EFFECT OF MULTI-GATES REGULTATORS OPERATIONS ON DOWNSTREAM SCOUR PATTERN UNDER SUBMERGED FLOW CONDITIONS

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ABSTRACT

Failures barrages or parts of them may be expected when excessive scour patterns are observed downstream of such structures. Severe and excessive scour may be largely due to unsymmetric operation of gates especially when a multi-vents barrage or regulator is being considered. Previous investigations proved that the scour patterns downstream hydraulic structures are functions of the bottom velocities among other relevant factors such as Froude number, operation of gates, …. etc. In this paper, the results of an experimental investigation on the effects of operations of gates of mutli-vents regulators on scour pattern are presented. The observed results on scour patterns are well explained in terms of bottom velocity patterns over the rigid bed upstream of the movable bed. The experimental program was carried under submerged flow conditions. Symmetric and unsymmetric operation of main gates and emergency gates are considered. An electromagnetic flow meter is used to measure the velocity components (in x and y directions) near bed at a predefined mesh over both the rigid bed and the movable bed. Both the pattern of the velocity vectors and the scour pattern for each run are plotted to qualitatively trace the interactive effects between the velocity pattern (relative magnitude and direction of the bottom velocity over the rigid bed) and the scour pattern (distribution of scour holes and the relative location of the maximum scour depth). It is observed that the scour pattern and hence the maximum depth of scour is a function of the bottom velocity pattern, operation of gates, type of gates (main or emergency), Froude number at the vena contracta, and submergence ratio. The qualitative and quantitative effects of all these parameters on the relative maximum scour depths are presented.

Keywords: Hydraulics, Multi-vents, Operations, Scour, Velocity, Stilling basins, Submerged flow

INTRODUCTION

Most of existing heading-up hydraulic structures as regulators consists of multi-vents and most of the problems downstream such structures are due to wrong operation of the multi-vents leading to unpredicted velocity patterns or (velocity distributions) which in turn leads to unexpected scour patterns. Due to the existence of piers and abutments as parts of these structures, the flow issuing out of their gates behaves as flow in sudden expanding stilling basins when all or parts of gates are working together. Mostly, symmetric flow in sudden expanding stilling basins resulted in symmetric scour downstream of the basin and vice versa, Negm et al. [7,8]. Such scour can be controlled through the use of different energy dissipation tools such as sills, Mohamed, Negm & El-Saiad [3] and Saleh, Negm & Ahmed [17]. On the other hand, velocity distribution over rigid bed upstream of the movable bed helps in depicting the nature of scour patterns downstream of the rigid bed. Studies on velocity distribution downstream single vent hydraulic structures may be found in Saleh [13,15], Saleh, Owais, and Drewes [14] and Ghzaw, Saleh, & Salem [16]. Moreover, the submerged flow are the mostly encountered in the field downstream the gates. Many studies are available in the literature about the submerged flow and submerged hydraulic jump characteristics under numerous flow conditions. few example of such works include those of Govinda & Rajaratnam [2], Rajaratnam [10,11,12], Narasimhan & Bhargara [5], Abdel-Aal [1] and Negm et al. [6]. An extensive study on the effect of different parameters on velocity and scour patterns was carried out in Zagazig University by Mohamed [4] and Negm et al. [9].

In the present research paper, the effects of the symmetric and asymmetric operation of gates of multivents regulator on the relative maximum depth of scour downstream a rigid bed was investigated experimentally. Submerged flow conditions were considered. The flow below gates issues from either the main gates, the emergency gates or from mixed operation of the main and the emergency gates. Dimensional analysis of the problem indictaed that the relative maximum depth of scour was a function of the initial Froude number, $F_1 = v_1/(gy_1)^{0.5}$ where v_1 is the velocity at depth y_1, bottom velocity ratio, $\psi = v_b/(gy_b)^{0.5}$, with v_b the bottom velocity at distance y_b above bed and g is the gravitational acceleration, the submergence ratio, S, (defined as the tailwater depth over the initial depth of the jump) and the type of gates under operation, ω, according to the following function:

$$ds/y1 = f(\psi, S, F_1 \text{ and } \omega) \qquad (1)$$

EXPERIMENTAL WORK

The experimental work was conducted in one of the laboratory flumes of the Hydraulic Research Institute (HRI), National Water Research Center, Ministry of Water Resources and Irrigation, Delta Barrages, Egypt. The flume was of re-circulating adjustable type. It is 44.1 m long, 60 cm deep and 40 cm wide. The tailgate was fixed at the end of the flume to control the depth of flow for each run. Discharge measurements were carried out using a pre-calibrated sharp-crested rectangular weir. The weir was calibrated using an ultrasonic flowmeter with an accuracy of about ± 1%.

The experimental model consisted of two vertical convergent baseform wood plates (which is not affected by water) with a length of 45cm, and followed by two vertical parallel baseform plates with a length of 70cm. These parts were fixed over a false bed, which was located at a distance of 12cm from the flume bed. The distance from the main gate to the end of the apron was 125cm, as shown in Figure 1. Two piers with length 55cm, made from baseform were fastened at the contraction part. Three vertical gates (made of clear Perspex) slide through vertical grooves. The false bed height was 12 cm and the model height equals 48 cm**.** Grooves for both main gates and emergency gates were provided. The distance between the main and emergency gates was 40 cm. The main gates were denoted by A, B and C from bottom to top in the plan of Figure 1 while the emergency gates were denoted by 1, 2 and 3 from bottom to top.

The effect of submergence ratio (y_t/y_1) was studied for operation case including the operation of the three main gates (A+B+C) i.e. model No. 1. Other models investigated the effects of gates operations under constant submergence. More than 217 runs were performed, 36 runs using model No. 1 and the rest for other models. The three main gates (Model No. 1) was operated under submergence of S=4.5 to 9.0 and Froude number ranging from 2.0 to 5.5, while the other models from No. 2 to No. 17 (table 1) were operated under a fixed average submergence of about 5.8 and with the same range of a Froude number as for model No. 1.

