Effect of height of curved deflector on maximum local scour downstream of multi-vents regulators

Abdelreheem A. Ibrahim[a] Abdelazim M. Negm[a] and Abdelazim M. Ali[b]
[a] *Water & Water Structures Eng, Dept., Faculty of Eng., Zagazig University, Zagazig, Egypt*
Email: reheem2007@yahoo.com
[b]*Hydraulics Research Institute, National Water Research Center, MWRI, Egypt*

Recently, it is planned to redesign and construct major hydraulic structures such as New Esna, and New Nega Hammadi barrages. The design of these multi-vents structures were carried under the submerged hydraulic jump conditions. These huge structures face a harmful effect caused by local Scour Downstream (DS) their stilling basins. An experimental program was carried out on multi-vents regulator laboratory model provided with curved perforated deflectors as an energy dissipation device. The curved perforated deflector is carefully designed to be located at pre-specified position in the stilling basin as obtained from previous investigations. Models of curved perforated deflector of different heights were tested under different submerged flow conditions in order to investigate the effect of height on both maximum depth of scour and length to the maximum depth of scour DS multi-vents regulators. The scour dimensions DS of the stilling basins were measured. Dimensional analysis was used to initially derive general expression for the scour parameters as a function of the independent dimensionless parameter such as flow submergence, Froude number, operational scenario, and relative height of deflector wall. The effect of these independent parameters on the main parameters of scour is investigated. Using this new type of deflector wall under certain heights, it was possible to reduce the scour to about 85 to 100% compared to the case with no deflector.

نظرا لاهمية التحكم فى النحر خلف المنشآت الهيدروليكية للحفاظ عليها من المخاطرالعديدة للنحر الموضعى فان هذا البحث يدرس تأثير ارتفاع طريقة جديدة للتحكم فى النحر الموضعى خلف منشآت التحكم مثل القناطر. هذه الطريقة الجديدة هى استخدام موجه (أو موزع) منحنى عبارة عن حائط حاجز يوضع فى مواجهة السريان خلف البوابات عند موضع معين فى حوض التهدئة ويسمح هذا الموجه بمرور المياه من خلاله حيث به فتحات كما يسمح بمرورالمياه من فوقه حيث أنه مغمور وكذلك تمر المياه من جانبية حيث أنه لايشغل كامل عرض القناة. وبهذا فهو يعيد توزيع تيار المياه فيعاد توزيع السرعات وتهدأ السرعات القريبة من القاع ويقل بالتالى النحر كما أظهرت ذلك الدراسات السابقة. ويهتم هذا البحث أساسا بالكشف عن تأثير ارتفاع هذا الموجه على الخصائص الاساسية للنحر الموضعى ممثلة فى أقصى عمق نسبى للنحر والطول النسبى حتى مركز حفرة النحر. وقد اجريت التجارب المعملية فى قناة كبيرة الابعاد نسبيا ذات عرض 40 سم وعمق 60 سم وطول 44.1 متر، وقد اريت التجارب بمعهد بحوث الهيدروليكا بالمركز القومى لبحوث المياه بالقناطر. وقد استخدمت ارتفاعات مختلفة للموجه تحت ظروف السريان المغمور فوق الحرج. وقد تم عرض النتائج كدالة فى رقم فرود والارتفاع النسبى للموجه وسيناريوهات تشغيل البوابات. حيث أظهر البحث أنه كلما زاد ارتفاع الموجه قل العمق الاقصى للنحر حتىوصل صفرا فى بعض الحالات. كما أظهرت النتائج أن التشغيل المتماثل للبوابات هو الامثل مقارنة بالتشغيل غير المتماثل حيث أعطى الاخير قيم للنحر أعلى بكثير من الاول عند نفس ظروف السريان ونفس الارتفاع للموجه.

Keywords: Local scour, Hydraulic structure, Multi-vents Regulators, Submerged flow, Curved perforated deflector wall

1. Introduction

Local scour DS of multivents regulators may endanger the floor of the structure and consequently major damage for the structure may be expected. Hydraulic jump is normally formed DS the control structure as the issuing supercritical flow meets the downstream subcritical flow. Stilling basins are designed to confine the hydraulic jump to protect the eridoble bed from being strongly scoured. A good source of most published papers on the hydraulic jumps and stilling basins could be found in Hager [1]. The submerged hydraulic jump was studied by Govinda Rao and Rajaratnam [2], Rajaratnam [3, 4], Narayanan and Bhargara [5], Abdel-Gawad and

McCorquodale [6], El-Azizy [7], Long [8], Negm et al. [9] and Abdel-Aal [10].

On the other hand, Zidan, et al., [11], Hassan, et al., [12] investigated the local scour DS of the hydraulic structure. Khalifa, et al., [13] studied the effect of different arrangement of rectangular stilling basins on local scour DS one vent regulator exposed to supercritical flow. Abouel-Atta [14] investigated the scour phenomena due to a radial free hydraulic jump flowing over a rigid diverging apron to an erodible bed. Ali [15] investigated the best location of baffle sill and different variables affected upon the local scour DS hydraulic structures. Mohamed et al., [16] studied the effect of different positions and heights of a continuous sill on scour DS of hydraulic structures. El Masry, [17] studied experimentally the effect of a fully angle baffled apron on the local scour DS a heading-up structure. Saleh, et al., [18] studied the effect of asymmetric side sill on maximum scour DS of sudden stilling basins. Negm et al., [19] investigated the effects of operation of gates of multi-vents regulators on flow patterns along the bed via the analysis of the measured velocities near to bed. Also, Negm et al., [20] proved that the symmetric operation policy of gates reduces the scour dimensions compared to the asymmetric operation of gates. Negm et al., [21] proved, experimentally, that the best location of the curved deflector for reducing the scour dimensions and for symmetric and reduced velocity vectors is at 0.06L from the sudden expansion. At this location the values of relative velocity near to bed at the end of stilling basin is minimum and consequently minimum values for relative maximum scour depth were produced. They found that the average reduction in the relative maximum scour depth due to the presence of the curved deflector is about 85%.

