

***Water Resources and Surveying Engineering***

**Impact of the Weir Slit Location, the Flow Intensity and the Bed Sand on the Scouring Area and Depth at the Dam Upstream**

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**ABSTRACT**

A total of 48 experiments were conducted to investigate the impact of slit weir dimensions and locations on the maximum scour depth and scour area created upstream. The slit weir model was a 110 mm slit opening, and it was installed at the end of the working section in a laboratory flume. The flume was 10.0 m long, 30 cm wide, 30 cm deep, and almost middle. It includes a 2 m working section with a mobile bed with 110 mm in thickness. In the mobile bed, two types of nonuniform sand (with a geometric standard deviation of 1.58 and 1.6) were tested separately. The weir dimensions and location were changed with flow rates. Then dimensions of the slit weir were changed from 60 x 110 mm to 60 x 70 mm (width x height), while the location of the slit weir was changed from the center of the flume to its side. Finally, the flow rates were changed from 2.6 to 8 l/s. The maximum value of scour depth and scour area was recorded 72 mm and 32357 mm<sup>2</sup> when the slit height, the flow rate, D<sub>50</sub> of the movable bed were 110 mm, 8 l/s, 0.3 mm, respectively.

**Keywords:** Slit weir, sediment type, upstream scour, weir location, weir dimension, flow intensity.

**تأثير موقع فتحة الهدار , شدة الجريان و رمل القاع على مساحة وعمق حفرة الانجراف في مقدمة السد**

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**الخلاصة**

تم إجراء 48 تجربة للتحقيق في تأثير أبعاد ومواقع الهدار ذي الشق الضيق على أقصى عمق ومساحة انجراف متكونة في مقدمة السد. كان نموذج الهدار ذا فتحة 110 مم تم تثبيته في نهاية مقطع العمل داخل مجرى القناة المختبرية. طول القناة كان 10.0 مترًا وعرضها 30 سم وعمقها 30 سم وفي منتصفها تقريبًا يوجد مقطع عمل بطول 2 متر مع قاع متغير بسمك 110 مم. تم اختبار نوعين من الرمل غير المنتظم في القاع المتحرك (بانحراف معياري هندسي 1.58 و 1.6) بشكل منفصل. تم تغيير

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أبعاد الهدار وموقعه مع معدلات التصريف. ومن ثم تغيير أبعاد فتحة الهدار من  $60 \times 110$  مم إلى  $60 \times 70$  مم (العرض  $\times$  الارتفاع) بينما تم تغيير موقع فتحة الهدار من المنتصف إلى الجانب. أخيرًا، تم تغيير معدلات التصريف من 2.6 إلى 8 لتر / ثانية. سجلت أقصى قيمتين لعمق ومساحة انجراف وكانتا 72 مم و 32357 مم 2 عندما كان ارتفاع الشق، ومعدل التدفق  $D_{50}$  للقاع المتغير مساويًا لـ 110 مم، 8 لتر / ثانية، 0.3 مم.

**الكلمات الرئيسية:** الهدار الضيق، نوع الرواسب، الانجراف في المقدمة، موقع الهدار، أبعاد الهدار، شدة الجريان.

## 1. INTRODUCTION

All rivers carry sediment that originates from erosion processes and causes river slope collapse upstream or sediment accumulation in the basins (**AL-Thamiry and AbdulAzeez 2017**). Many rivers carry sediment to reservoirs. Reservoirs trap sediments because of the backwater and reduced velocities in the reservoir. The sedimentation of the reservoir will cause operational problems and a reduction in reservoir capacity. For hydropower dam, the sedimentation around hydropower intake reduces the production of electricity from the dam hydropower system. Other negative effects of sediment transport in water are migration of pollutants, increased flood risk, geomorphic evolution in the river system, and increased debris flow (**Ota et al., 2017**).

Generally, the frequent removal of sedimentation by dredging from reservoirs and locations near the hydropower intakes after floods is costly. Also, it usually interrupts hydropower production, so alternative methods in which the above disadvantages can be avoided are intended. Many researchers worldwide are working to find effective and economical methods for controlling sedimentation near hydropower intake. The discharge of the sediment accumulation during the flood by the following water from a dam gate/slit weir is economical. However, the amount of water used to carry the sediment accumulation away from the hydropower intake should be minimum. This solution will reduce the cost and maximize the usage of reservoir water storage (**Ota et al., 2017**).

