International Journal of Scientific & Engineering Research, Volume 6, Issue 10, October-2015
ISSN 2229-5518

The Effect of Relative Discharge on Local Scour Downstream Combined Structure

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Abstract— ***In this research, a study was conducted experimentally to investigate the scour hole dimensions downstream the combined structures which consist from weir and gate due to the effect of the relative discharge (Q_r) between the flow above the compound weir to the flow under the gate. Twenty models have been designed, and every model is formed from composite weir consists of two geometric shapes with rectangular gate of constant dimensions. In this study, the experiments was conducted in a laboratory channel was constructed from blocks and concrete with length of 18 m, 1 m width and depth of 1 m, where the laboratory models were installed after 7 m from the main gate which is controlling the passage of water from the main reservoir into the flume. At the beginning, the calibration process was conducted to identify the actual discharge values that pass in the flume, then one hundred experiments were conducted in order to derive formulas for investigating the non-dimensional depth (SD/d_{50}) and non-dimensional length (SL/d_{50}) of the scour hole due to the effect of (Q_r). The bed of the flume was spreaded with sand as a layer of 30 cm in thickness for a distance 4 m downstream combined structure. Two samples of sand were used in the experiments with different median size of particles (d_{50}), the first of 0.7 mm and the second of 1 mm. Using the Excel program 2013, Eight polynomial relationships were derived to calculate the dimensionless scour depth (SD/d_{50}) in terms of the relative discharge (Qr), where the resulted coefficients of determinations (R^2) from these relationships were high.***

Index Terms— Local scour, Combined structures, Relative Discharge.

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1 Introduction

Weirs and gates are the common and important structures which are used in controlling and adjusting the flow in irrigation channel. Weirs widely used for flow measurements. One of the weirs demerits is they need to be cleaned of sediment and trash periodically. Sluice gates are used extensively for flow control and water measurement for long time. One disadvantage of the sluice gates is they retained the floating materials.

In order to maximize their advantages, weirs and gates can be combined together in one device, so that water could pass over the weir and below the gate simultaneously.

Fig. 1 shows this structure, this compound device create a new hydraulically condition in compression with weir or gate, each other alone. The combined weir and gate systems can be used in minimizing sedimentations and depositions [1].

The economic aspect is one of the important factors in the creation of such a project and to reduce the cost of any project is the preoccupation with taking into consideration the structure will be run optimally and without causing any damage to the future.

The non-use of concrete floor at downstream of the structure, which are designed to dissipate energy flow passing over the edge of the weir is one of the most important methods that will reduce the cost, and it must use the alternative is less expensive and available and ensures the lack of access scour subsequently leads to the occurrence of damage in the structure and keep it fully within the allowable limits.

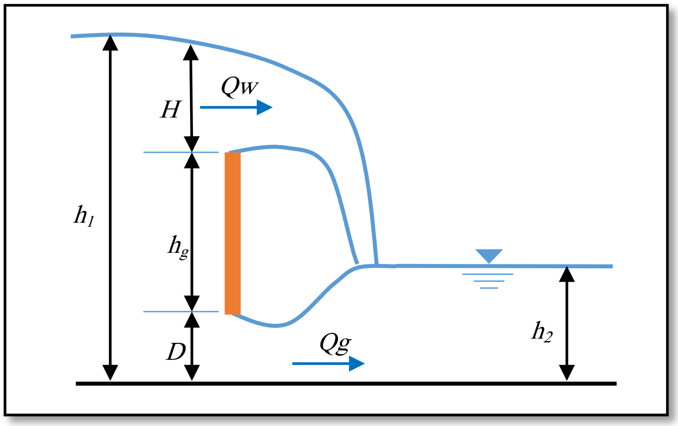


Figure 1 Definition sketch for combined free flow over weirs and under gates

Ahmed [2], investigated the scour characteristics downstream weirs, gates and combined structures consist of weir and gate had been conducted. The study included the measurement of maximum scour depth (D_s) and the length (L_s) of scour hole downstream these structures. Also, the effects of structure height, under sluice opening height, discharge variation and bed material size (D_{50}) on the depth and length of scour hole. Two empirical relationships were obtained to estimate (D_s/D_{50}) and (L_s/D_{50}) in terms of Froude number (Fr_0) , relative water surface fall ($\Delta H_w/P$), relative opening height ($h_0/\Delta H_t$) and relative discharge (q_u/q_d) for compound gates with high correlation coefficients.

Dehghani et al. [3] studied the scour characteristics of scour hole downstream of combined free over weir and below gate experimentally. The conceptual model of flow field downstream of combine flow over the weir and under the gate indicates that there are interactions between the flows over the weir and under the gate and the scour hole cuts and fills alternatively. By increase of Froude number, the maximum depth of scour (hs), length of scour (l_1) and sedimentation length (l_2) increase.