2. Correlating the main parameters

Dimensional analysis, based on Buckingham theory, was used to develop functional relationship between the maximum depth of scour and the relevant variables (as shown in fig. 1). The maximum depth of scour, d_s, could be expressed in terms of other variables of interest as follows:

$$d_s = f(B, b_e, d_{50}, y_1, y_t, h_d, V_1, \rho, \rho_s, \mu, g, \omega). \quad (1)$$

In which, B, is the flume width, b_e, is the effective width DS of working gates and equals (number of opening gates multiplied by the width of one gate), d_{50}, is the mean diameter of the sand base, y_1, is the supercritical flow depth, y_t, is the tail water ρ_s depth, h_d, is the height of the curved deflector, V_1, is the velocity of the supercritical flow of depth y_1, ρ the density of water, ρ_s , is the density of sand particles, μ, is the dynamic viscosity of water, g, is the gravitational acceleration, and ϖ, represents the operational policy of the gates.

Since d_{50}, and ρ_s were kept constant throughout the experimental program, they will be removed from eq. (1). Also, the effect of viscosity is assumed of secondary importance in estimating the scour parameters, as the flow is mainly gravitational, therefore the effect of μ can be neglected. Eq. (1) reduces to:

$$d_s = f(B, b_e, y_1, y_t, h_d, V_1, \rho, g, \omega). \quad (2)$$

Which when converted in non-dimensional form takes the form

$$\frac{d_s}{y_1} = f(S, e, H_o, F_1, \omega) . \quad (3)$$

In which d_s/y_1 is the relative maximum depth of scour, $S = \frac{y_t}{y_1}$ is the submergence ratio which is kept unchanged in this paper, $e = \frac{B}{b_e}$ is the expansion ratio and $H_o = \frac{h_d}{y_1}$ is the relative height of the curved deflector.

3. Experimental work

The experimental work was conducted in the Hydraulic Research Institute (HRI), National Water Research Center, Ministry of Water Resources and Irrigation, Delta Barrages, Egypt. The used flume is recirculating and adjustable one of 44.1 m long, 60 cm deep and 40 cm wide. The tailgate which is fixed at the end of the flume is used to control the depth of flow DS the sluice gate. The discharges were measured using rectangular weir which was calibrated using ultrasonic flowmeter.

Fig. 1 shows the experimental model details. It consists of two vertical convergent baseform made of wood which is carefully treated such that its volume does not change with time as affected by water. Each of these two walls is of length of 45 cm. They are followed by two vertical parallel baseform plates with a length of 70 cm. These parts were fixed over a 12 cm thick false bed. The distance from the main gate to the end of the apron is 125 cm, as shown in fig. 1. Two piers each with a length of 55 cm, made of baseform were fastened at the contracted part with 50 cm length. There are three vertical gates which made of clear perspex, and slides through vertical grooves. The height of the regulator model is 48 cm above the false bed.

The objective of the present investigation is to study the effect of height of the deflector on the scour parameters DS of the solid apron of the regulator. Fig. 2 shows the details of the tested deflector. The deflector has 28% waterway (solid area 72%), Negm et al., [22] and fixed at 0.06L (with L is the length of the basin), Negm et al. [21]. Five heights (2 cm, 3 cm, 4 cm, 5 cm and 6 cm.) were tested under the same flow conditions. Different operational scenarios of gates were considered viz (symmetric and asymmetric operations). The total number of conducted runs was 84. The effect of submergence ratio was studied for operating all gates by Negm et al., [20] and hence is this study the submergence ratio were kept unchanged (S=5.8). The experimental work was conducted under supercritical flow condition with Froude number ranging from 2.0 to 5.5.

The following procedure was followed to collect the experimental measurements, (i) Fix the deflector model of certain height at its position on the rigid bed and wait until the model is completely dried; (ii) switch on the pump allowing a certain required discharge to gradually pass through certain gate opening; (iii) The tail gate was adjusted to form submerged jump over the rigid bed; (iv) The movable bed (sandy soil) was re-leveled horizontally with the fixed bed after reaching the equilibrium conditions; (v) The running time of the test was started; (vi) The pump was turned off once the run time was terminated, [each run is allowed to last about 50 minutes where about 95% of maximum scour occurs, Negm et al [20]; (vii) The tail gate was screwed gradually until the channel became empty; (viii) The scour mesh was measured; and (viv) The experiment was repeated until the required range of Froude number is covered; (x) Another deflector height was tested by repeating the above procedure.

4. Experimental results

All possible relationships were plotted to enable well understanding of the effect of relative height on relative maximum depth of scour and on the relative length to maximum scour. Using the experimental data, the dimensionless parameters were computed to evaluate the effects of the relative height (H_o= h_d/y_1=0.75, 1.25, 1.80, 2.45 and 2.8) of the curved wall. The effect of height was examined for fixed submergence ratio, S = 5.8, fixed waterway of Ao = 0.28, at fixed relative position of the deflector wall, Lo = 0.06. All tests were conducted for a range of Froude number from 2.0 to 5.5. In the next sections, only the most important relationships of the relative maximum scour depth, ds/y1 and the relative length to maximum scour, Ls/y1 against Froude number were presented for all possible operational scenarios of gates.

5. Discussions and analysis

5.1. Operation of all gates

Fig. 3 presents the relative maximum depth of scour versus Froude number for values of the relative height of the curved deflector wall of 0.75, 1.25, 1.80 and 2.45 and no deflector case. (Initial case). The relationship between F_1 and d_s/y_1 is increasing linearly for all values of F_1 and H_o. Clearly, the initial case produces the maximum values of d_s/y_1 for all values of