(**Baued and Hagger, 2000**) conduct a series of experiments on a hydraulic channel to study the effect of weir placed at the end of the flume. They notice Tornado vortices that were in charge of large-scale scour and sediment transport in basins. (**Nagata et al., 2005**) developed a numerical model to predicting flow and bed scour nearby river hydraulic structures. They found that the model represents the effect of non-equilibrium transport of sediment into the bed-deformation model by conjugating stochastic for entrainment of sediment and deposition with the momentum equation of sediment particles. The non-equilibrium of sediment transport phenomena was predominant around the body of the hydraulic structure. (**Lauchlan, 2004**) carried out an experimental investigation to simulate the movement of suspended-load and bed-load over ramp slopes such as weirs and dikes. He observed a strong down vortex that was formed at a vertical weir and created a scour hole. (**Powell, D. and Khan, 2011**) studied the sedimentation movement due to an orifice upstream, all experiments were carried out in a rectangular-shaped box with a dimension of 3.35 m long, 2.13 m wide, and 1.22 m deep. He used Plexiglas for the tank side and front to observe the flow during the experiments. He noticed a pair of different phases of sediment transport. The movement of sediments resulted from exceeding the bed shear during the first phase and the movement of sediment toward the orifice during the second phase. The mechanisms of the two phases of the sediment transport were noticed for all tests with different heads over the orifice and sediment sizes. The relation between scoured volume, sediment size and scour depth with head diverted on the orifice was proposed.



(Ota and Sato, 2015) proposed an empirical and numerical relationship between flow components and flow process near the slit weir. The experimental side of the work was conducted on a laboratory flume under clear water conditions. The bed deformation caused by local scour was measured. The minimum flow rate passed through the weir was 2.9 l/s which was about 70 % of the maximum flow rate. The maximum flow rate was 4.1 l/s, the value of flow depth was 62.8 mm, approach velocity was 0.13 m/s, Froude and Reynolds numbers were 0.17 and 8200, respectively. (Ota and Sato, 2015) noticed that scour didn't reach equilibrium state during the experiments equal to 16 hours, so the study was focused on non-equilibrium scour. (Ota et al., 2016) conducted a series of experiments, and the collected data was used to validate a proposed numerical model. They applied the proposed numerical model for two kinds of laboratory tests: (1) local scour upstream of slit weir, (2) sediments release from a dam gate representing open channel flow, and closed conduit occurs together. (Ota et al., 2016)

were carried out 45 runs on scour inception using rectangular hydraulic flume. (Hajikandi et al., 2017) were carried out 16 experimental tests on a rectangular tank located above a reservoir. The apparatus used was 0.145 m long, 0.1 m wide, and 1.05 m deep; many circular and rectangular orifices with an area of 38.45 cm<sup>2</sup> were used. Scour pattern upstream was occurred with two initiated conditions. The area formed upstream of the rectangular orifice was found with a value 1.43 larger than the circular orifice value. All runs were carried out using fixed and movable beds. At the fixed bed, the site of influence upstream of both orifice shapes was nearly elliptical. (Keshavarzi et al., 2020) conducted experiments under clear water scour conditions with three types of sediments sizes, and all experiments were carried out under three different pressure heads upstream of the orifice. They measured temporal variation of maximum scour volume, scour depth, and length of scour hole. In the scour hole, three flows were observed, and these were semi-spiral, inward, and outward flow. Also, they concluded that the scour hole was affected by sediments size and the flow head zones. They proposed the following relationship between the flow from a circular orifice, time, and velocity of approach.

$$Ds/d_0 = 0.17 (t U_0 / D_0)(0.18)H_0/ D_0(-0.21)d_{50}/d_0(-0.15) \quad (1)$$

## 2. The experimental work

The experimental work includes describing the apparatus used, preparations of materials, procedure, studied variables, and experimental design.

### 2.1 The Flume

Amfield Equipments Ltd., UK, manufactures the flume used in the laboratory experiments. It is located at the Hydraulic laboratory, Department of Water Resources Engineering, College of Engineering, University of Baghdad. A water circulation system was fixed to the flume body. The flume is 10.0 m long, 0.3 m wide, and 0.3 m deep. It was modified to include a 2 m working section in the middle of the flume. The working section was filled with sediments to a depth of 11 cm, and a ramp was provided to make a smooth flow transition from the original flume bed to the mobile bed of the working section. At the end of the working section, a slit weir from Plexiglass was fixed tightly, as shown in **Fig. 1**.