A movable sand bed of length 9.0m and 0.12m thickness was formed just DS the stilling basin, the geometric mean diameter equals 0.5mm. A point gauge was used to measure the dimensions of scour hole downstream the basin of the multi-vents regulator.

Flow velocity in the model was measured using an electromagnetic currentmeter. The time for measuring velocity could be controlled and also continuous readings could be obtained. The electromagnetic currentmeter type E.M.S. was manufactured by Delft Hydraulics, Holland. This currentmeter is a well-known pipe flowmeter employing Faraday's induction law for velocity measurements of a conductive liquid moving through a magnetic field. The electromagnetic currentmeter measures the velocities in the range 0 to 2.5 m/s with an accuracy of ± 0.01 m/s upto ± 1 % of value measured.

The electromagnetic currentmeter was used to measure the velocity components in two directions, one in the flow direction (v_x) at distances 25, 50, 75, 85, 95, and 105cm from the beginning of the sudden expanding section and the other in the lateral direction (v_y) near the bed at distances 10, 20 and 30 from the glass side as indicated by Figure 2. These measurements were distributed over the floor of stilling basin and the mobile bed. The velocity measurements of every test were collected into two text files, the first one for the coordinates of the measured point and the second, for the measured velocity data.

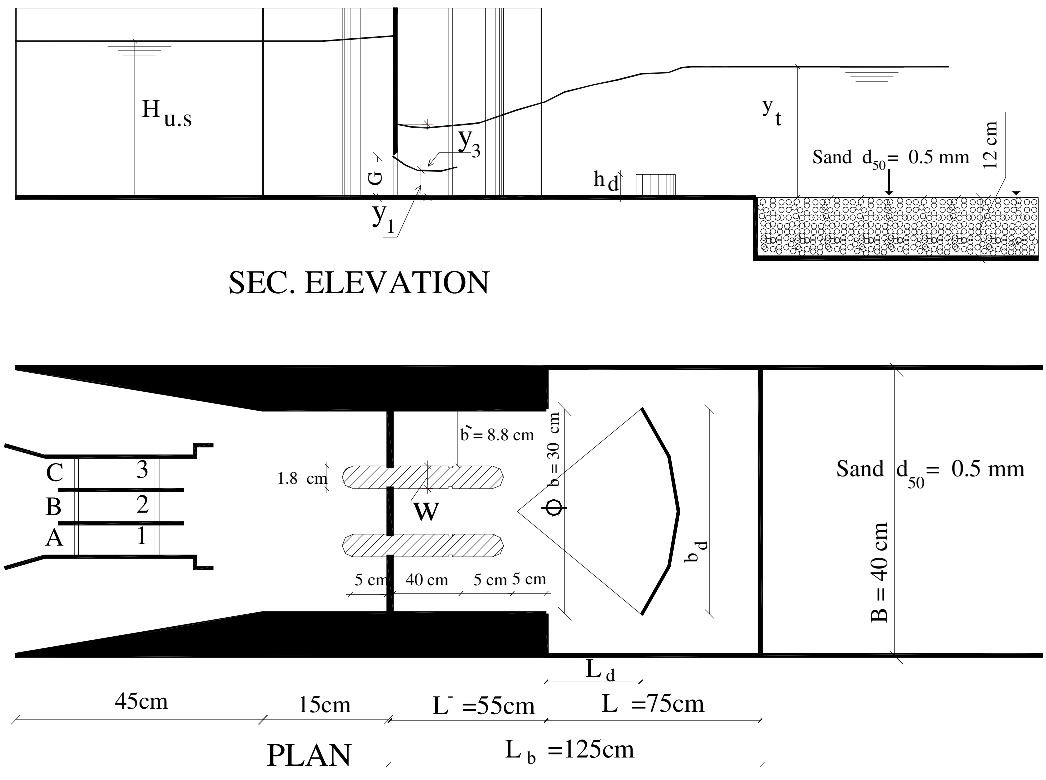

Figure 1. Experimental model arrangements (h_d=b_d= 0 in the present research).

Table 1. Tested models in the experimental program

Model No.	Scenarios of operating gates
1	A+B+C (operating all main gates)
2	1+2+3 (operating all emergency gates)
3	A+C+2 (operating two separated main gates and middle emergency gate)
4	B+1+3 (operating one middle main gate and two separated emergency gates)
5	B+C+1 (operating two adjacent main gates and one side emergency gates)
6	C+1+2 (operating two adjacent emergency gates and one side main gate)
7	A+C (operating two separated main gates)
8	A+C (operating two separated emergency gates)
9	A+3 (operating one side main gate and one side emergency gate)
10	A+B (operating two adjacent main gates)
11	1+2 (operating two adjacent emergency gates)
12	A+2 (operating one side main gate and middle emergency gate)
13	B+1 (operating middle main gate and one side emergency gate)
14	B (operating middle main gate)
15	2 (operating middle emergency gate)
16	A (operating side main gate)
17	1 (operating side main gate)

The time of each run was taken as 50 minutes where about 94% of relative maximum scour occurred as determined experimentally. The following procedure was followed to collect the experimental measurements, (i) The pump was switched on and the required discharge was passed gradually using the control valve, (ii) The height of gate opening is adjusted as required, (iii) The tail gate was adjusted to have submerged hydraulic jump over rigid bed, (iv) The movable bed (sandy soil) was re-leveled horizontally with the fixed bed once the equilibrium was achieved, (v) The running time of the test was started, (vi) The electromagnetic currentmeter (provided with readout system) was used to record the velocities in the direction of the flow and normal to the flow direction at the different points indicated in Figure 2, (vii) After 50 minutes , the run time was terminated, and the pump was switched off, (viii) The tail gate was screwed gradually until the channel became empty, (ix) The scour mesh was measured, (x) Another model was operated and steps from (i) to (x) were repeated.