Sobeih et al. [4] investigated the scour depth downstream weir with openings. The study was based on an experimental program included 171 runs. These runs were carried in a rectangular flume with openings fixed in the body of weirs. Three cases of opening arrangements were included, no opening, one opening and three openings. Different diameters of openings 1.27 cm, 1.9 cm and 2.54 cm, different heights at 0, 0.25 and 0.5 of weir height were tested under different flow conditions.

The experiments showed that for most considered values of openings diameter either case of one opening or three openings, the value of h/p = 0.25 gave the smaller values of scour depth, while the value of h/p = 0.5 gave the higher values of scour depth. Also, it was noticed that for most considered values of openings height, the value d/p = 0.149 gave the smaller values of scour depth for case of one opening but for case of three openings, the value d/p = 0.075 gave the smaller values of scour depth.

Finally empirical formula was developed for estimating scour hole depth in terms of downstream flow conditions, Froude number, height of the weir, number of openings, area of openings, diameters and heights of the openings.

2 The Laboratory Models

Twenty models were used in the experimental work to investigate the derive formulas describe the relationships between scour hole dimensions and relative discharge (Q_r). Laboratory experiments have been conducted by a channel which was manufactured by the researcher and was built from blocks and concrete, and consists of the following parts as shown in Fig. 2:

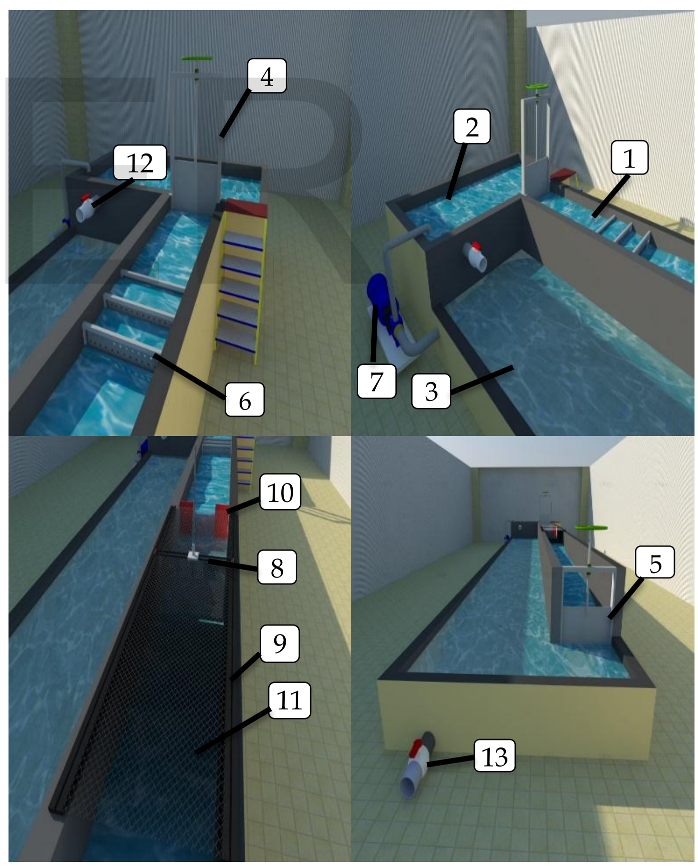


Figure 2 The Flume Parts and Accessories: 1. The flume, 2. Head basin, 3. Lateral basin, 4. Vertical sluice head gate, 5. Vertical sluice tail gate, 6. Stilling screens, 7. Main pump, 8. Gauge point, 9. Rails, 10. Iron frame, 11. BRC mesh, 12. Overflow valve, 13. Exhausting and cleaning valve

A calibration process was conducted to the flume by using a standard weir which is designed according to USBR limitations for standard sharp crested weir with 90° V notch [5]. The laboratory models were divided into four groups with respect to compound weir shape as shown in Fig. 3:

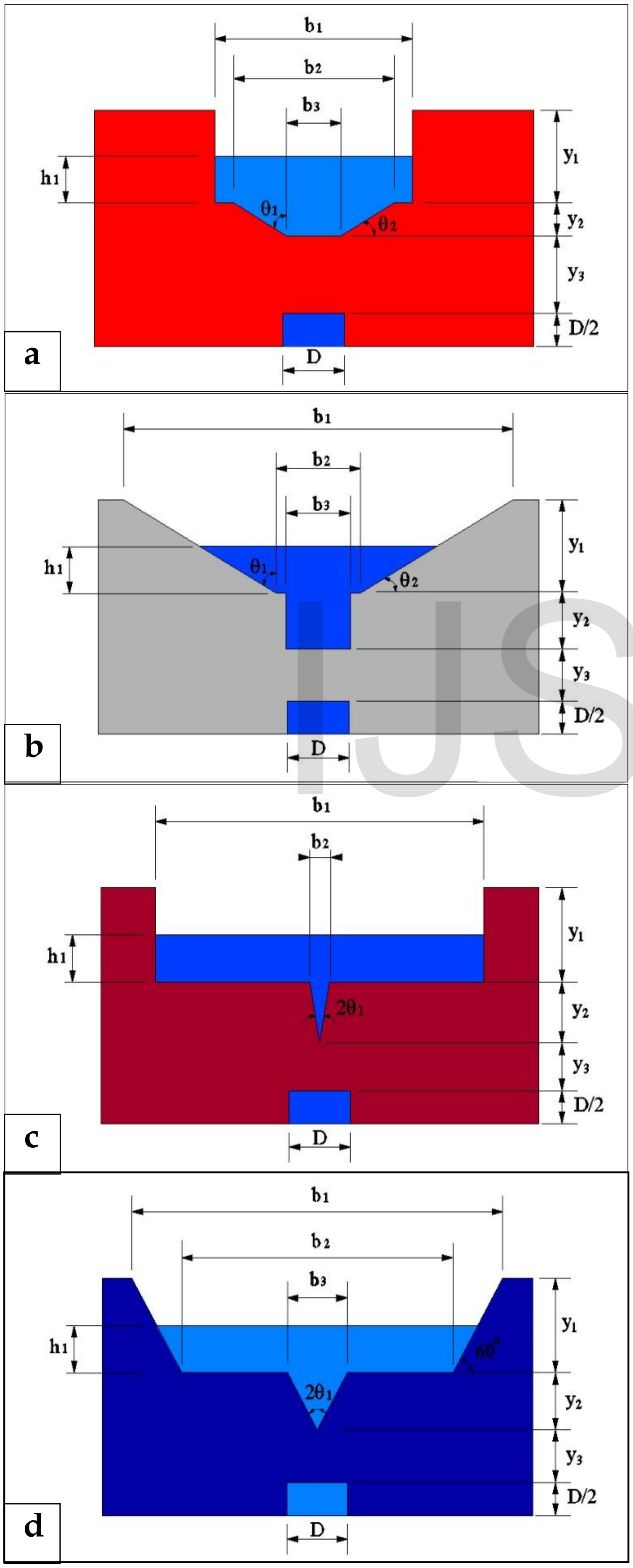


Figure 3 General definition sketch for: a. first five models b. Second five models c. Third five models d. Fourth five models

The geometrical dimensions for all tested models are listed in Table 1. It should be mentioned that the following geometric parameters are constant for all the tested models:

1. The width (B) = 1 m and the overall height (L) = 0.5 m. for all models.
2. The height of upper part of compound weir (y_1) for all models = 0.2 m.
3. The rectangular gate dimensions are same for all models = (0.14 m. width * 0.07 m. height).

Table 1: Geometric Properties for Laboratory Models

Model No.	y_2 (m)	y_3 (m)	b_1 (m)	b_2 (m)	b_3 (m)	D (m)	Θ_1^o	Θ_2^o
1	0.07	0.16	0.45	0.37	0.12	0.14	60	30
2	0.09	0.14	0.4	0.29	0.11	0.14	45	45
3	0.11	0.12	0.37	0.23	0.1	0.14	30	60
4	0.12	0.11	0.35	0.18	0.09	0.14	20	70
5	0.14	0.09	0.34	0.13	0.08	0.14	10	80
6	0.12	0.11	0.88	0.19	0.15	0.14	60	30
7	0.09	0.14	0.76	0.36	0.18	0.14	45	45
8	0.08	0.15	0.61	0.38	0.2	0.14	30	60
9	0.07	0.16	0.58	0.43	0.22	0.14	20	70
10	0.06	0.17	0.53	0.46	0.26	0.14	10	80
11	0.13	0.1	0.75	0.05	-	0.14	10	-
12	0.12	0.11	0.7	0.09	-	0.14	20	-
13	0.11	0.12	0.65	0.13	-	0.14	30	-
14	0.1	0.13	0.6	0.2	-	0.14	45	-
15	0.09	0.14	0.55	0.31	-	0.14	60	-
16	0.15	0.11	0.95	0.72	0.05	0.14	10	-
17	0.14	0.14	0.9	0.67	0.1	0.14	20	-
18	0.12	0.15	0.86	0.63	0.14	0.14	30	-
19	0.11	0.16	0.8	0.57	0.22	0.14	45	-
20	0.09	0.17	0.76	0.53	0.31	0.14	60	-

Each model was examined by five values of actual discharge (Q_{act}) which are 0.037, 0.031, 0.026, 0.011 and 0.006 m^3/s.

3 Sieve Analysis for Bed Materials Samples

In this study, sand was used as a material for the bed of flume and the samples which were selected included all the grades of sand from coarse to fine and as classified by the USCS classification [6].

To investigate the effect of sediment size as an effective parameter on the scouring process, two samples were selected to conduct the laboratory experiments with two mean diameter, the first of 1 mm and the second of 0.7 mm.Sieve analysis and preparation of the quantities required was conducted by NSGF Company for production of sand and gravel filters. The results of sieve analysis for both samples mentioned above are as shown in Fig. 4 and Fig. 5.