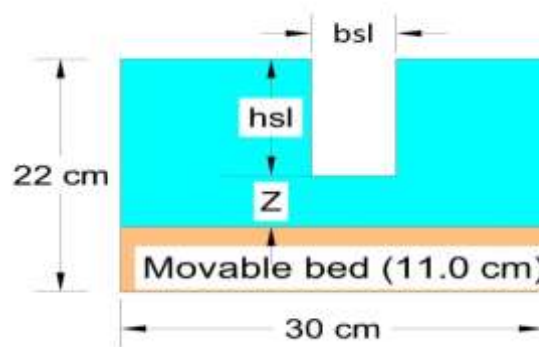
**Figure 1.** The flume and the working section used in the experiments.

A point gauge with an accuracy of  $\pm 1$  mm was used to measure both scour and water depths. In this study, a total of 48 runs were achieved, and after every run, the working section was leveled and prepared for the next run.

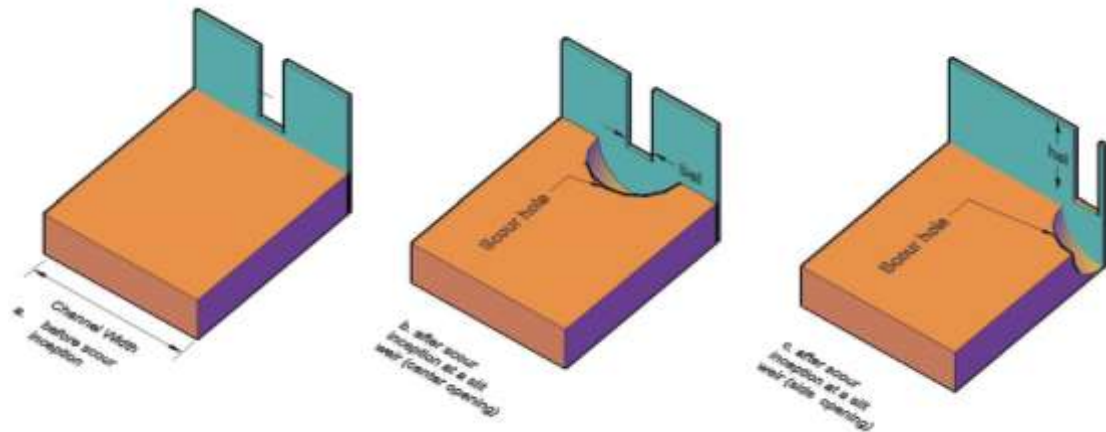
## 2.2 The weirs

Flow measurements are used to control the available water flow needed for different uses since surface water becomes an important source to overcome shortages resulting from changes due to the shortage of climate changes (Abed, 2021).

Weirs models used in this study were made of transparent Plexiglas, and each model was 4 mm thick, 300 mm wide, and 220 mm high (Fig. 2). The maximum dimensions of the slit were 110 mm x 60 mm ( height x width ), and the weirs models were placed vertically and tightly in the flume to prevent water leakage ( Fig. 3).



