Minimizing Scour of Contraction Stepped Spillways

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Authors' contributions

This work was carried out in collaboration between all authors. Author ASA designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors THNA and YAM managed the analyses of the study. Author YAM managed the literature searches. All authors read and approved the final manuscript.

Original Research Article

ABSTRACT

The scour downstream spillways can endanger the stability of the dams. Hence, determining the scour depth downstream of spillways was vital importance which scours holes formed around and near the foundations of spillways can endanger the stability of dams and may lead to their failure. So, this paper, investigate the scour downstream contraction stepped spillways. The experimental flume used 16.2 m length, 66 cm width and 65 cm depth. The used number of stepped spillways was 4 Sep, contraction ratio was 60% from flume width and the opening area in breaker 10% from the breaker area on all sides putting in down of breakers. The breaker used above the stepped spillway with different shapes of openings as rectangle, triangle and trapezoidal and different numbers by 2, 4, 6 and 8 of beakers. The divergent angle changes by $45°$, $30°$, $15°$ and $10°$. The results were showed that the best numbers of openings is 4openings with rectangle shape because it reduces the scour by 54.51%. In finally to improve this scour by divergent angle lead to the best angle is $10°$ can minimize the scour is 65.38%.

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1. INTRODUCTION

Spillways are structures constructed in dams in order to drain water in excess of the reservoir capacity. Although flow through these structures is associated with a great deal of energy loss, a scour hole is created due to the impact of the high-velocity jet on the erodible downstream bed. Bormann and Julien [3] reviewed experimental studies of scour downstream of hydraulic structures below free and submerged jets. Balachandar and Kells [2] showed that the dynamics of local scour is dependent on the tailwater depth. Dargahi [4] presented an experimental study to examine the similarity of scour profiles and the scour geometry. No experimental evidence was found in support of the similarity. Power-law type equations were introduced to predict the scour geometry, mainly in terms of the head above the spillway crest and the grain size of the sediment bed. Marion et al. [10] conducted a series of tests to determine the effect of bed sill spacing and sediment grading on the potential erosion by jets flowing over the sills. Adduce and Sciortino [1] presented both numerical and experimental investigations on local scour downstream of a sill followed by a rigid apron. A one-dimensional numerical model simulating the evolution of the scour hole was developed and tested by laboratory measurements. Dey and Raikar [5] studied the scour below a high vertical drop. They presented influences of various parameters and dimensionless parameters for their study. Hamidifar and Nasrabadi [8] conducted experimental study to investigate the scour downstream of a roughened apron located downstream of a hydraulic jump. They carried out tests with five different roughness height sand one bed material size under different flow conditions. Giuseppe Oliveto [7] deals with the temporal and spatial evolution of local scour downstream of low head spillways with a horizontal apron, it was found that the main dimensionless parameters governing the scouring process are the tailwater densimetric Froude number, the relative time and the relative distance of the toe of the hydraulic jump from the apron edge. Fadaei-Kerman E. and Barani G.A. [6] study numerical simulation of flow over a chute spillway is presented using the Computational Fluid Dynamics (CFD) method. The flow characteristics such as velocity, pressure and depth through the spillway have been calculated for four different flow rates.

Jianbo Zhang [9] study the volume of fluid (VOF), mixture and Eulerian methods are utilized to simulate the air-entrainment by coupling with the Reynolds-averaged Navier–Stokes/large eddy simulation (RANS/LES) turbulence models. The free surface deformation, air volume fraction, pressure, and velocity are compared for the three different numerical methods.

The studies investigators have made important contributions to the knowledge of the phenomena of local scour downstream of hydraulic structures in the relevant flow situations. The aim of the present research is focusing on the evaluation of the depth local scour downstream from contraction stepped spillway under different angles of downstream and using breakers above these spillways with different number of openings and shapes to find the best to improve scour downstream spillways.

2. EXPERIMENTAL WORK

Experimental work was carried out in the Hydraulic and water Engineering Laboratory, Faculty of Engineering, Zagazig University, Egypt. The experimental flume 16.2 m length, 65 cm depth and 66 cm width as shown in Photo 1. The measuring discharge by weir was found in the lower flume, equation of the weir is: $Q = 1.088*Y^{1.523}$, Where: Y is the height of water over the weir crest, Q: discharge. The openings in breakers and downstream divergent angle in flume as shown in photo (2) the median size (D50) was used equal 3.1 mm from Fig. 1. The required time for each test was from the relationship between d_s/d_s Equilibrium was plotted with the time as shown in Fig. 2, it was found that 90% of maximum scour depth was achieved at 2 hours.

