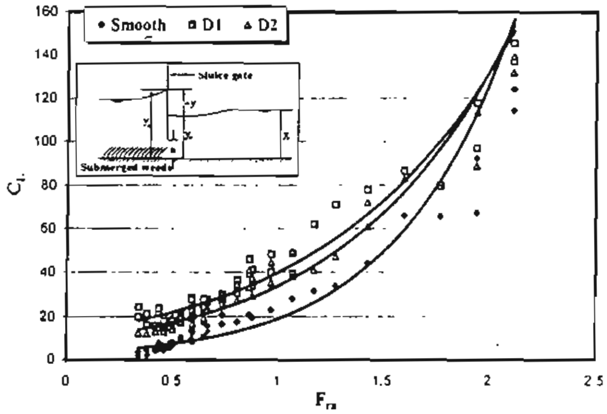


Fig. (20) Relationship between (C_L)and (F_{ra}) for the smooth case and the two weeds densities

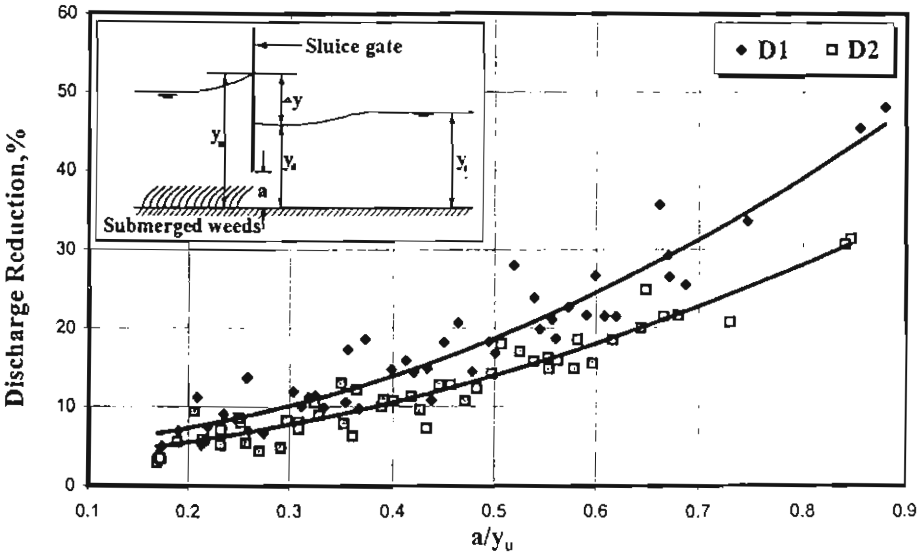


Fig. (21) Relation between (a/Y_u) and Discharge Reduction,% for the two weeds densities

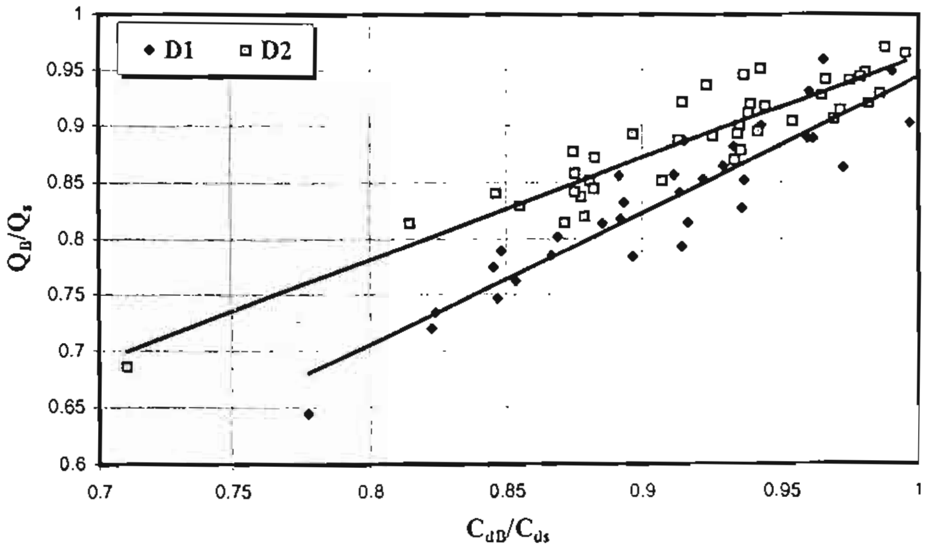


Fig. (22) Relationship between (Q_B/Q_s) and (C_{dB}/C_{ds}) for the two weeds densities