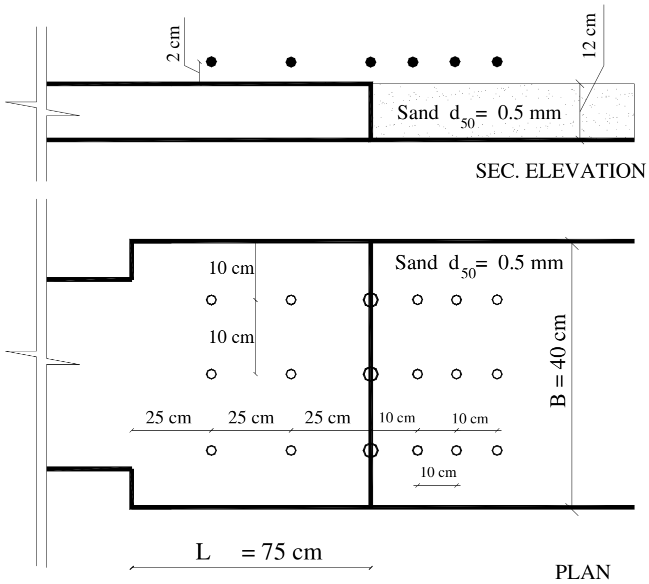

Figure 2. Locations where bottom velocities were measured

ANALYSIS AND DICUSSIONS

The results of all the runs were analyzed. The data files for velocities measurements were treated by vector velocity software available at HRI, to convert these data to script file which was converted into AutoCAD software. The AutoCAD software was used to draw the velocity vectors using the required suitable scale. Since the scour downstream the stilling was mostly affecting by the bottom velocity at the end of the basin. In the main time, the recorded scour measurements were plotted to indicate the scour pattern corresponding to each velocity pattern. Figures 3a and 3b presents a typical bottom velocity pattern and scour pattern when the three main gates (A+B+C) were operated under flow conditions represented by F_1=5.8 and submergence ratio S=7.92. Figure 3 indicated a symmetric pattern of the bottom velocity and a corresponding symmetric scour pattern. Also, the deposition were symmetric. Analysis of all collected data indicated that the symmetric operation of gates, either three gates, two gates or one gate results in symmetric velocity patterns and hence the scour patterns were also symmetric and vice versa. When a combination of main gate and emergency gate was operated in asymmetric way, the resulting patterns were relatively asymmetric. On the other hand, if the operations of the gates were asymmetric, both the velocity and the scour patterns were also asymmetric. Typical examples of the velocity and the scour patterns due to asymmetric operation of gates are presented in Figures 4a and 4b.

1. Effects of F1 and S on ds/y1 and Bottom Velocity Ratio

The maximum velocity at the end of the basin was extracted for all runs and converted into its corresponding dimensionless parameter as obtained from the dimensional analysis and was called the relative maximum bottom velocity and denoted by Ψ. Also, the maximum scour depth for each run was measured. The relative maximum scour depths were plotted as a function of the one or more of other parameters of equation (1). Similarly, Ψ was plotted as a function of one or more of F_1, S and ω.

Figures 5a and 5b present the variations of d_s/y_1 versus F_1 and Ψ versus F_1 for constant submergence ratios ranging from 4.7 to 9.0 when the three main gates were operated together. It is clear that both d_s/y_1 and Ψ are linearly increasing with the increase of F_1. Maximum values occur at lower submergence and vice versa, which can be attributed for the damping effect of the issuing jet by the weight of water due to submergence. Higher submergence means greater damping and hence less velocity and vice versa.

The relative bottom velocity (near bed) at the end of rigid bed, increases with the increase of the initial Froude number. Moreover, the relative bottom velocity near bed increases with the decrease of the submergence ratio, (and hence the relative scour depth increases with the decrease of submergence ratio). Therefore it is expected that the maximum depth of scour hole is higher for lower submergence and vice versa.

Statistical methods were used to develop an equation to predict the relative max depth of scour in the form

$$ds/y1 = 0.3 + 0.66\ F1 - 0.31\ S \qquad (2)$$

$$\Psi = 0.471 + 0.12\ F1 - 0.078\ S \qquad (3)$$

The value of the coefficient of determination (R^2) of equation (2) is 0.67 while the mean relative error (MRE) is 0.22 and those of equation (3) is R^2=0.90 and MRE =0.06.

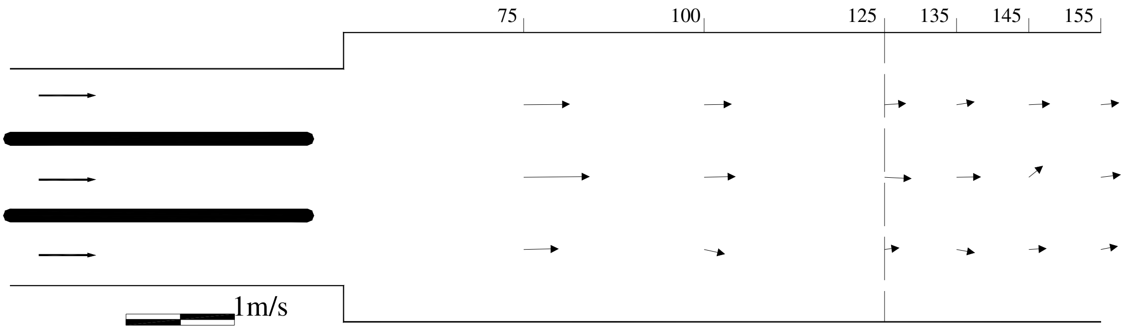

Figure 3a Bottom velocity pattern for operation case (A+B+C) at F_1 =5.8 and S =7.92