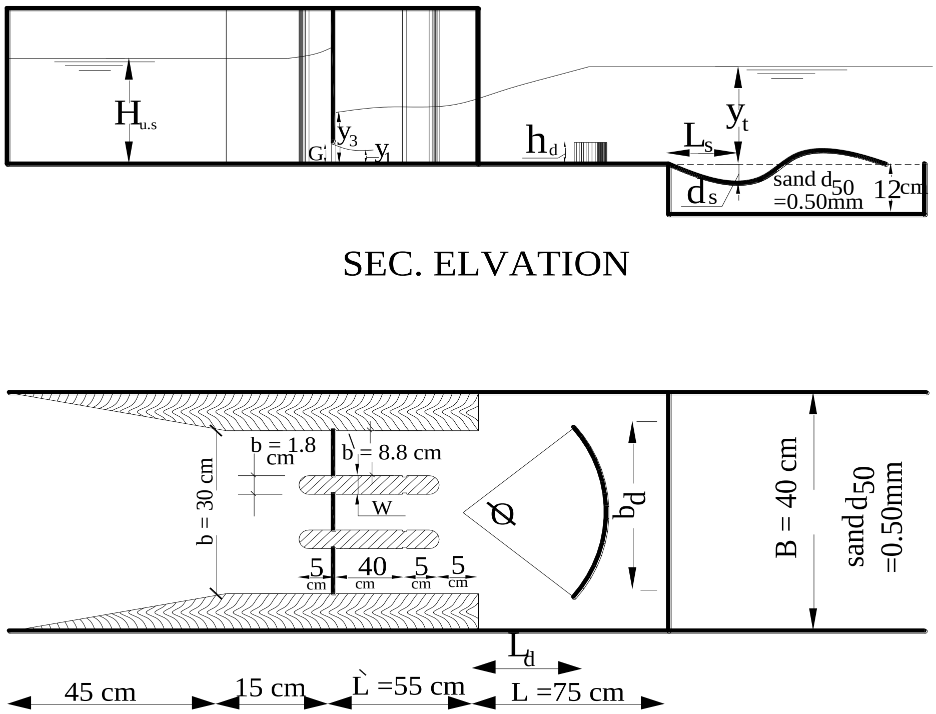

Fig. 1. Definition sketch and dimensions of the test model.

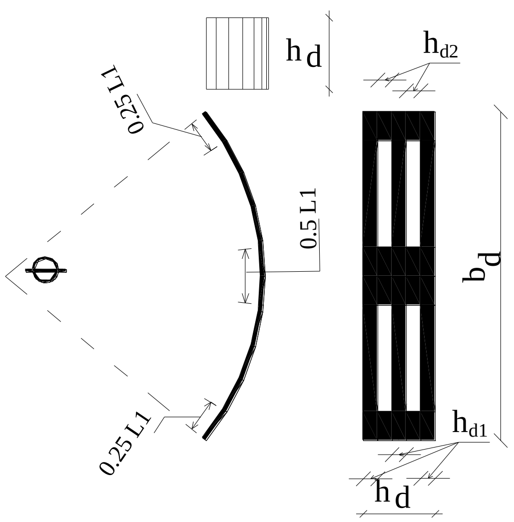

Fig. 2. Details of the used curved deflector.

Froude number while the minimum values of d_s/y_1 were produced when the relative height of wall was 2.45. Other values of H_o produced values of d_s/y_1 between those of the initial case and H_o = 2.45. This indicates that the more increase of the height of the deflector wall, the more the reduction in the relative maximum depth of scour, d_s/y_1, and hence the maximum scour is reduced which in turn will lead to a reduced protection works. At particular Froude number, e.g. F_1=4, the minimum values of d_s/y_1, were attained when Ho=2.45.

Similar observations for the relative length to the maximum scour could be reached by analyzing the relationship between L_s/y_1 and F_1 that presented in fig. 4. Obviously, L_s/y_1 increases linearly with F_1 for all values of F_1= and H_o. The higher the values of Ho, the lower the values of L_s/y_1. Hence, minimum values of L_s/y_1 occurred at H_o=2.45 and maximum values occurs at H_o = 0. At particular Froude number, e.g. F_1=4, the minimum values were attained when H_o=2.45.

5.2. Symmetric operation of two gates

Figs. 5 and 6 present similar relationships as those of Figures 3 and 4, respectively, but for operating two symmetric gates. Exactly similar trend was observed. Comparing fig. 3 to fig. 5 and fig. 4 to fig. 6, it is clear that the values of $ds/y1$ and $Ls/y1$ for operating all the gates are lesser than those for operating two gates (2/3 of all gates) at same flow conditions. This recommends the policy of operating all gates to safeguard the structure against excessive scour problems. It should be mentioned here that the line representing Ho=1.8 was omitted (it lies between the lines 1.25 and 2.45) as the trend is clear from figs. 3 and 4.

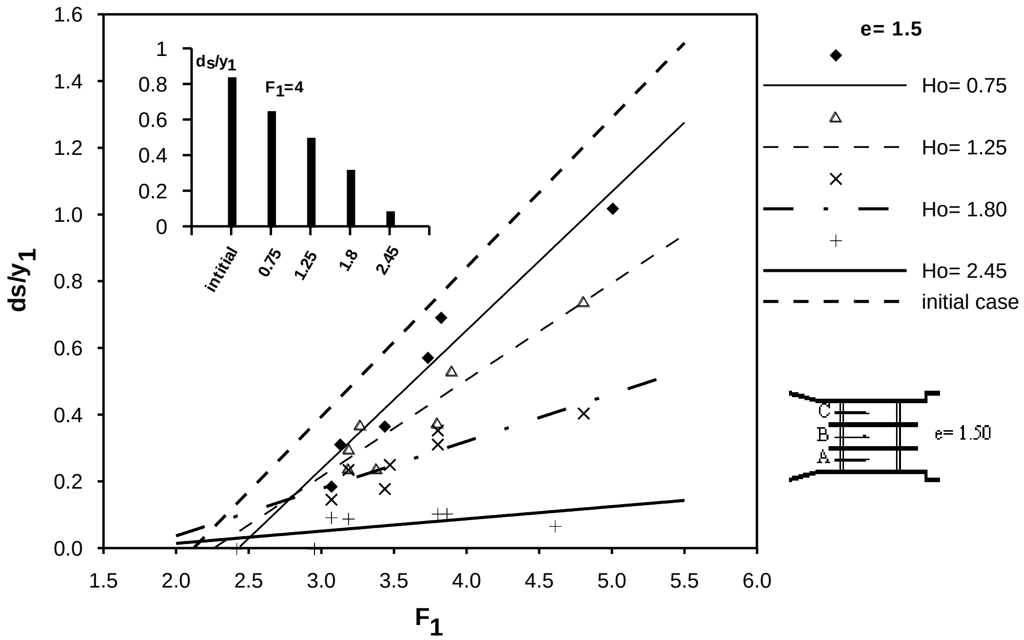

Fig. 3. The relationship between ds/y_1 and F_1 for different Ho and operating all gates at S = 5.8, and Ao= 0.28 at Lo= 0.06.