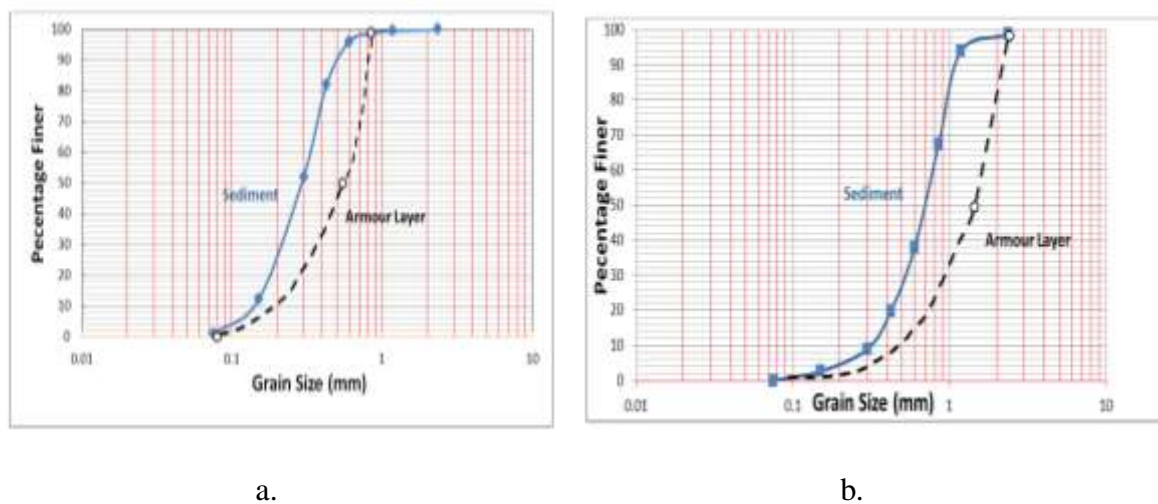
**Figure 2.** Front view of a slit weir center opening.



**Figure 3.** Locations of the weir models in the flume.

### 2.3 Bed Material

In this study, two types of nonuniform sediments were used in the working section with median grain size,  $D_{50} = 0.3$  mm and  $D_{50} = 0.7$  mm with the geometric standard deviation  $\sigma_g = 1.61$  and  $1.58$  respectively. To get the nonuniformity of sediment, different sizes were mixed with weight proportions for the sediment of median size of 0.7 mm and 0.3 mm get nonuniform sediment of median size of 0.7 mm. The sand used in this study was brought from Karbala city, Al Ukhather station, because it is well-graded to ensure nonuniformity in size distribution (Maatooq and Hameed, 2020). A mass of 250 kg of sand was used in the experiments, sieve analysis was made, and a sample of 500 gm from each size was used to plot the gradation curves (**Fig. 4**).



**Figure 4.** Grain size distribution curve for bed material (a.  $D_{50} = 0.3$  mm, b.  $D_{50} = 0.7$  mm).

For nonuniform sediment, the particle size distribution's geometric standard deviation,  $\sigma_g$  should be more than 1.3 (Melville and Coleman, 2000). In this study, an armoring layer formed in the scour hole after running the experiments. Armor layer formation within the scour hole reduces the scour volume formed near the weir site (**Fig. 5**). The ratio  $v/v_a$  is a measure of flow intensity for the scouring that occurred within the nonuniform mobile bed, and it is equivalent to  $v/v_c$  for the



uniform sediment. The velocity  $v_a$  is used to marks the transition from clear water scour to live bed conditions for nonuniform sediments, while  $v_c$  is the threshold scouring velocity.

**2.4 Flow Intensity Determination ( $v/v_c$ )**

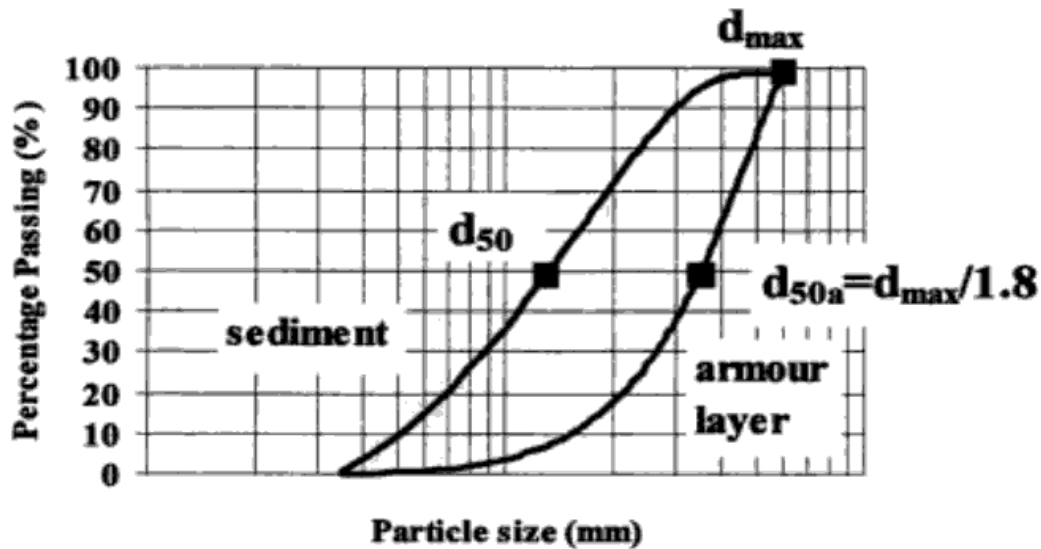
Clearwater scour occurs when the velocity of flow becomes equal or greater than threshold velocity for general bed movement if no sediments were supplied to the scour hole from upstream (Melville and Coleman, 2000). If the ratio  $v/v_c$  is less than 1, the clear water scour exist for uniform bed sediments ( $\sigma_g < 1.3$ ), for nonuniform sediments ( $\sigma_g > 1.3$ ) the value of  $((v - (v_a - v_c))/v_c) < 1$ .