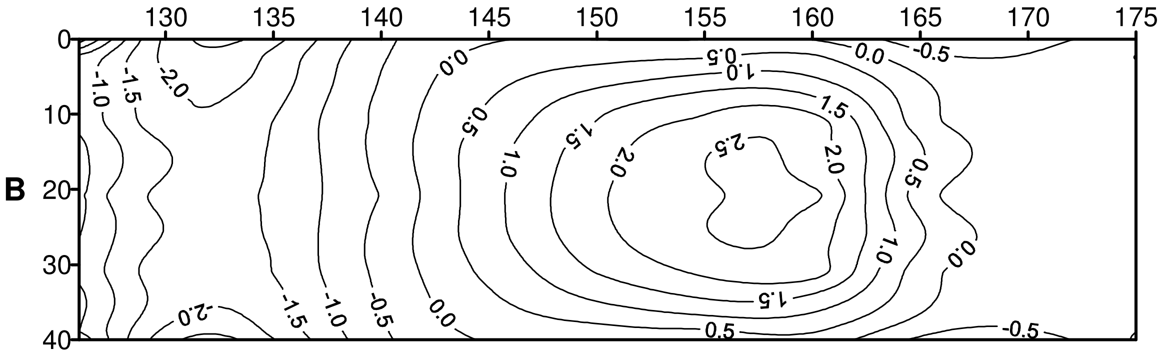

Figure 3b Scour pattern for operating gates (A+B+C) at F_1 =5.8 and S =7.92 corresponding to bottom velocity pattern presented in Figure 3a.

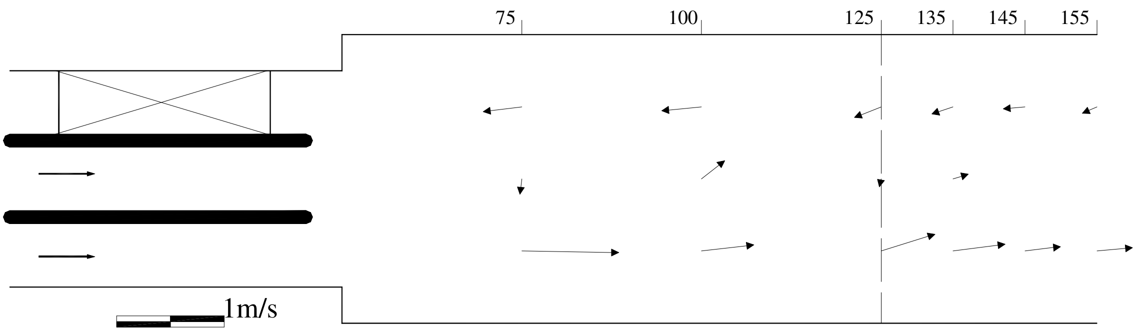

Figure 4a. Bottom velocity pattern for operating gates (A+B) at F_1 =4.07 and S =5.25

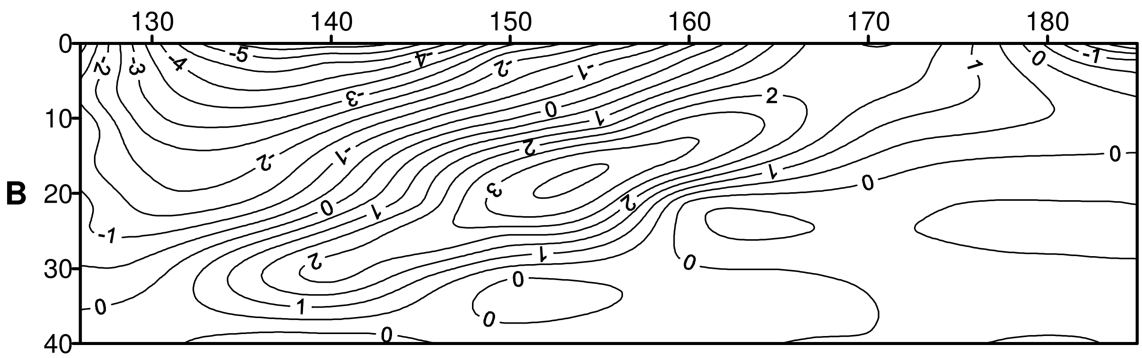

Figure 4b. Scour pattern for operating gates (A+B) at F_1=3.76 and S =5.74, corresponding to bottom velocity pattern presented in Figure 4a.