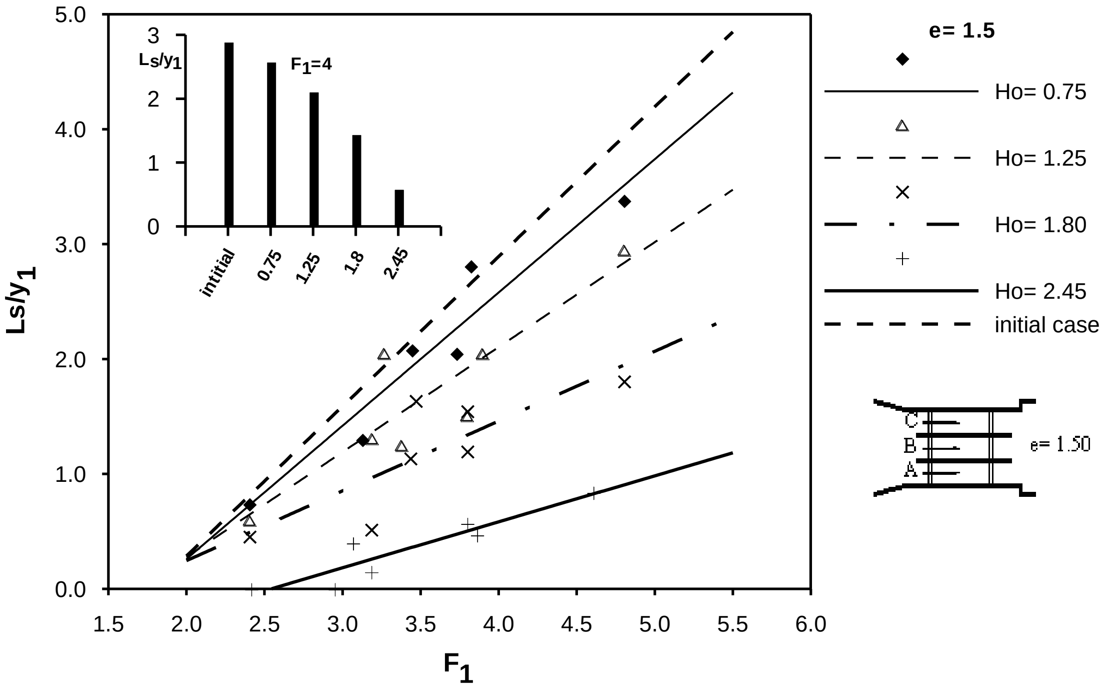

Fig. 4. The relationship between Ls/y_1 and F_1 for different Ho and operating all gates at S= 5.8, and Ao= 0.28 at Lo= 0.06.

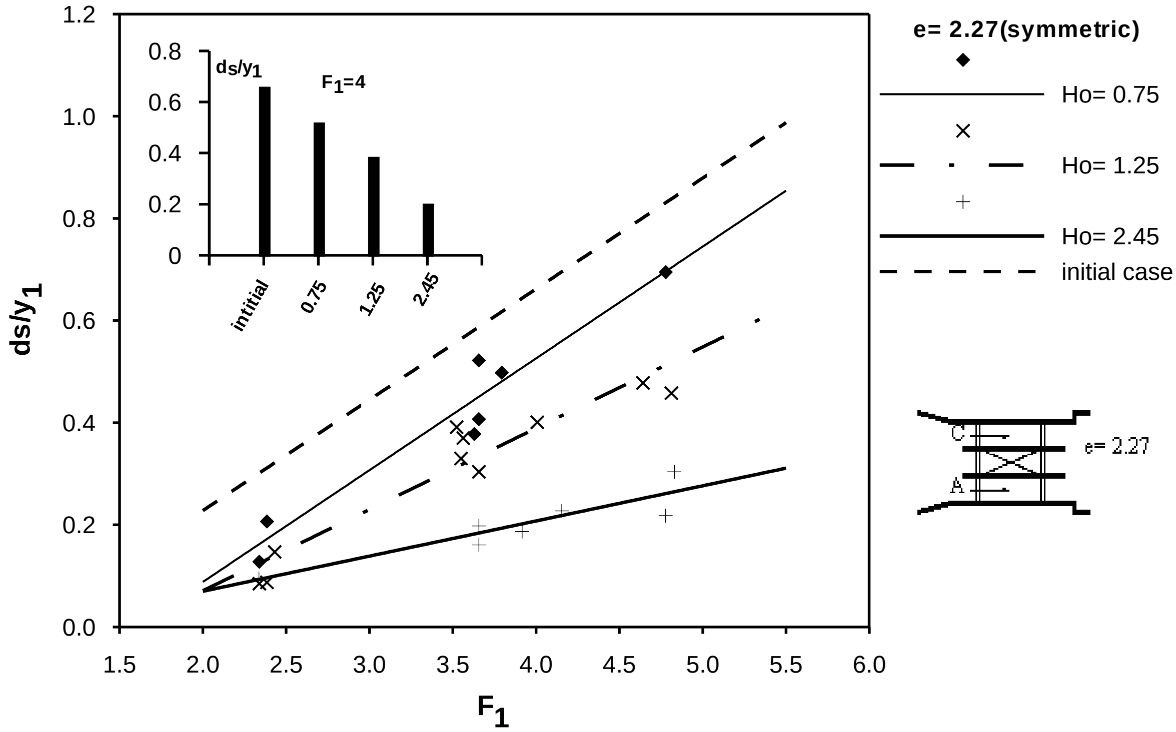

Fig. 5. The relationship between ds/y1 and F1 for different Ho and operating two symmetric gates (A+C) at S= 5.8, and Ao= 0.28 at Lo= 0.06.