3. DIMENSIONAL ANALYSIS

The dimensional analysis of the experimental flume in Fig. 3. Approach of π- Buckingham theory is obtained:

$$\frac{ds\ max}{yc} = f\left(\frac{B-2C}{B}, \alpha, \frac{A0}{Ab}, N, F_0\right) \qquad (1)$$

Where: $d_{s\ max}$: maximum depth of scour, y_c: critical water depth of spillway, B:flume width = spillway width, C: Width of side wall in spillway, B: the channel width = the step Width, F_0: Froude number in upstream of spillway and α : downstream divergent angle, N: number of openings in breakers.

Photo 1. General view flume in lab

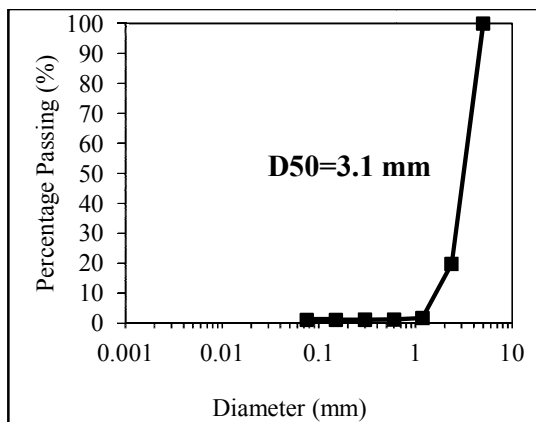**Photo 2. The openings in breakers and downstream divergent angle in flume**

Fig. 1. Sieve analysis of the sample

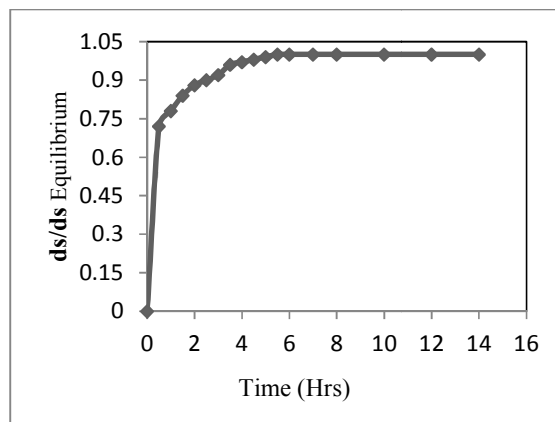**Fig. 2. Ratio of maximum to equilibrium scour depths ($d_s/d_{s\ Equilibrium}$) versus time**
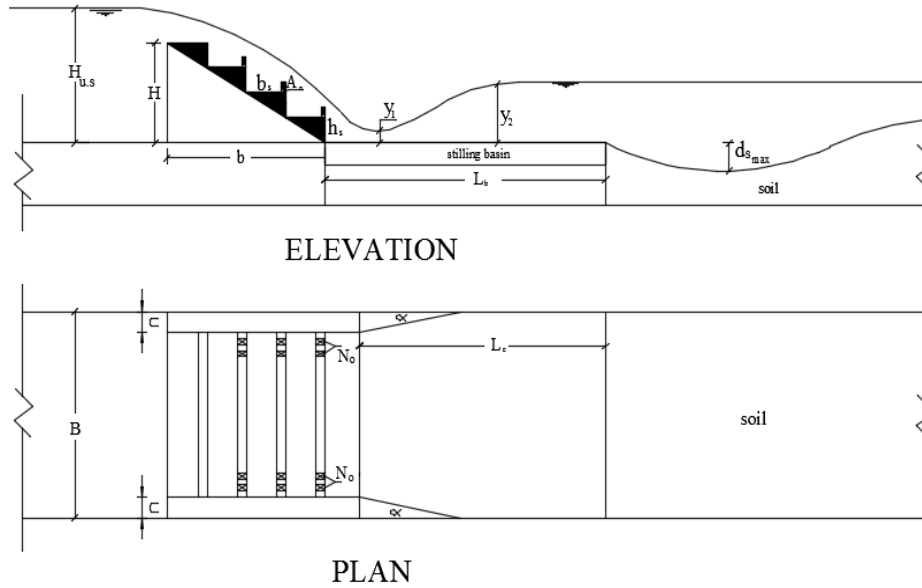
Fig. 3. Definition sketch for the experimental models

4. ANALYSIS AND DISCUSSION

The used number of stepped spillways was 4 Sep, contraction ratio was 60% from flume width and the opening area in breaker 10% from the breaker area on all sides putting in down of breakers.