where:

$v$  = Approach flow velocity

$v_a$  = Critical velocity necessary for scour occurrence with armoring layer.

$v_c$  = Critical velocity necessary for scour occurrence without armoring layer



**Figure 5.** Determination of the armor velocity (Melville and Coleman, 2000).

the following two equations have been proposed by (Melville and Coleman, 2000) were used to determine the critical velocity and threshold velocity for armoring:

$$v_c = 0.049 + 0.053d_{50}^{1.4} + (0.066 + 0.072d_{50}^{1.4})\log \frac{y}{d_{50}} \tag{1}$$

$$v_a = 0.039 + 0.018d_{90}^{1.4} + (0.052 + 0.025d_{90}^{1.4})\log \frac{y}{d_{90}} \tag{2}$$

where  $y$  is approach flow depth and  $d_{90}$  is used in place of  $d_{max}$ , which is unlikely to be known (Melville and Coleman, 2000).



### 3. Experimental design

The experiments were done in the laboratory, where the studied variables are summarized in **Table 1**.

**Table 1.** Dimensions and locations of the slit weirs.

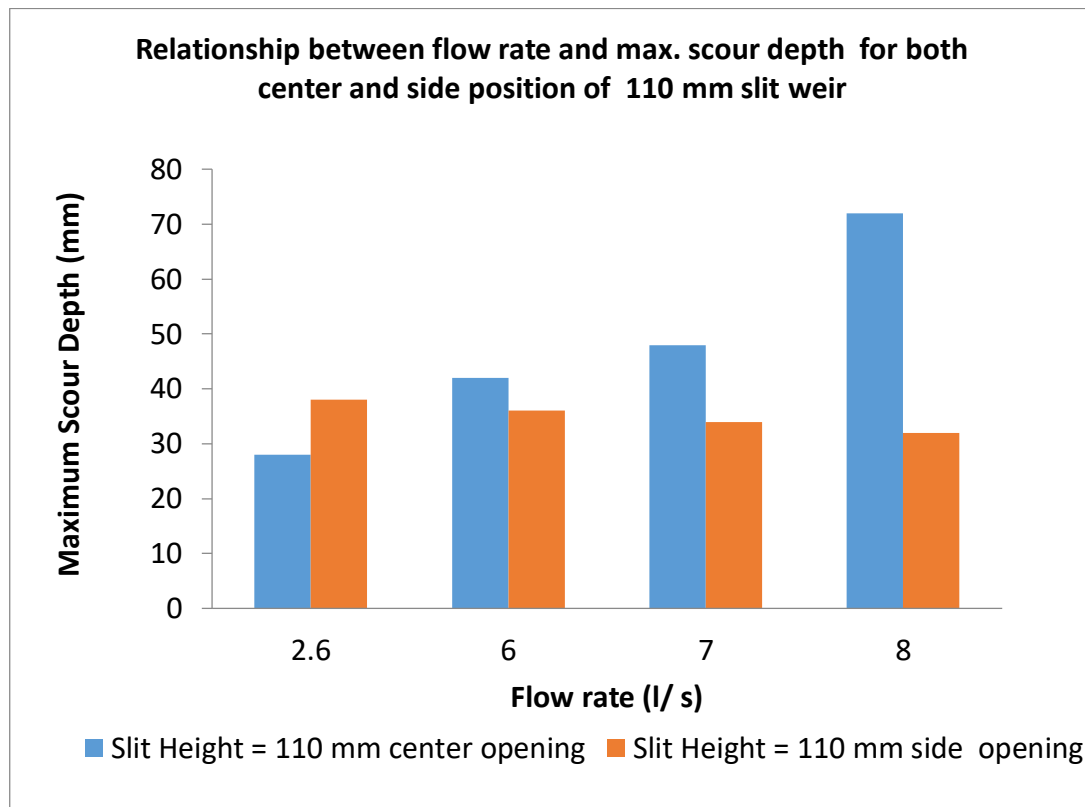
Case	No. of tests	Slit weir height (cm)	Slit position	Slit width (cm)	Bed material	Flow rate l/s	$v-(v_a-v_c)/v_c$
A1 – E6	30	7 - 11	center	6	0.3	2.6 -8	0.39 – 0.91
F1 – F8	8	11	side	6	0.3	2.6 -8	0.54 – 0.89
G1 – G6	6	11	side	6	0.7	2.6 -8	0.58 – 0.96
H1 – H4	4	11	center	6	0.7	2.6 -8	0.48 – 0.96