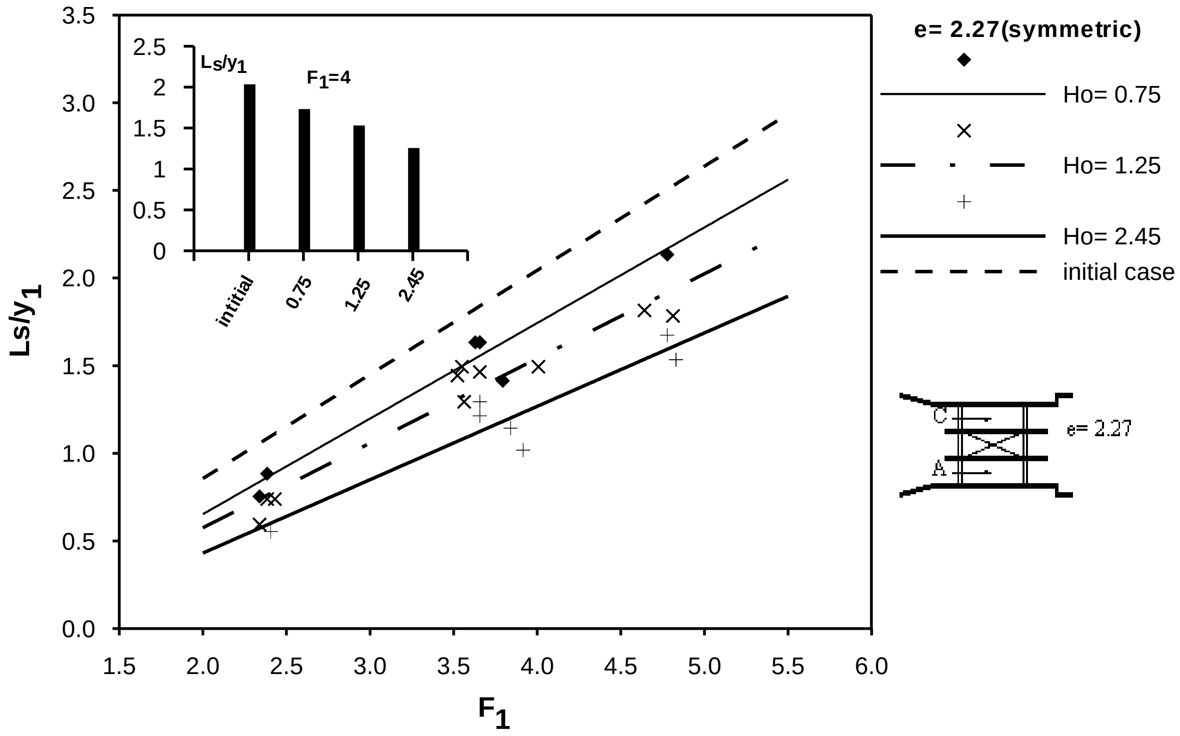

Fig. 6. The relationship between Ls/y1 and F1 for different Ho and operating symmetric two gates (A+C) at S= 5.8, and Ao= 0.28 at Lo= 0.06.

5.3. Asymmetric operation of two gates

The results of operating two asymmetric gates are presented in figs. 7 and 8 for the relationships d_s/y_1 and L_s/y_1 versus F_1 for different relative heights of the deflector wall of 0.75, 1.25 and 2.45 and the initial case (Ho=0.0). All the relationships follow the same linear trend as the previous figures for operating all gates and for symmetric operation of two gates. It could be noticed that the minimum values of the investigated parameters are obtained when the value of the relative height are maximum and vice versa.

Comparing fig. 7 with figs. 3 and 5, it is clear that the values due to symmetric operation is smaller than those of asymmetric operation and those of operating all gates are also smaller than those of the asymmetric operation. Similar observations could be noticed when comparing fig. 8 with those of 4 and 6 for L_s/y_1. This leads to the fact that symmetric operation of two gates is much better than asymmetric operation of two gates and the operation of all gates is better than symmetric operation of 2/3 of the gates. Consequently, to protect the structure from the severe effects that might be occurred due to excessive scour, it is advised to symmetrically operate the gates if it is not possible to operate all the gate due to maintenance or presence of faults in some gates.

5.4. Symmetric operation of one gate

The relative maximum depth of scour versus Froude number for different Ho is presented in fig. 9. It is interesting to observe the high effect of increasing the height of the deflector in reducing ds/y1. Clearly, the higher the deflector, the smaller the values of the relative maximum depth of scour at the same flow conditions. The maximum scour due to Ho=2.45 is very small compared to all other tested cases. Another additional relative height of Ho=2.8 is tested to further investigate the effect of larger heights. The figure indicates that the scour is nil when the relative height of the deflector increases to 2.8.

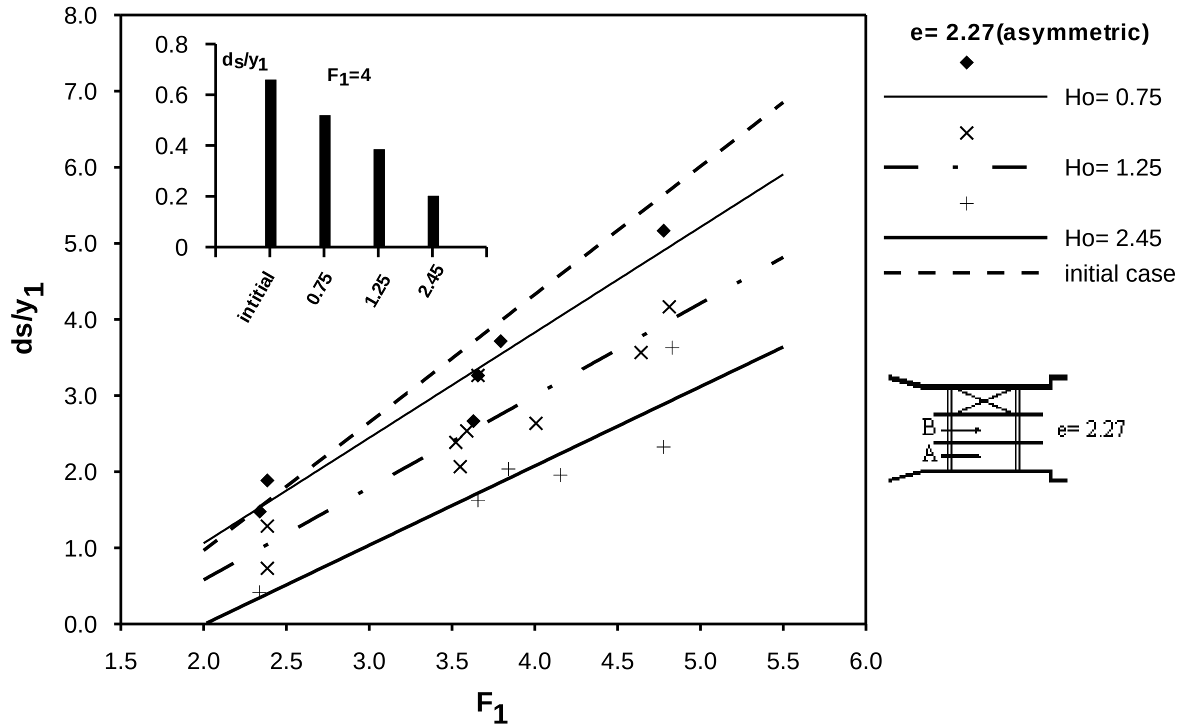

Fig. 7. The relationship between ds/y1 and F1 for operating two gates (A+B) with different Ho with S= 5.8, and Ao= 0.28 at Lo= 0.06.