4.1 Effect of Shape Openings in Breakers on the Scour

The effect of shape openings in breakers on local scour depth was investigated experimentally. The shape openings in breakers are rectangle,

triangle and trapezoidal with constant area opening $(A_0/A) = 0.1$. The relationship between the maximum relative scour depth $(d_{s\ max}/y_c)$ and upstream Froude number (F_0) is shown in Fig. 4, for different shape openings in breakers. This figure shows that, the maximum relative scour depth increases as Froude number increases. In Fig. 5 shown scour hole in the contour maps for different shapes of openings. The reduction ratio of sour by using different shape openings in breakers rectangle, triangle and trapezoidal by 47.77%, 24.05% and 9.62%, so the best shape of opening is rectangle.
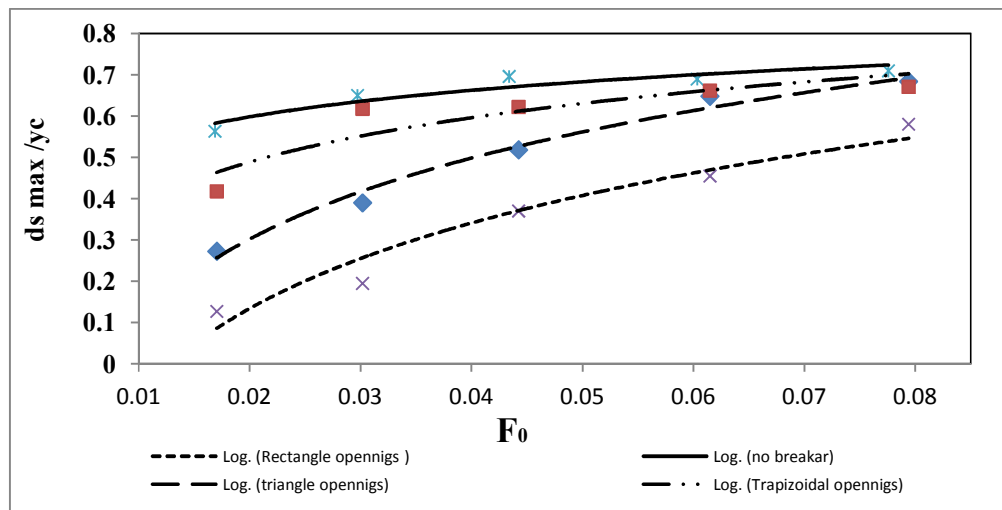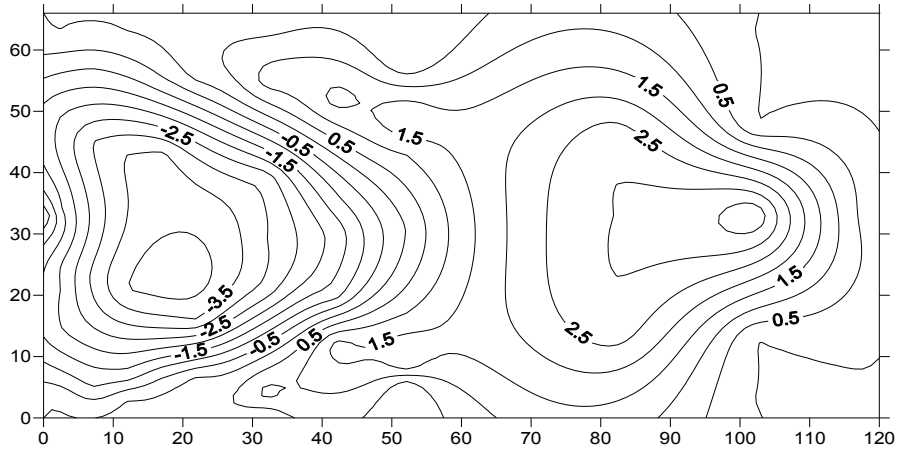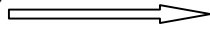

Fig. 4. The relationship between $d_{s\ max}/y_c$ and F_0 at different shape openings in breakers
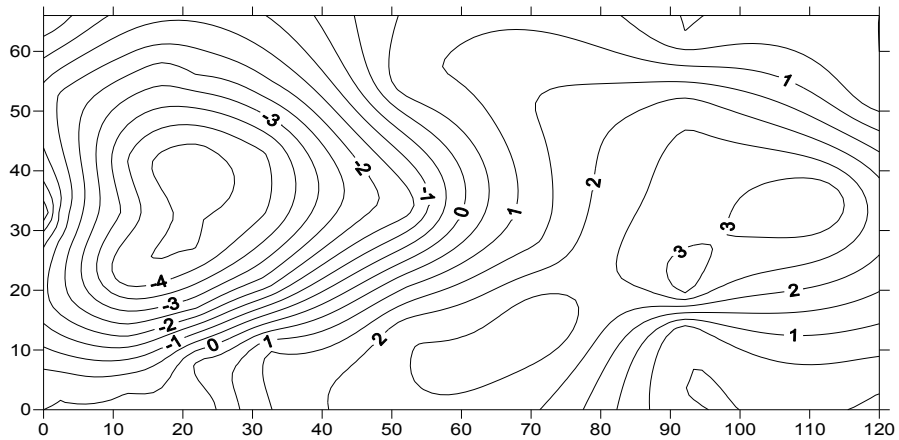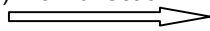
4