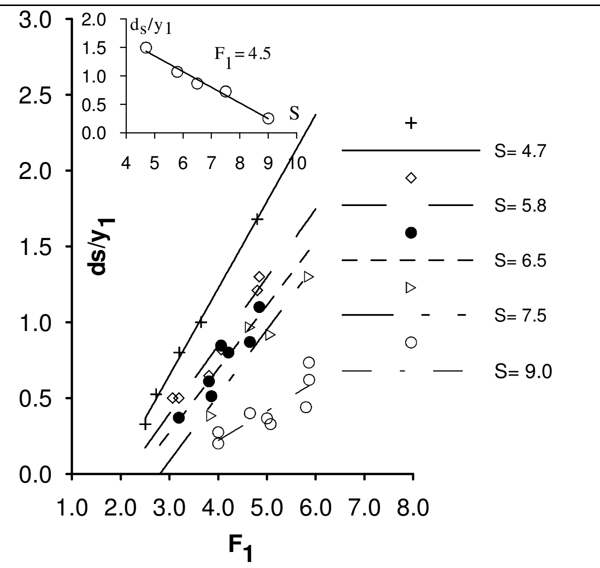

Figure 5a. d_s/y_1 versus F_1 for constant S and operation gates A+B+C

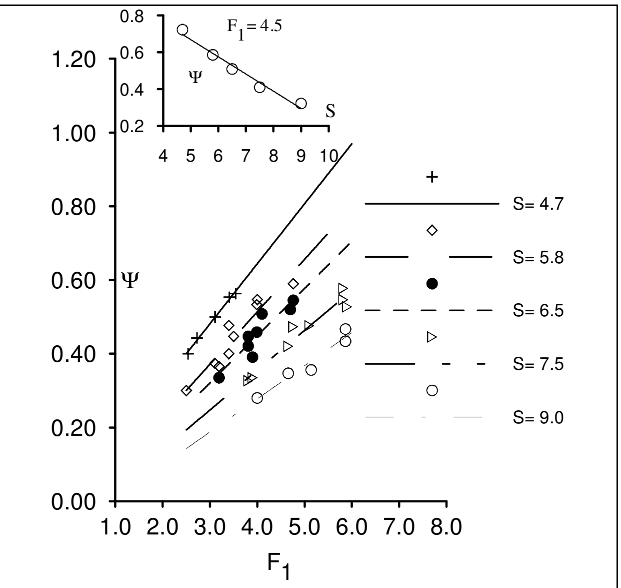

Figure 5b. Ψ versus F_1 for constant S and operating gates A+B+C

2. Effect of Operating the Three Gates

Figure 6a presents the variations of d_s/y_1 with F_1 for different scenarios of operating three gates. Similarly, Figure 6b presents the variations of Ψ with F_1 for the same scenarios of operation as for Figure 6a. The operation of the three main gates A+B+C yields minimum values of Ψ and ds/y1 at all F_1 values while the operation of one side main gate A, and anther two emergency gates 2+3, yields maximum values of Ψ and ds/y_1 at all F_1 values. Other combinations of operating of gates yields values in between these two extremes. It is interestingly to observe that the increase in the velocity ratio from the minimum value to the maximum value (e.g. at F_1=4.5) is about 20% while it is about 400% for the relative maximum scour depth. This indicates that the relative scour depth is highly sensitive with minor changes in the velocity ratio. In other words, ds/y1 is highly sensitive with the change of the velocity ratio, Ψ.

3. Effect of Operating Two Gates

The variations of d_s/y_1 with F_1 and Ψ with F_1 for different scenarios of operating two gates are presented in Figures 7a and 7b respectively. The operation of A+B yields minimum values of Ψ and d_s/y_1 for all values of F_1, followed by the operation case A+3 then 1+3, which all represents symmetrical (A+B, 1+3) or semi-symmetrical operation (A+3). Maximum values are due to asymmetrical operation due to one main gate B and one emergency gate 1. Other operational cases yield values of Ψ and ds/y1 which are in between the minimum and the maximum values. A typical increase of 60% in Ψ yields about 100% increase in d_s/y_1 at F_1 = 4.5.