The geometric standard deviation σ_g of the sand size equal to 2.27 for the first sample and 2.62 for the second sample, which is implies that the sand is of well-graded soil. The σ_g is defined as: [7]

$$\sigma_g = \sqrt{\frac{d_{84.1}}{d_{15.9}}} \qquad (1)$$

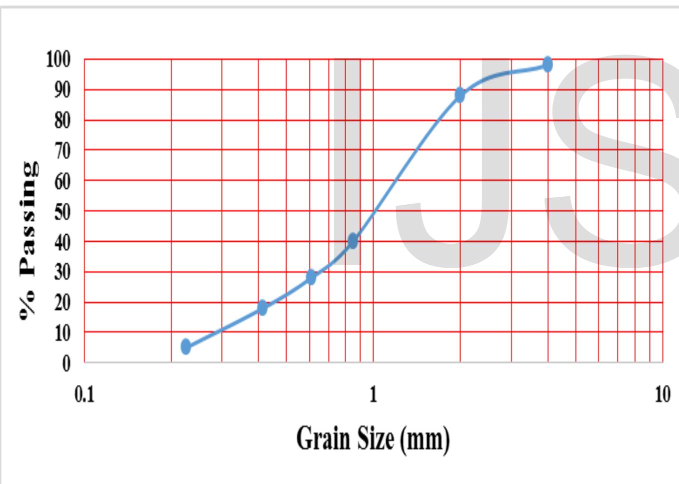


Figure 4 Sieve analysis of bed material for the first sample (d_{50} = 1 mm)

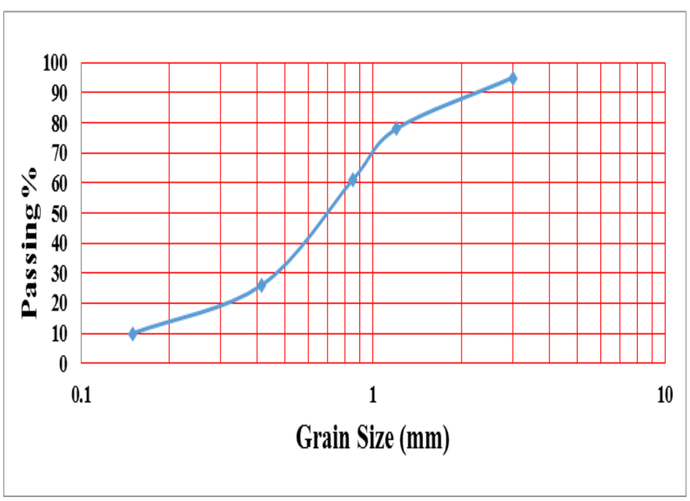


Figure 5 Sieve analysis of bed material for the second sample (d_{50} = 0.7 mm)

4 Results Discussions and Analysis

4.1 Effect of Qr on SD/d_{50}

For the first five models, the results show that the values of SD/d_{50} increase when the value of Q_r. The maximum value recorded at model no. 1 with value of 361.4 when Q_r equal to 1.41 with d_{50} equal to 0.7 mm. While the minimum value recorded at model no. 5 and was 78 when Q_r equal to 0.1 with d_{50} equal to 1 mm (Fig. 6).

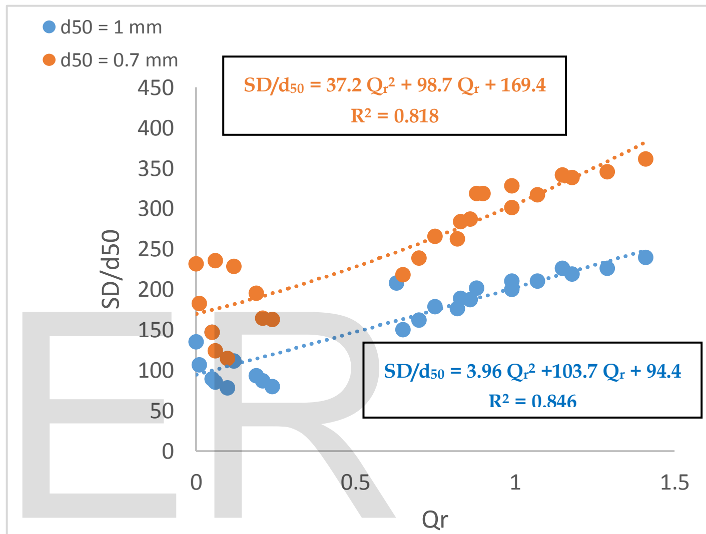


Figure 6 Relationship between SD/d_{50} and Q_r for the first five models

Fig. 7 shows that the maximum value of SD/d_{50} recorded was 390 when Q_r equal to 1.8 with d_{50} equal to 0.7 mm in model no. 10, while the minimum value of SD/d_{50} recorded was114 for Q_r value of 0.24 in model no. 6 with d_{50} equal to 1 mm.