(i) Flow direction

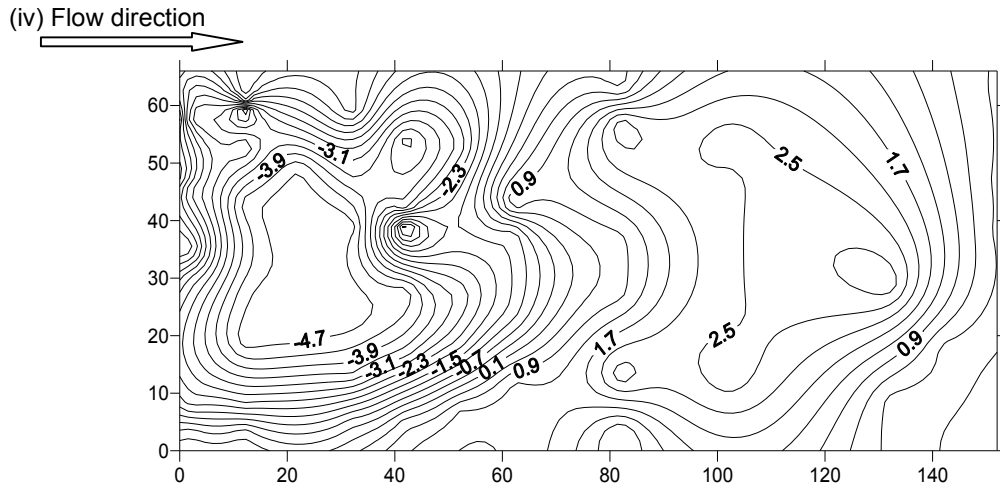(ii) Flow direction

(iii) Flow direction

(iv) Flow direction

Fig. 5. Scour contour maps for different shape openings in breaker, (i) = no breaker, (ii) = rectangle, (iii) = triangle and (iv) trapezoidal at Q = 35L/s