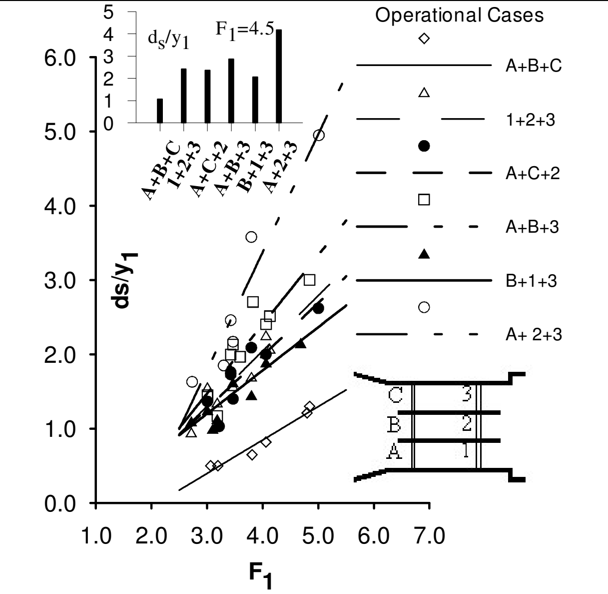

Figure 6a. d_s/y_1 versus F_1 for operating three gates together

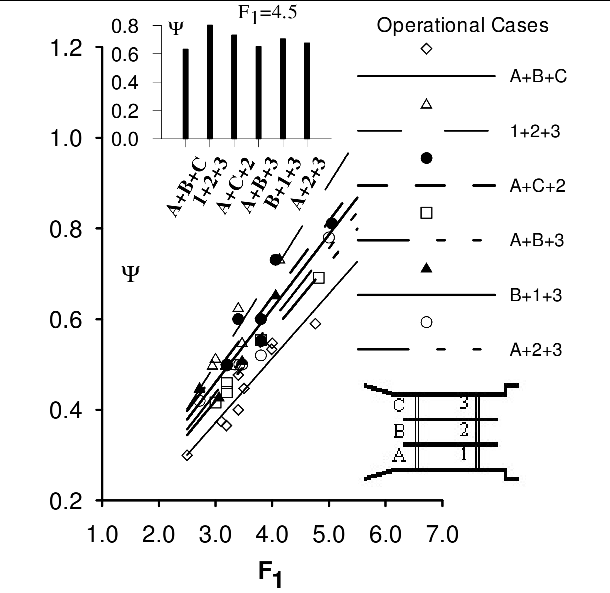

Figure 6b. Ψ versus F_1 for operating three gates together

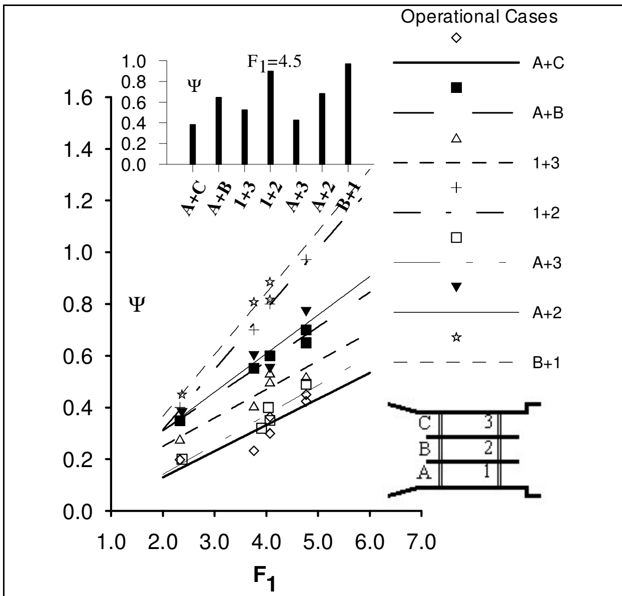

Figure 7a. d_s/y_1 versus F_1 for operating two gates together

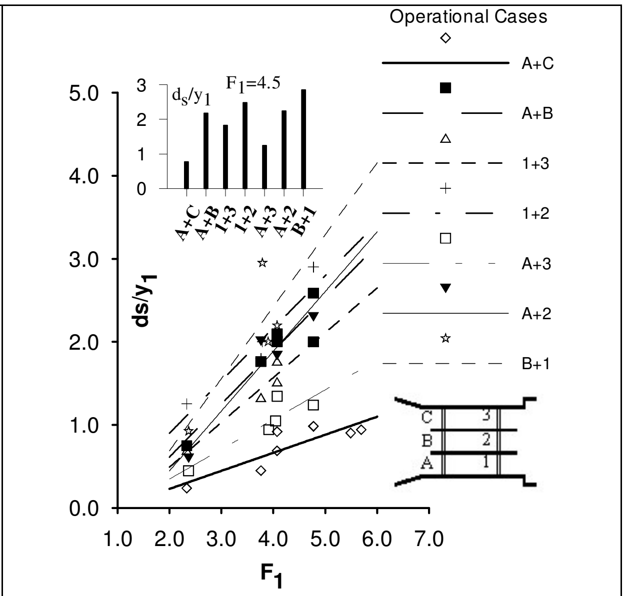

Figure 7b. Ψ versus F_1 for operating two gates together

4 Effect of Operating One Gate

Figures 8a and 8b present the results obtained by testing the operation of only one symmetric or asymmetric gate either main or emergency. Again, the operation of the middle vent (symmetric operation) yields minimum values of Ψ and d_s/y_1 for all values of F_1 as for other symmetric operation of two or three gates.

5- Comparisons of results Due to Gates Operation

Let e represents the expansion ratio which may be defined by width of the channel to the total width of the operated gates in any mode (main, emergency or combination). This will yield three cases when the gates are operated in symmetrical mode. They are e=1.5 (three gates are operated), e=2.27 (two gates are operated) and e=4.54 (one gate is operated). The variation of ds/y_1 with F_1 and Ψ with F_1 for the three expansion ratios are shown in Figures 9a and 9b respectively. It is evident that the operation of two gates in general yields lower values of d_s/y_1 and Ψ for values of F_1 higher than 3.0. Similarly, when the gates are operated in asymmetrical mode, two values of e results in. They are e=2.27 (two asymmetric gates) and e=4.54 (one asymmetric gate). Figures 10a and 10b present the results for these two expansion ratios. Again, operating two asymmetric gates was better than operating one asymmetric gate.