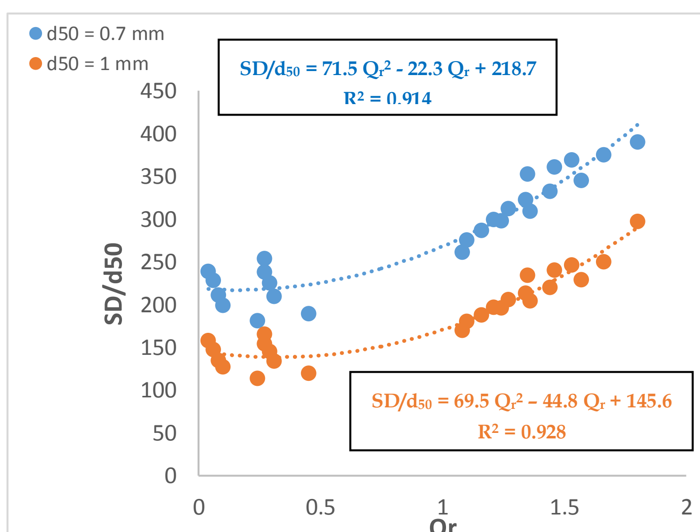


Figure 7 Relationship between SD/d_{50} and Q_r for the second five models

In the third five models, Fig. 8 shows that the maximum value of SD/d_{50} recorded was 348.6 when Q_r equal to 1.99 with d_{50} equal to 0.7 mm in model no. 15, while the minimum value of SD/d_{50} recorded was110 for Q_r value of 0.012 in model no. 11 with d_{50} equal to 1 mm.

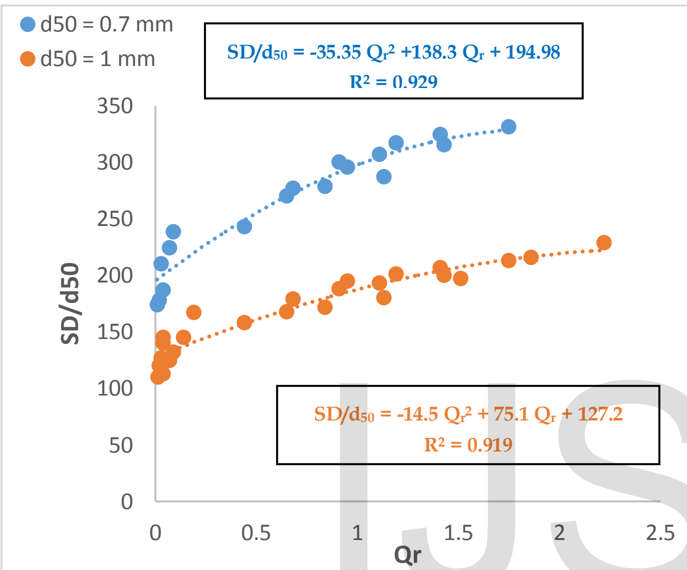


Figure 8 Relationship between SD/d_{50} and Q_r for the third five models

In the fourth five models, Fig. 9 shows that the maximum value of SD/d_{50} recorded was 347.1 when Q_r equal to 1.46 with d_{50} equal to 0.7 mm in model no. 20, while the minimum value of SD/d_{50} recorded was 96 for Q_r value of 0.011 in model no. 16 with d_{50} equal to 1 mm.

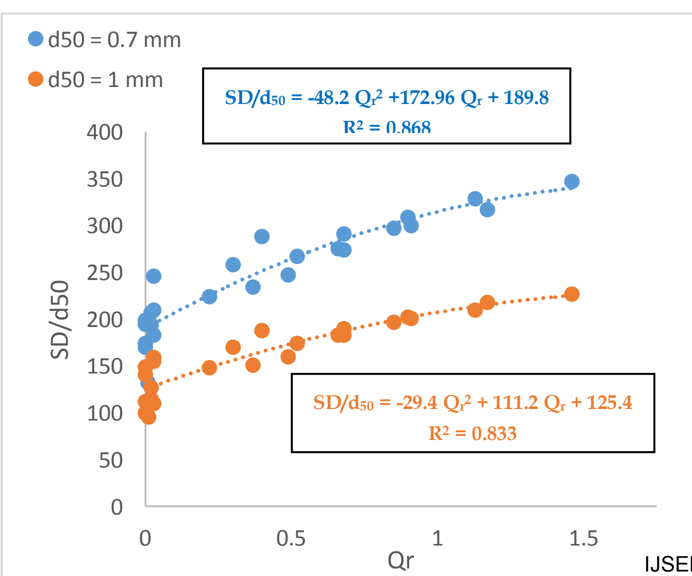


Figure 9 Relationship between SD/d_{50} and Q_r for the fourth five models

4.2 Effect of Qr on SL/d_{50}

For the first five models, the results show that the values of SL/d_{50} increase when the value of Q_r. The maximum value recorded at model no. 1 with value of 2571.4 when Q_r equal to 1.41 with d_{50} equal to 0.7 mm. While the minimum value recorded at model no. 5 and was 800 when Q_r equal to 0.1 with d_{50} equal to 1 mm (Fig. 10).