4.2 Effect of Number of Openings in Breakers on the Scour

The effect of Number of opening in breakers that rectangle shape on local scour depth was investigated experimentally. The Number of opening in breaker (N) = 2, 4, 6 and 8. The relationship between the maximum relative scour depth ($d_{s\ max}/y_c$) and upstream Froude number (F_0) is shown in Fig. 6, for different Number of opening in breaker. This figure shows that, the maximum relative scour depth increases as Froude number increases. The best number of openings is 2 because the more of openings as orifice increase water depth above it so velocity increase ($v=\sqrt{2g\ H}$). The scour hole is shown in Fig. 7 and the reduction ration of sour by using different Number of opening in breaker 2, 4, 6 and 8 by 47.77%, 54.51%, 34.76% and 15.53% , so the best number of openings in breakers 2 openings all sides equal to 4 openings in all breaker.
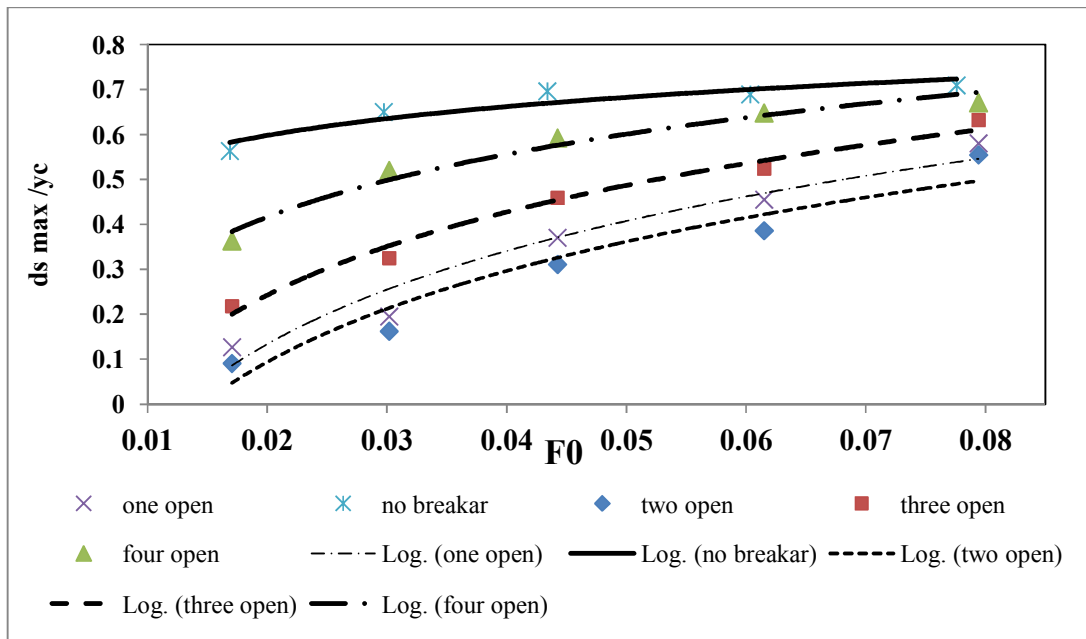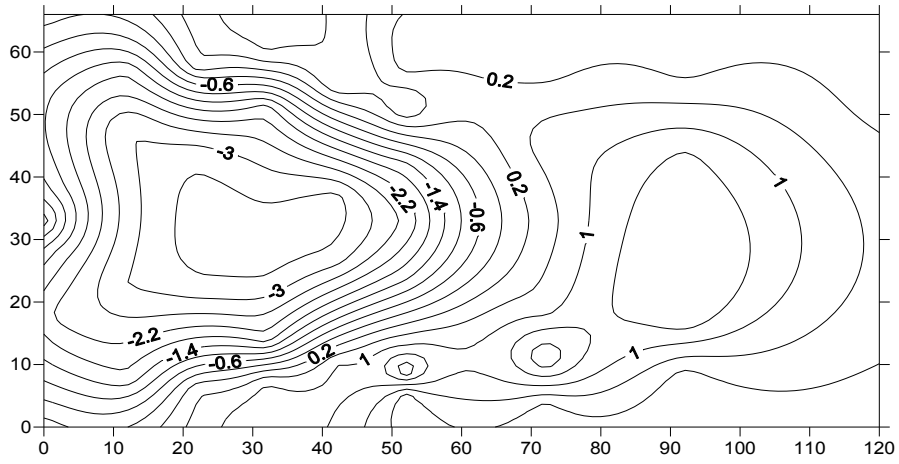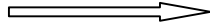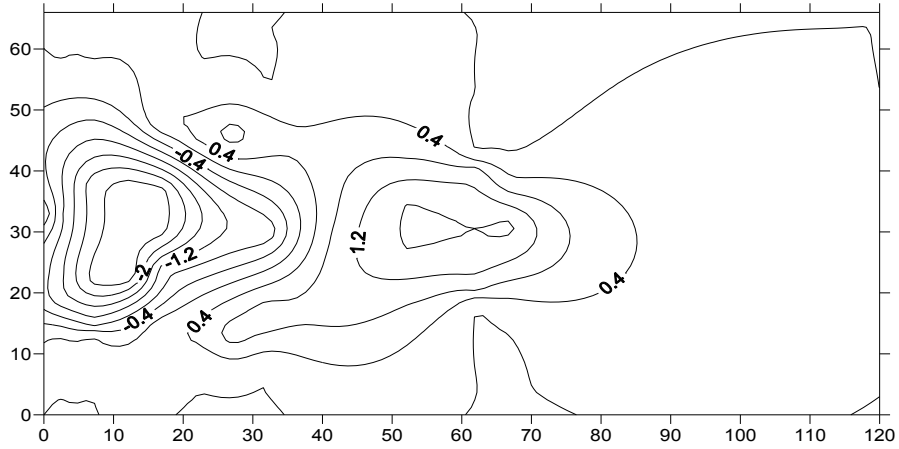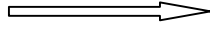

Fig. 6. The relationship between $d_{s\ max}/y_c$ and F_0 at different number of opening in breakers
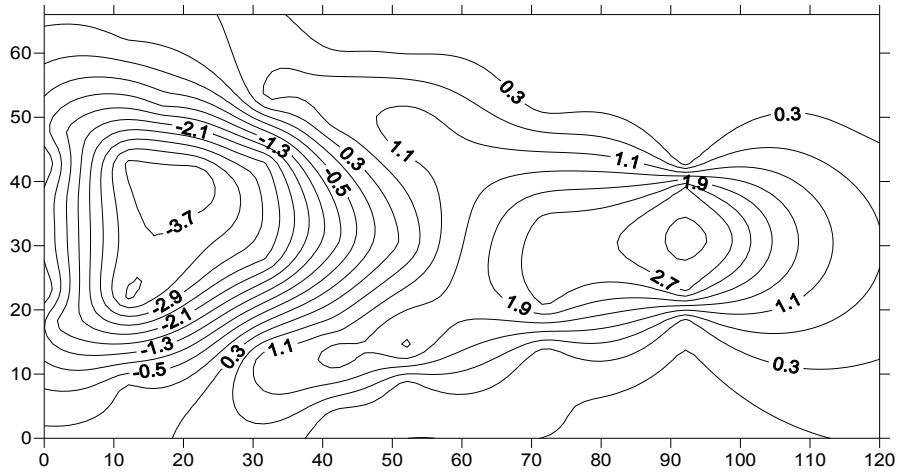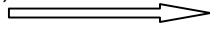
(i) Flow direction