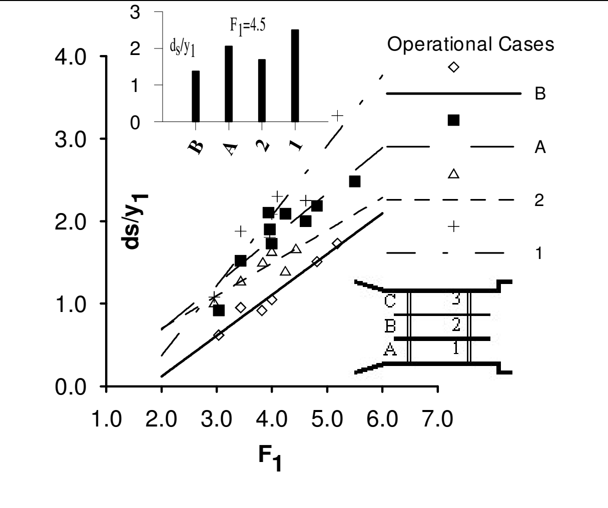

Figure 8a. d_s/y_1 versus F_1 for operating one gate

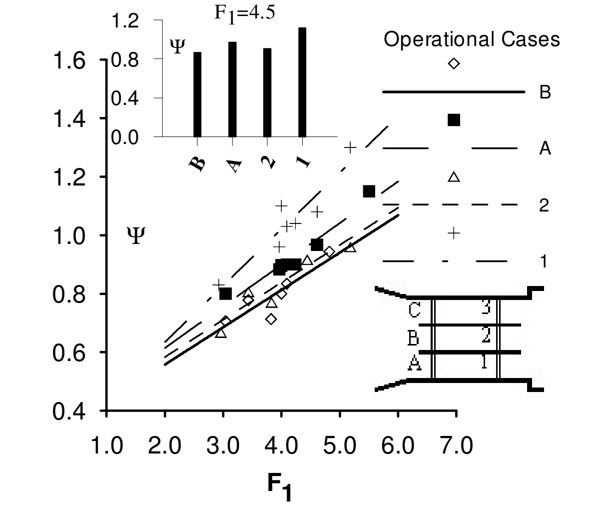

Figure 8b. Ψ versus F_1 for operating one gate

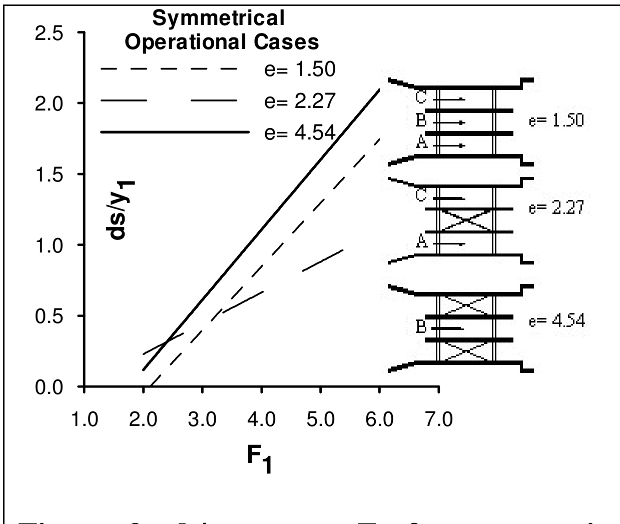

Figure 9. d_s/y_1 versus F_1 for symmetric operation and different e

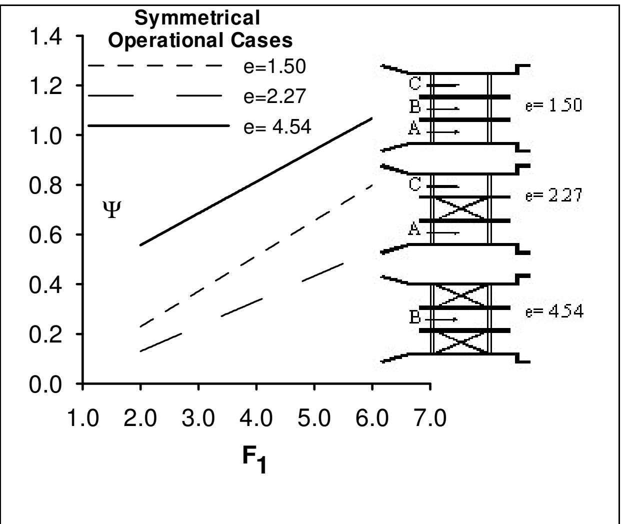

Figure 9b. Ψ versus F_1 for symmetric operation and different e

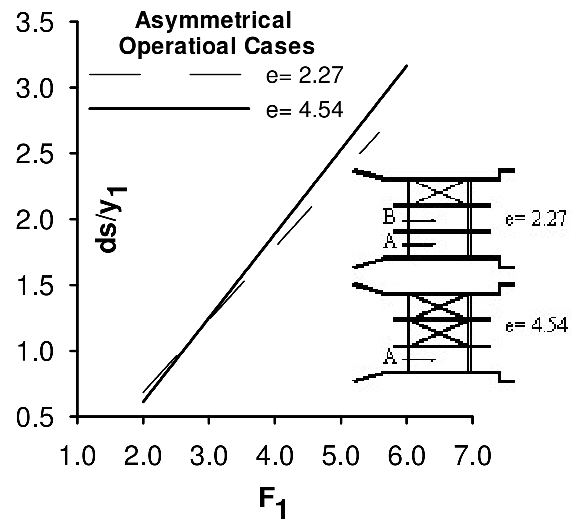

Figure 10a. d_s/y_1 versus F_1 for asymmetric operation and different e

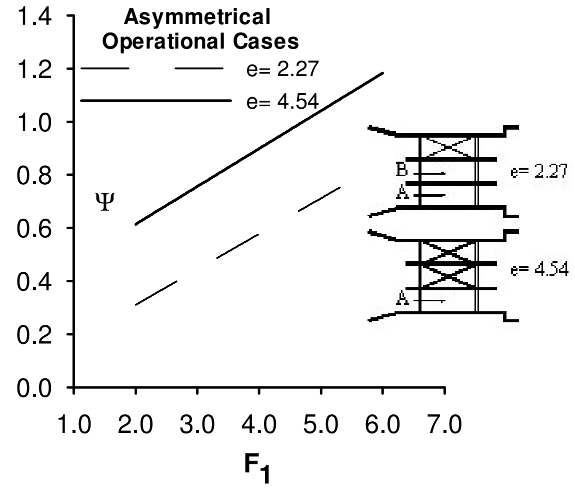

Figure 10b. Ψ versus F_1 for asymmetric operation and different e

6. Effects of F1, S, Ψ and e on $L_s//y_1$

The distance from the end of the rigid bed to the center of the scour hole where maximum scour occurs was measured for each run. Analysis of all collected data indicated that the relative length to the maximum scour depth was a function of the initial Froude number, submergence ratio, operation mode of the gates and expansion ratio. Figures 11, 12, 13, 14, 15 and 16 present the variation of L_s/y_1 with F_1 to investigate the effect of different constant submergence ratios, the effect of operating three gates, the effect of operating two gates, the effect of operating one gate, the effect of expansion ratio for symmetrical operations and the effect of expansion ratio for asymmetrical operation. Clearly, the ratio L_s/y_1 was increased by increasing F_1.

Also, these figures indicated that scour hole was formed nearer to the rigid bed (shorter L_s/y_1) when the submergence ratio was higher, the operation mode was symmetric and when the expansion ratio was equivalent to operating two gates either in symmetrical or asymmetrical mode (e=2.27).