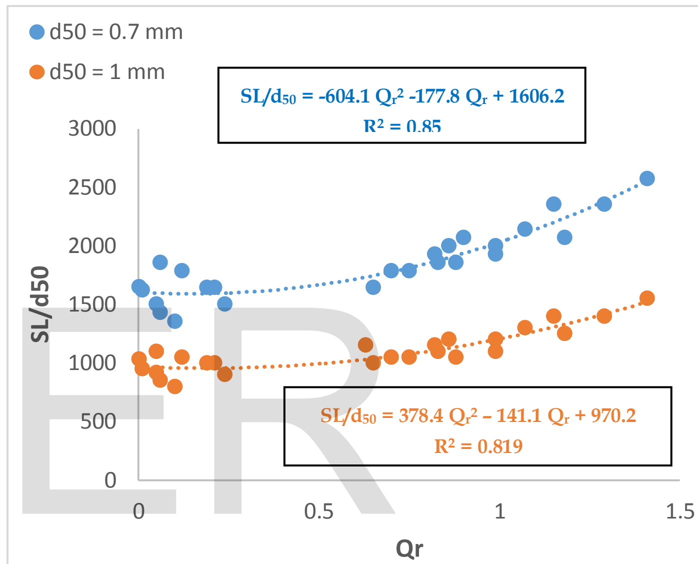


Figure 10 Relationship between SL/d_{50} and Q_r for the first five models

Fig. 11 shows that the maximum value of SL/d_{50} recorded was 2714.3 when Q_r equal to 1.8 with d_{50} equal to 0.7 mm in model no. 10, while the minimum value of SL/d_{50} recorded was 900 for Q_r value of 0.24 in model no. 6 with d_{50} equal to 1 mm.

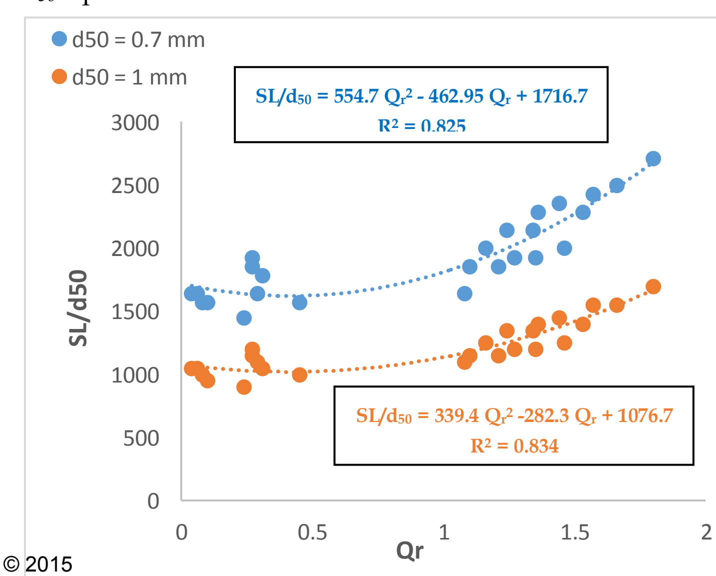


Figure 11 Relationship between SL/d_{50} and Q_r for the second five models

In the third five models, Fig. 12 shows that the maximum value of SL/d_{50} recorded was 2428.6 when Q_r equal to 1.99 with d_{50} equal to 0.7 mm in model no. 15, while the minimum value of SL/d_{50} recorded was 850 for Q_r value of 0.012 in model no. 11 with d_{50} equal to 1 mm.