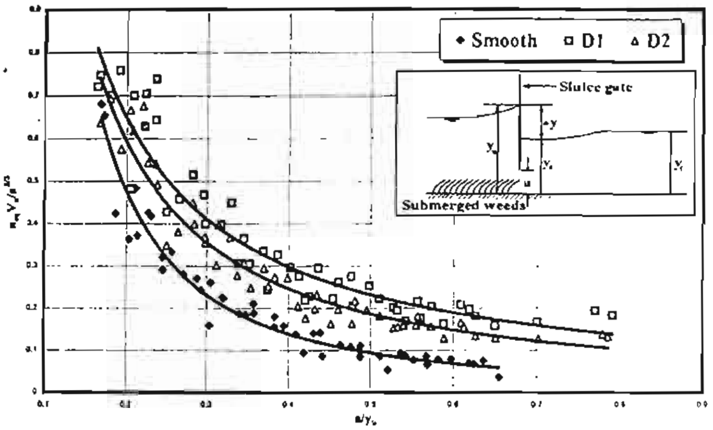


Fig. (23) Relationship between $(n_{eq}V_a/a^{2/3})$ and (a/y_u) for the smooth case and the two weeds densities

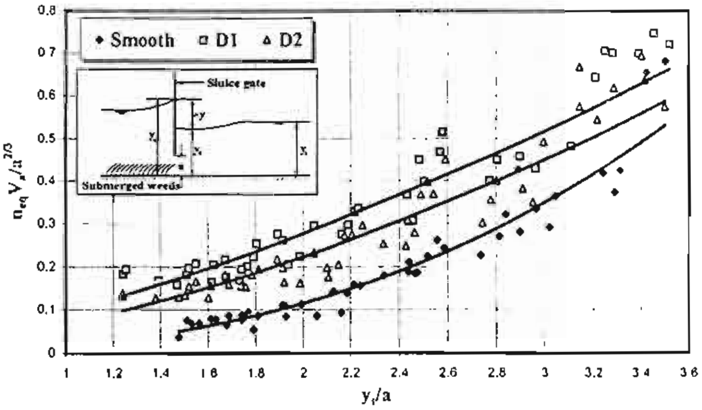


Fig. (24) Relationship between $(n_{eq}V_a/a^{2/3})$ and (y_t/a) for the smooth case and the two weeds densities

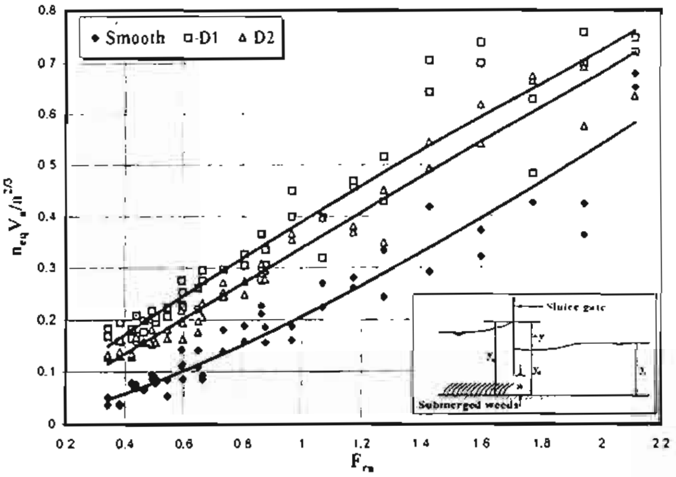


Fig. (25) Relationship between $(n_{eq}V_a/a^{2/3})$ and (F_{ra}) for the smooth case and the two weeds densities