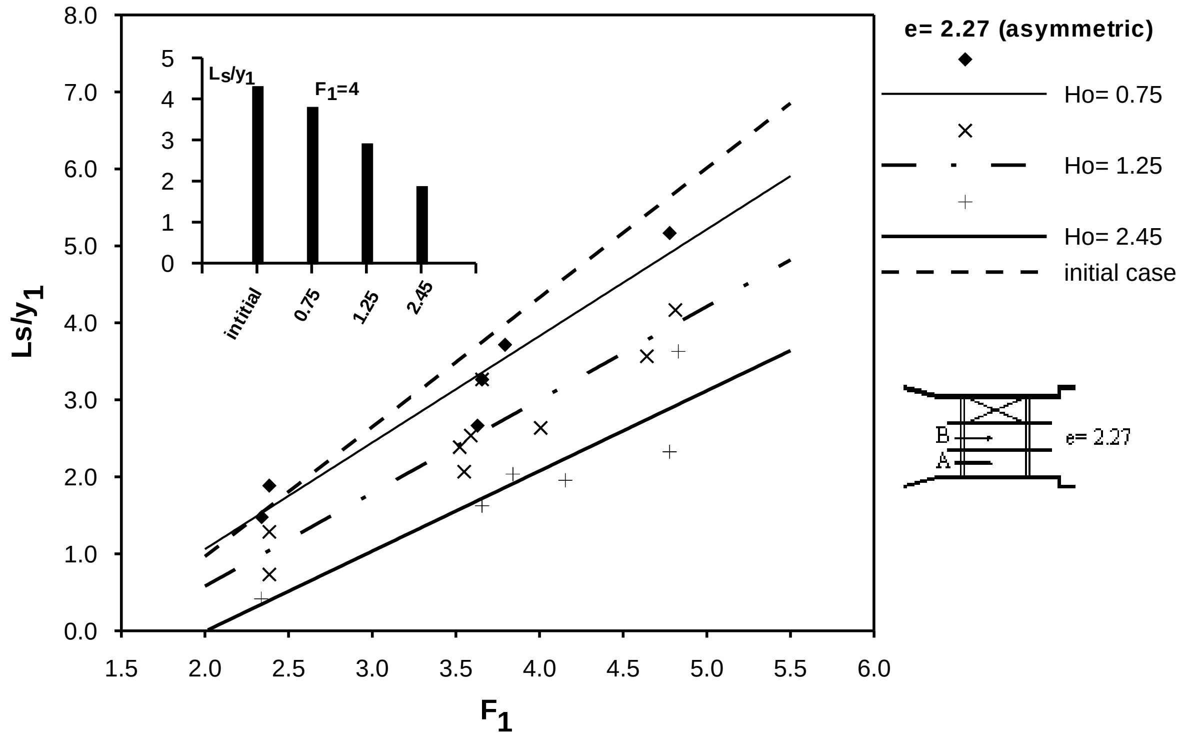

Fig. 8. The relationship between Ls/y_1 and F_1 for operating two gates (A+B) with different Ho with S= 5.8, and Ao= 0.28 at Lo= 0.06.

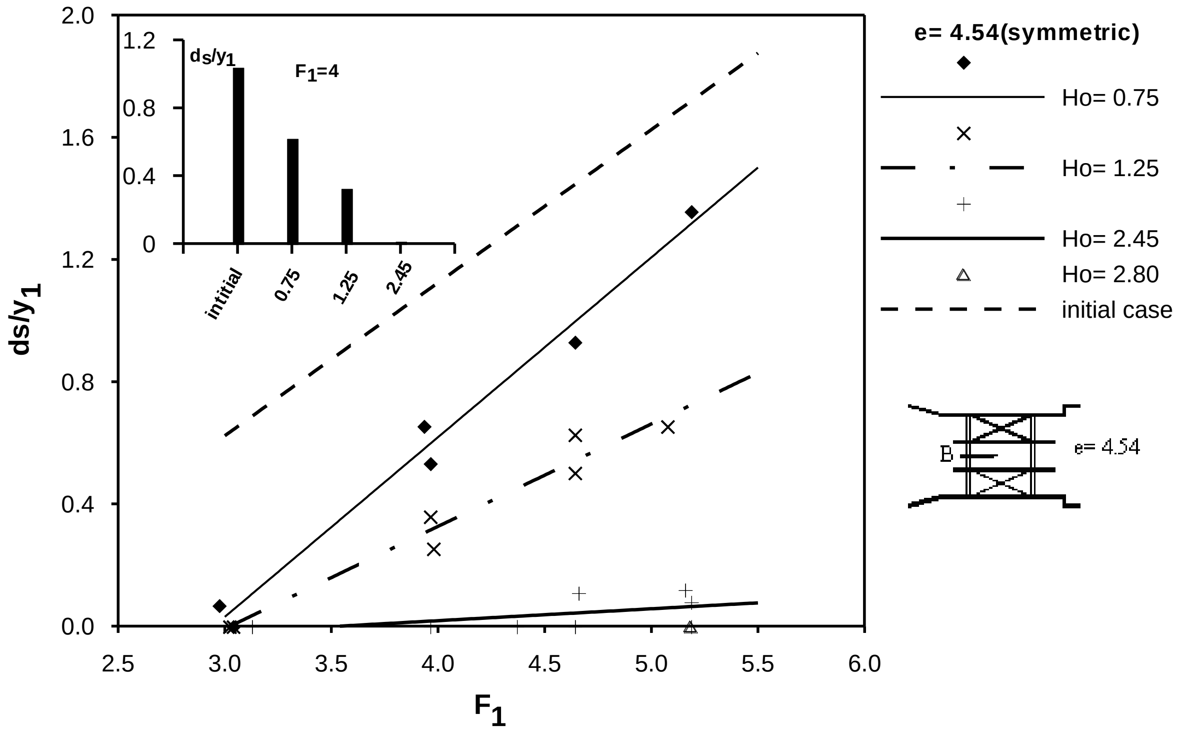

Fig. 9. The relationship between ds/y1 and F1 for different H_o and operating one gate (B) at S= 5.8, and A_o= 0.28 at L_o= 0.06.