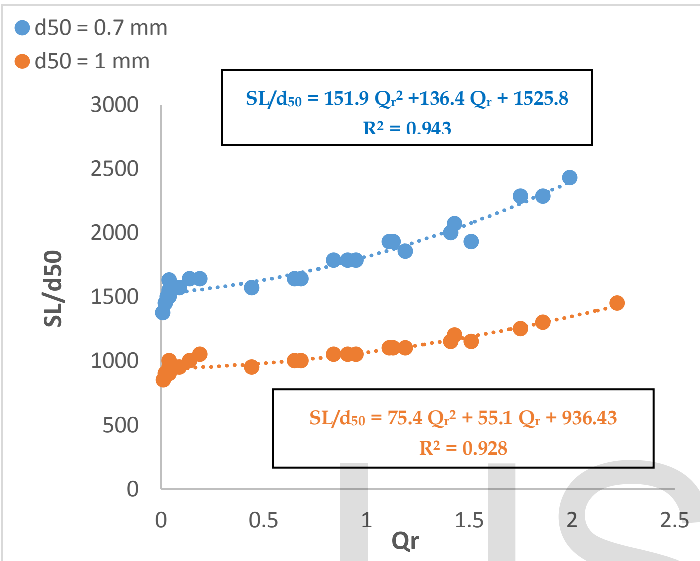


Figure 12 Relationship between SL/d_{50} and Q_r for the third five models

In the fourth five models, Fig. 13 shows that the maximum value of SL/d_{50} recorded was 2357.1 when Q_r equal to 1.46 with d_{50} equal to 0.7 mm in model no. 20, while the minimum value of SL/d_{50} recorded was 800 for Q_r value of 0.011 in model no. 16 with d_{50} equal to 1 mm.

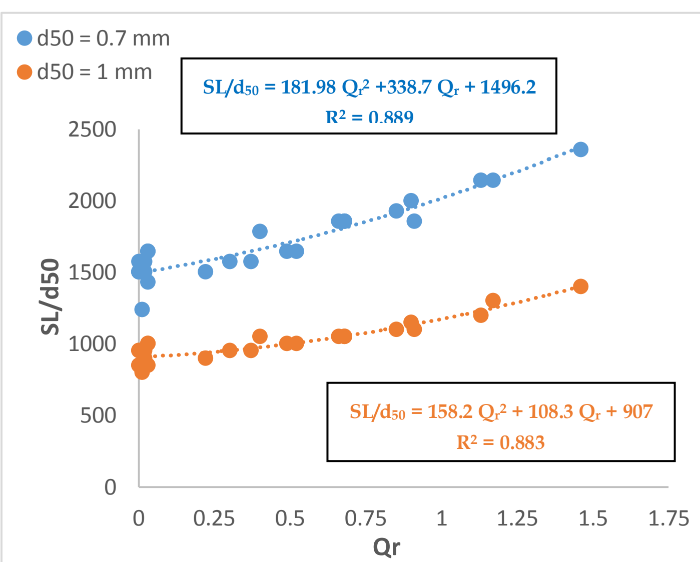
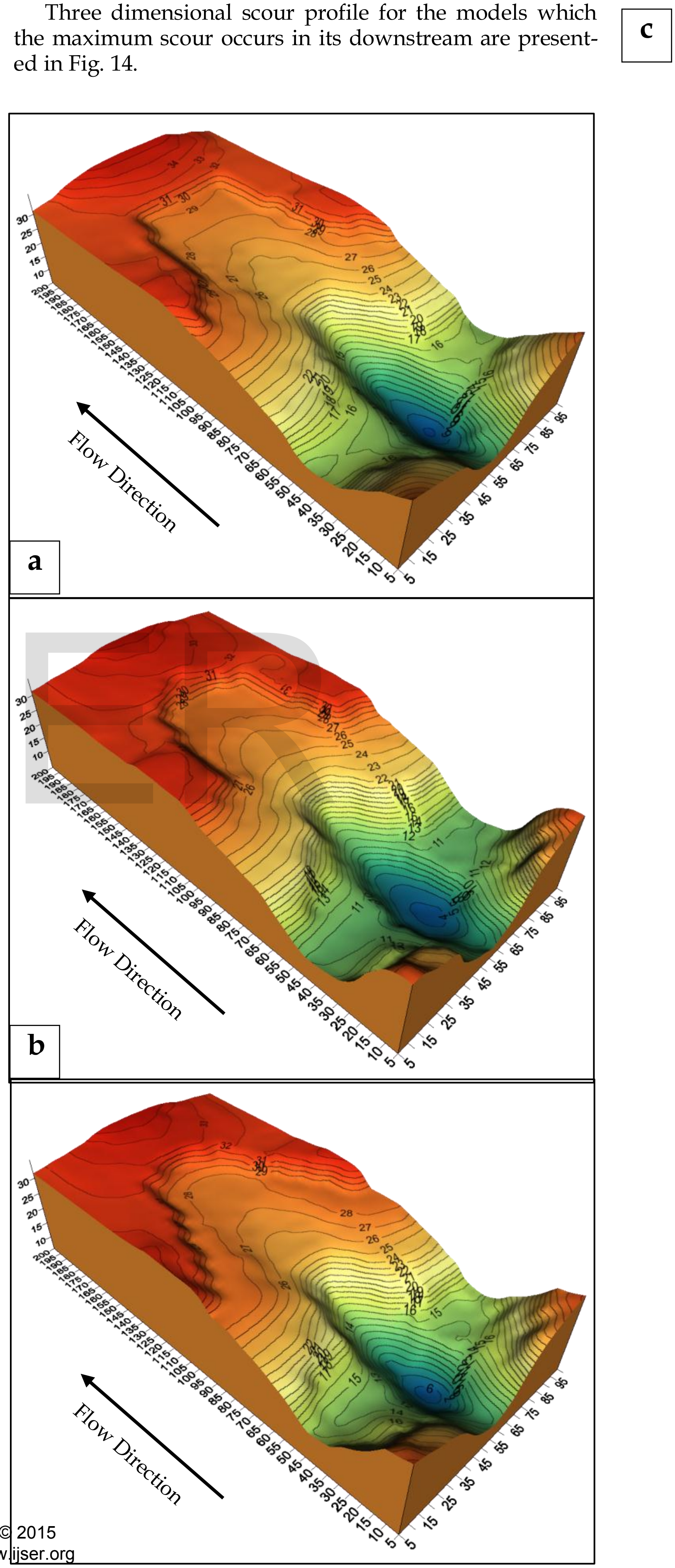
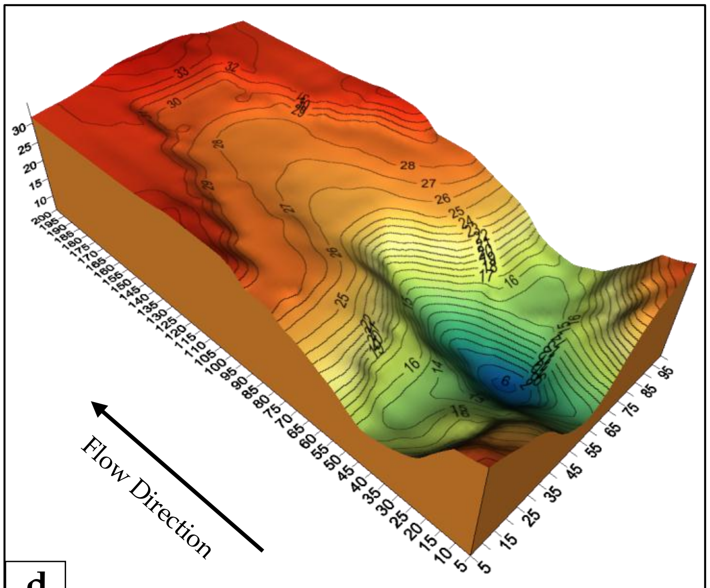