(ii) Flow direction

(iii) Flow direction
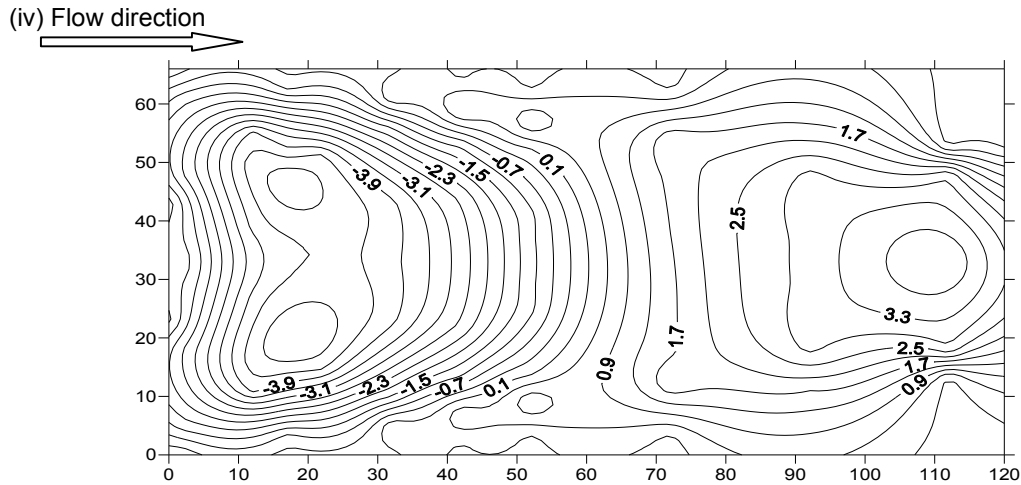
(iv) Flow direction

Fig. 7. Scour contour maps for different number of opening in breakers (i) =2, (ii) = 4, (iii) = 6 and (iv) = 8 at Q = 30L/s