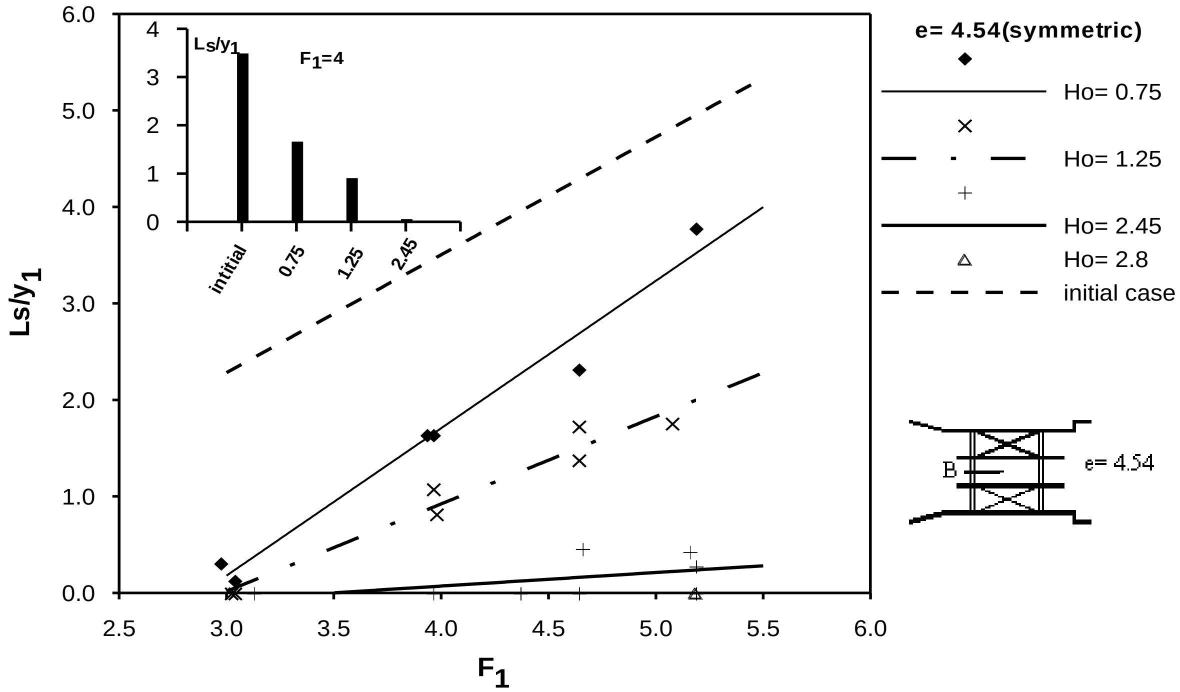

Fig. 10.The relationship between Ls/y1 and F1 for different H_o and operating one gate (B) at S= 5.8, and A_o= 0.28 at L_o= 0.06.

On the other hand, the relative length to the maximum scour is reduced (as shown in fig. 10) which means that the main scour hole occurred nearer to the solid bed compared to all other tested cases. This may endanger the whole structure if the bed downstream the solid apron is not protected against scour. Alternatively, it has the advantage of saving the costs of protecting the floor against the harmful effect of scour.

5.5. Asymmetric operation of one gate

Similar figs. 11 and 12 for the asymmetric operations of one gate (one side gate) are presented to investigate the trend of variation of the two basic parameters, relative maximum scour depth and relative length to the maximum scour with the Froude number. It is observed that similar trend of variation is observed as in the case of symmetric one gate, symmetric two gates, asymmetric two gate and operation of all gates. Comparing the values of the two parameters at a particular Froude number with their corresponding values for operating symmetric one gate, it is observed that the values of asymmetric operation is higher than those of symmetric operation. This recommends the use of symmetric operation if it is not possible to operate all the gates.

5.6. Concluding remarks

The results presented in figs. 3 and 4 indicate the curved deflector has a great reduction effect on the parameters d_s/y_1 and L_s/y_1 as they decrease with the increase in Ho. It is expected that this decrease in these parameters will continue as H_o increases until the scour reaches zero as in case of using *Ho* = 2.8 at symmetric operation of one gate fig 9. Further increase in H_o may lead to more portion of discharge to pass through the deflector waterway passage causing more increase in the near bed velocity and hence increasing the scour process. At this point, a detailed experimental program is needed to investigate all the possible combinations of higher heights and larger A_o.