Figure 13 Relationship between SL/d_{50} and Q_r for the fourth five models

Three dimensional scour profile for the models which the maximum scour occurs in its downstream are presented in Fig. 14.





d

Figure 14 3D- Scour Profile in a) Model 1 b) Model 10 c) Model 15 d) Model 20 ,for Q= 0.037 m^3/s and d_{50} = 0.7 mm (Surfer ver. 11) (All dimensions in cm.)

5 Conclusions

In this study, the following conclusions are concluded from SD/d_{50} and SL/d_{50} vs. Q_r for various values of actual discharges Q_{act} and d_{50}:

1. The results show that the maximum values of SD/d_{50} for the twenty models was recorded generally in the second five models and especially in model no. 10 which its compound weir consist of trapezoidal upper part and rectangular lower part. The maximum scour depth was recorded as 27.3 cm in sandy bed with d_{50} of 0.7 mm and 30 cm thickness. Also the maximum scour depth was recorded against actual discharge of 0.037 m^3/s and relative discharge Q_r equal to 1.8. While the minimum value of SD/d_{50} was recorded in model no. 16 which its compound weir consists of trapezoidal upper part and triangular lower part. The minimum value was 18.8 cm in sandy bed with d_{50} of 1 mm and 30 cm thickness with the same value of actual discharge and Q_r equal to 0.4.
2. The results show that the maximum values of SL/d_{50} for the twenty models was recorded generally in the second five models and especially in model no. 10 also. The maximum scour length was recorded as 1.9 m in sandy bed with d_{50} of 0.7 mm. Also the maximum scour length was recorded against actual discharge of 0.037 m^3/s and relative discharge Q_r equal to 1.8. While the minimum value of SL/d_{50} was recorded in models no. 5, 11 and 16 (Fig. 3: a, c and d). The minimum value was 1.05 m in sandy bed with d_{50} of 1 mm with the same value of actual discharge and Q_r equal to 0.88, 0.95 and 0.4 respectively.
3. Both values of SD and SL increase with increasing in the values of actual discharge passing through the flume and relative discharge between compound weir to the flow under the gate.
4. The most control hydraulic factor in the value depth and length of the scour hole is Froude number in terms of the mean size of bed material (d50) where always the relationship is positive, that is, when the value of Froude number increased each of SD and SL also increased for all models in all groups.
5. The size of the depositions changes with the depth and length of the scour hole where whenever the hole depth increased as a result from the free fall of water from the edge of the compound weir, the deposition of sediments was more, while the flow through the gate is helping to pay these sediments away and make the form seem more flat.
6. Whenever the weir width increased, the scour hole generated becomes more flat even with the increase in the value of discharge passing through it and this is evident by the results of the third and fourth five models.

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