4.3 Effect of Downstream Divergent Angle on the Scour

The effect of downstream divergent angle on local scour depth was investigated experimentally. The downstream divergent angle (α) = 90, 45, 30, 15 and 10. The relationship between the maximum relative scour depth ($d_{s\ max}/y_c$) and upstream Froude number (F_0) is shown in Fig. 8, for the different downstream divergent angle. The decreasing downstream divergent angle decreasing scour because of the width increase gradually. This figure shows that, the maximum relative scour depth increases as Froude number increases. The reduction ration of sour by using different downstream divergent angle (α) = 90°, 45°, 30°, 15° and 10° by 54.51%, 57.07%, 60.27%, 62.91% and 65.38%. The scour hole shown in Fig. 9 by contour maps showed the best angle which was 10° because the area increase gradually so the scour hole was lower values compared with different angles.
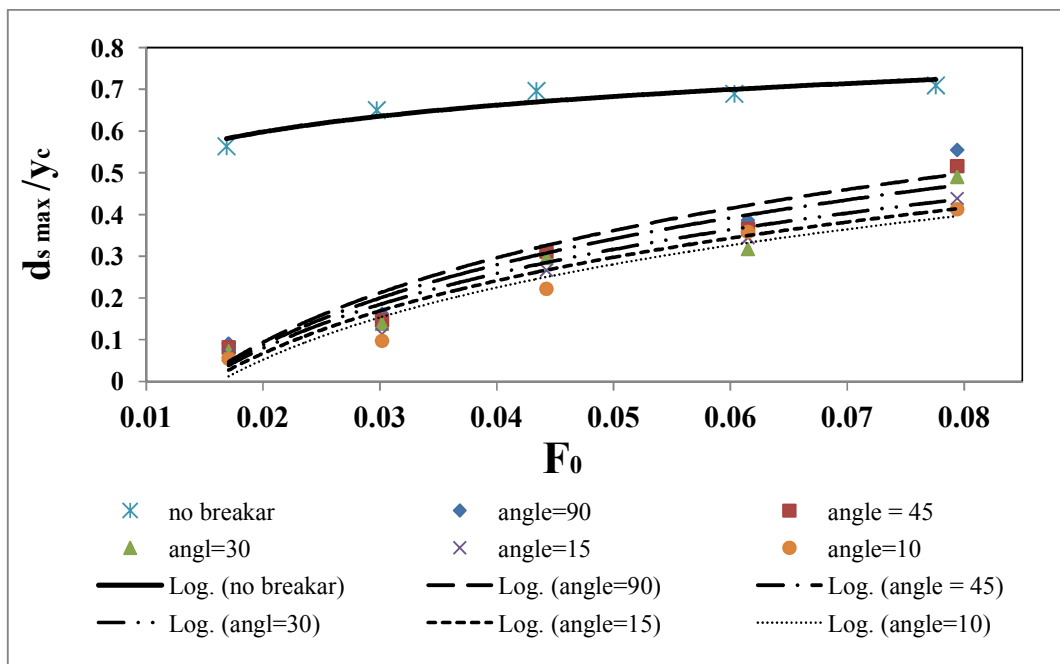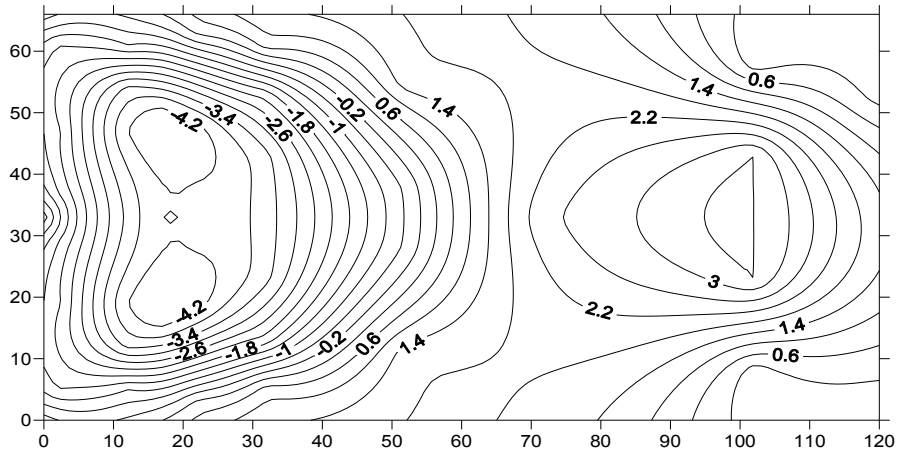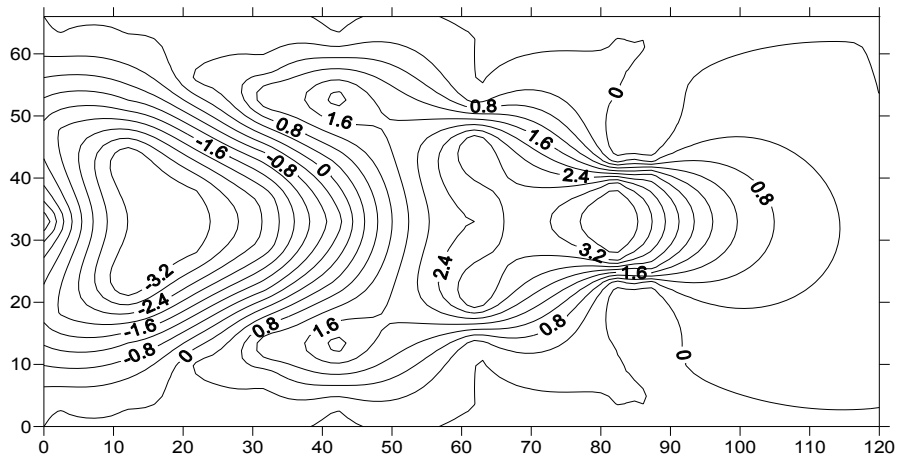

Fig. 8. The relationship between $d_{s\ max}/y_c$ and F_0 at different downstream divergent angle
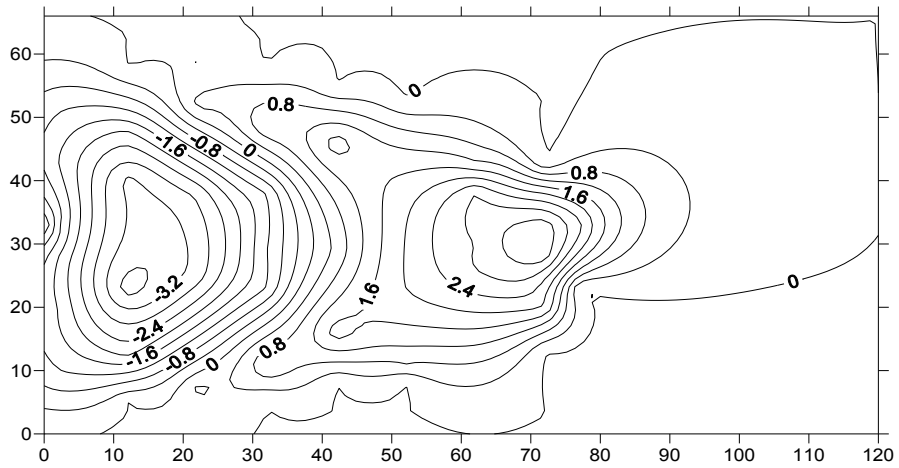
(i) Flow direction