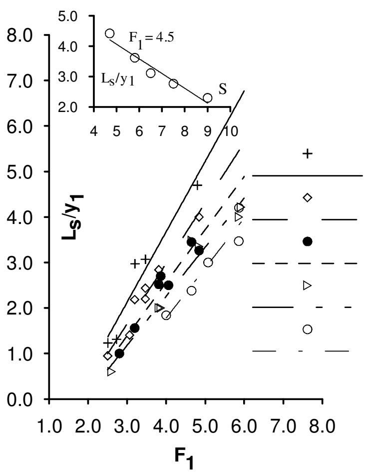

Figure 11. Ls/y_1 versus F_1 for different constant submergence

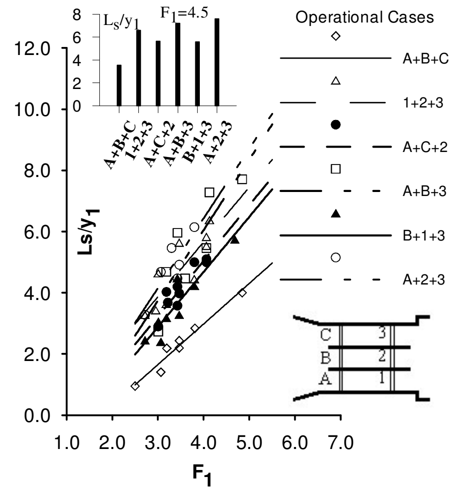

Figure 12. Ls/y_1 versus F_1 for different cases of operating three gates

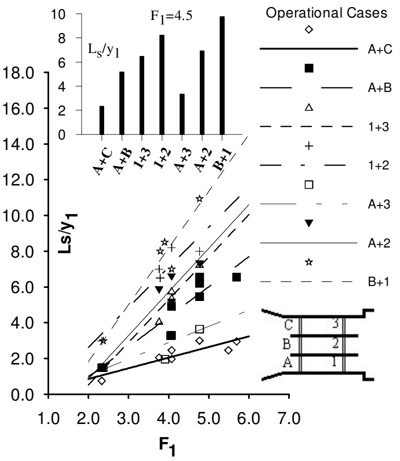

Figure 13. Ls/y_1 versus F_1 for different cases of operating two gates

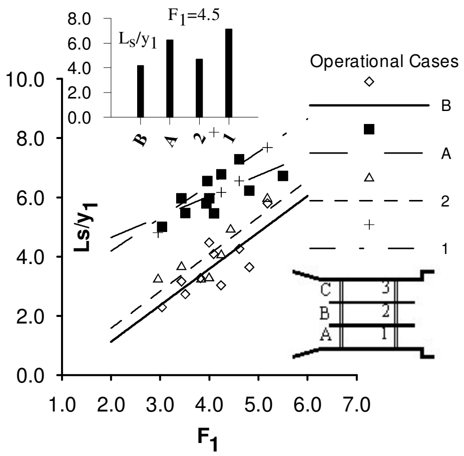

Figure 14. Ls/y_1 versus F_1 for different cases of operating one gate

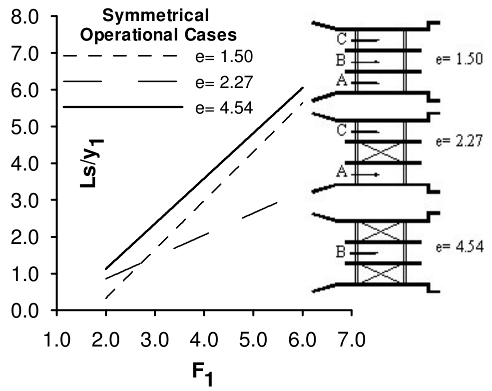

Figure 15. Ls/y_1 versus F_1 for symmetrical operation and different expansion ratio

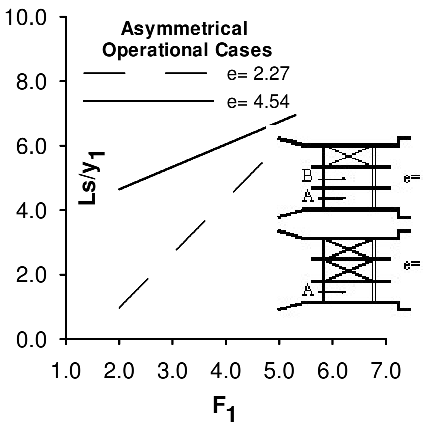

Figure 16. Ls/y1 versus F1 for asymmetrical operation and different expansion ratio

CONCLUSIONS

The present research paper highlights the following conclusions:

1- The relative maximum velocity near bed increases with the increase of the initial Froude number at constant submergence ratio, it decreases with the increase of submeregnce ratio at constant Froude number.
2- The relative maximum scour depth increases with the increase of the initial Froude number at constant submerged ratio, while it decreases with the increase of the submergence ratio at constant Froude number.
3- The relative position (length) of maximum scour depth increases in the Froude number at constant submeregence ratio, while it increases with the decrease of submergence ratio at constant Froude number.
4- When three gates are operated: (a) operating case (A+B+C i.e operating all main gates) produces minimum values for ds/y_1, Ls/y_1, and Ψ. in contrast the operating case (1+2+3 i.e. operating all emergency gates) produces the highest values for ds/y1, Ls/y and Ψ. the combined operation of main and emergency gates has values for ds/y_1, Ls/y_1, and Ψ in between the two previous cases. (b) operating case A+2+3 produces larger values for ds/y_1, Ls/y_1 and Ψ than A+B+3. (c) The symmetrical operational cases produces lower values for ds/y_1, and Ls/y_1 comparable to the asymmetrical operational cases.
5- When two gates are operated: (a) operating case (A+C, i.e. operating the two separated main gates) (expansion ratio 2.27) produces minimum values for ds/y_1, Ls/y_1 and Ψ. (b) the worst operational case is (B+1, i.e. operating the middle main gate and the side emergency gate). (c) For the asymmetric case (B+1) there is a great eddies at the end of the basin due to the reverse velocity leading to accumulation of sand particle over the third middle part of the stilling basin
6- When operatng one gate: (a) operating case ((B), i.e. operating the middle main gate) (expansion ratio 4.54) produces minimum relative velocity near bed, and hence minimum relative scour depth. (b) The asymmetrical operational case ((1), i.e. operating the side emergency gate) (expansion ratio 4.54) gives maximum relative velocity near bed and consequently maximum relative scour depth.
7- The best operational case which produces minimum values for ds/y_1, Ls/y_1 and Ψ has expansion ratio equals 2.27 either for symmetrical or asymmetrical and the worst one has an expansion ratio equals 4.54

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NOTATIONS

B: The flume width, [L].
be: The width DS of working gates, [L].
d50: The mean diameter of the sand base, [L]
F_1: Initial Froude number, $F1=v1/(gy1)^{0.5}$, [-]
g: The gravitational acceleration, $[LT^{-2}]$.
L_s: Distance from end of basin to the section of maximum scour, Length to the maximum scour, [L].
S: The submergence ratio (yt/y1), [-].
v_1: The velocity at the supercritical flow depth y1, $[LT^{-1}]$.
w: The pier width, [L].
y_1: The supercritical flow depth, [L].
y_b: The distance from the bottom to the location where the bottom velocity is measured, [L].
y_t: The tail water depth, [L].
ω: The scenario of operating gates systems, [-].
Ψ: The relative bottom velocity, $\Psi = vb/(gyb)^{0.5}$.