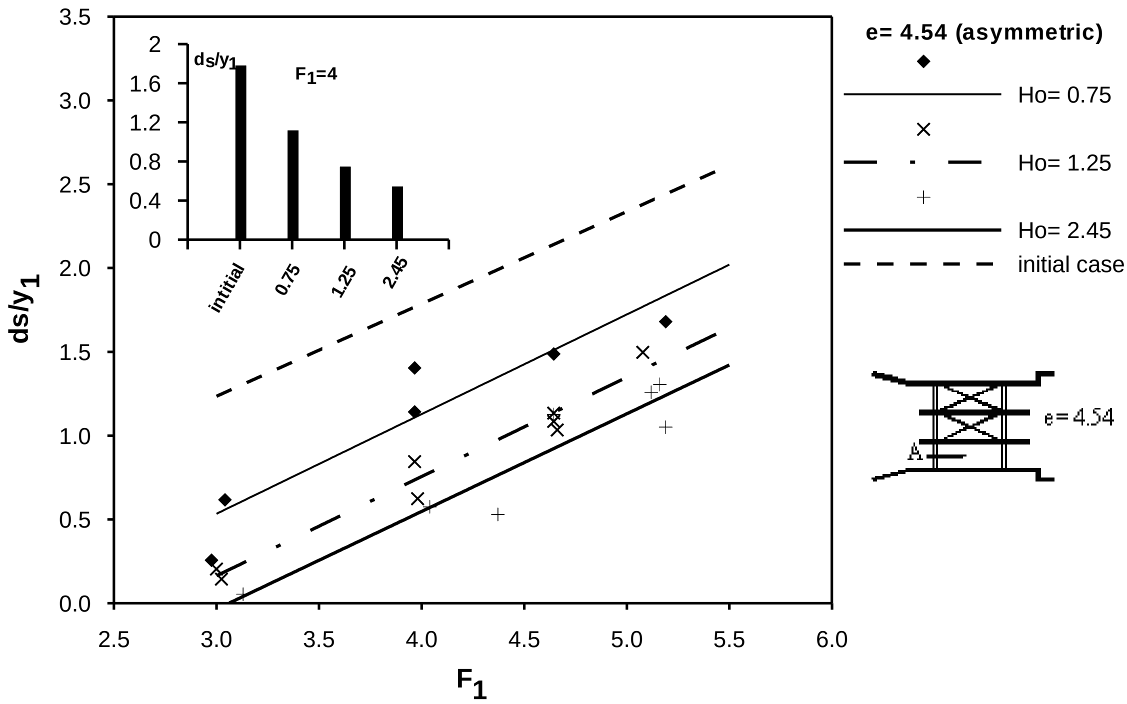

Fig. 11. The relationship between ds/y1 and F1 for different H_o and asymmetric operating one gate (A) at S= 5.8, and A_o= 0.28 at L_o= 0.06.

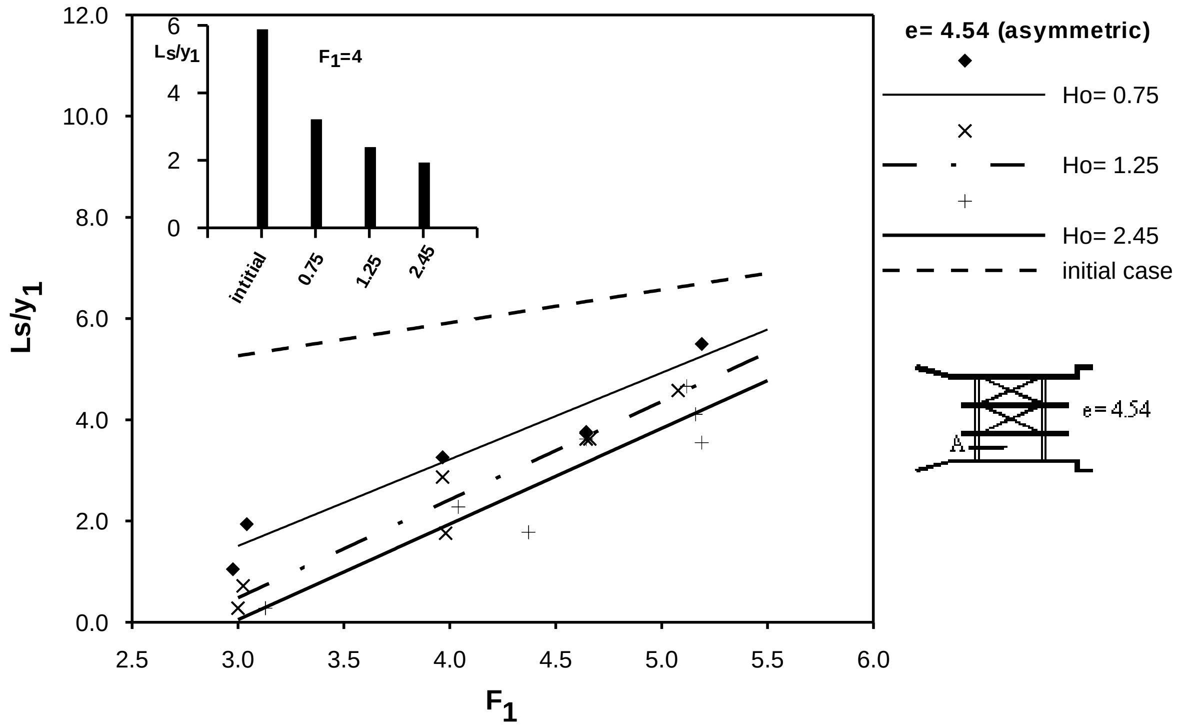

Fig. 12 The relationship between Ls/y_1 and F_1 for different H_o and asymmetric operating one gate (A) at S= 5.8, and A_o= 0.28 at L_o= 0.06.

6. Conclusions

From the above analysis and discussion, one could conclude the following conclusions which are applicable within the experimental limitations of the present study:

1- The relative maximum depth of scour, d_s/y_1, increases with the increase of the initial Froude number, F_1, for all values of the relative height, H_o, of the deflector for all tested operational scenarios of the gates and vice versa.

2- The reduction of the relative maximum depth of scour attains its maximum values when the relative height of the deflector is maximum.

3- The maximum the relative height, H_o, of the deflector, the minimum the relative distance to maximum scour, L_o.

4- It is advised to fully operate the regulators using all gates if possible, if not, partial operation of gates should be symmetrical.

Recommendations

1- An extensive research is needed to obtain the optimal relative height of the deflector for the optimal opened area of the deflector and the corresponding optimal opened area of the deflector if the height of the deflector is equal to the depth of water (free deflector).

2- The effect of the relative width of the deflector and the angle of orientation should be also investigated in order to obtain the optimal dimensions of the deflector as a scour minimizor and as an energy dissipater.

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Nomenclatures

a_o is the opening areas in the curved Deflector, [L^2],
A_t is the total surface area of the curved Deflector, [L^2],
B is the flume width, [L],
b_d, is the width of the deflector, [L],
b_e is the width DS of working gates, [L],
d_{50} is the mean diameter of the sand base, [L],
eg is the gravitational acceleration, [LT^{-2}],
h_d is the deflector height, [L],
Ho is the relative height of the deflector [-];
L is the basin length DS of sudden expanding cross section, [L],
L_d is the distance from the beginning of sudden expanding cross section to the curved deflector, [L];
Lo is the relative position of the curved deflector, [L_d/L],
S is the submergence ratio (y_t/y_1), [-];
v_1 is the velocity at the supercritical flow depth , y_1, [LT^{-1}],
w is the pier width, [L],
y_1 is the supercritical flow depth, [L],
y_t, is the tail water depth, [L],
ϕ is the deflector angle, [-],
μ is the dynamic viscosity of water, [$ML^{-1}T^{-1}$];
ρ_s is the density of sand particles, [ML^{-3}],
ρ is the density of water, [ML^{-3}], and
ω is the scenario of operating gates systems, [-].

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