(ii) Flow direction

(iii) Flow direction
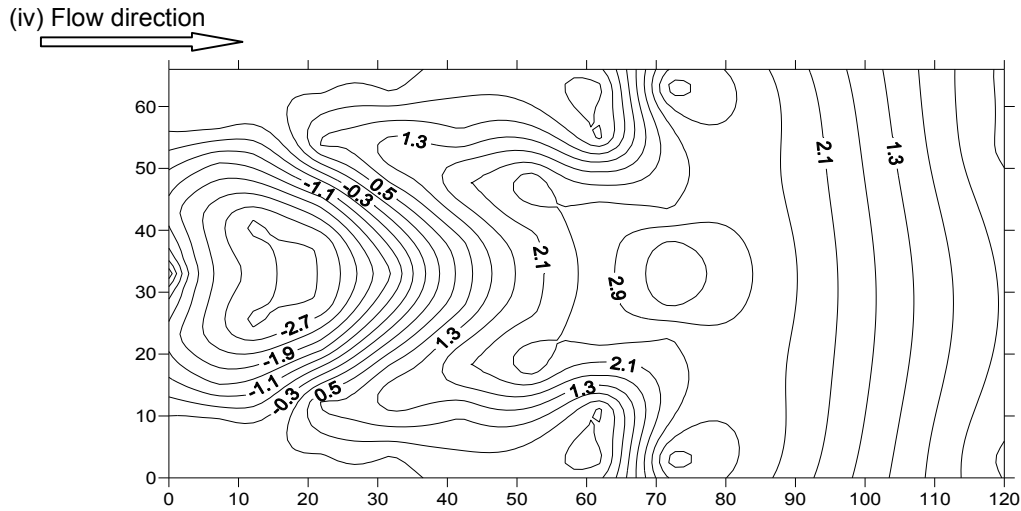
(iv) Flow direction

Fig. 9. Scour contour maps for different downstream divergent angle, (i) = 45°, (ii) = 30°, (iii) = 15° and (iv) =10° at Q = 35L/s

5. STATISTICAL ANALYSIS

The regression analysis was applied for all simulated cases to have a prediction model correlating the relative max. Scour depth with other independent parameters. Many of trials were carried out to have a general equation representing the whole independent parameters. The correlation coefficient for this equation was very small and cannot express the relative scour depth. So, predicted equations for different simulated models were created as follow:

$$d_{s\ max}/y_c = 0.047 + 0.152\ F_0 - 0.01N - 0.0001\ \alpha \quad (2)$$

The correlation coefficients and stander errors of Eq. (2) was (93%, 0.006). Fig. 10 Present the predicted values of relative scour depth versus measured data sets. It was found that the predicted equations express well the measured data.
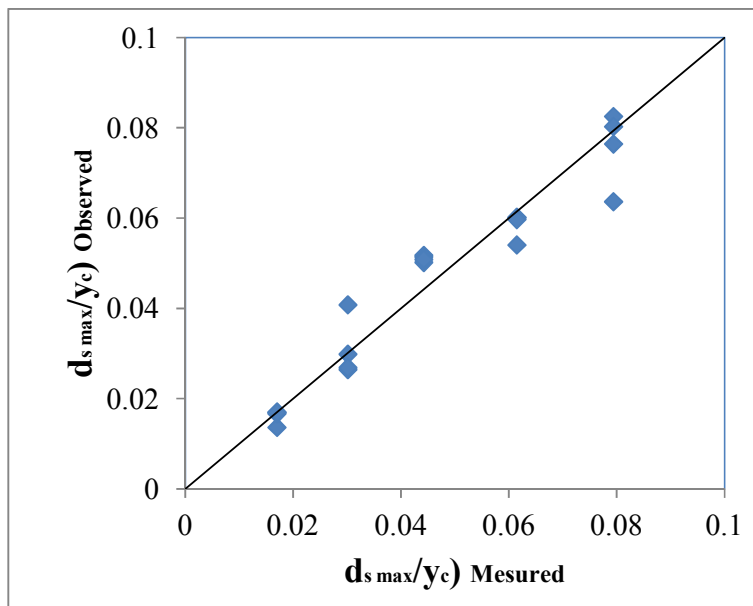

Fig. 10. Predicted values of Eq. (2) versus measured data for relative scour depth

6. CONCLUSIONS

The experimental study of stepped spillway at contractions case led to the following conclusions:

1- The maximum relative scour depth increases with increasing the upstream Froude number.
2- Increasing contraction ration ratio due to increase scour depth.
3- The scour reduced 47.77%, 24.05% and 9.62% for different shape of openings in breaker triangle and trapezoidal.
4- The scour reduced by 47.77%, 54.51%, 34.76% and 15.53% by for different number of openings 2, 4, 6 and 8.
5- The scour reduced by 54.51%, 57.07%, 60.27%, 62.91% and 65.38% for different downstream divergent angle (α) = 90°, 45°, 30°, 15° and 10°.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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