### 4. RESULTS AND DISCUSSION

Results of laboratory experiments are presented to describe the effect of main parameters (position of slit opening, bed material, flow intensity) on the dependent variables (maximum scour depth and surface area)

#### 4.1 Impact of Slit Weir Location and Flow Rate on the Maximum Scour Depth

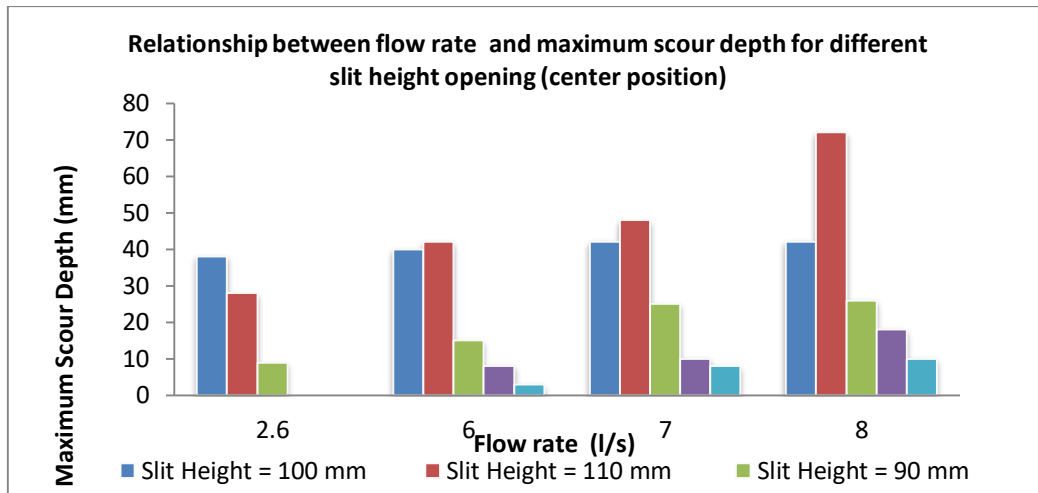
**Fig. 6** shows how the slit weir position and flow rates affected the maximum scour depth. Slit weir position represents an important factor that affects the geometry of the scour hole. It is considered one of the governing variables that directly affect the maximum scour depth and surface area. The experimental data shows the impact of the slit location (at the center of the weir or at the side of the weir) (height of 110 mm and width of 60 mm) on the scour depth after 4 hours from the commencement of the test. For both locations, the dimension of the slit was kept unchanged (Slit dimensions used was 110 mm x 60 mm).



**Figure 6.** Impact of slit position and flow rate on maximum scour depth.

For the tested slit weirs model with the slit dimensions of 110 x 60 mm located at the side, observations showed that maximum scour depth and surface scour area occurred with a flow rate of 2.6 l/s. **Fig. 7** shows the impact of slit weir dimensions, and flow rate on maximum scour depth. The maximum scour depth decrease with the increase in the slit height for different flow rates. The maximum scour depth was recorded with a slit height of 110 mm. This can be attributed to the fact that water vortices formed near the weir opening were entrained of bed particles and carried over the weir. It is observed that the lowest weir crest level (crest level and mobile bed level were the same) was associated with a maximum value of scour depth. Besides, a high flow rate was resulted in maximum scour depth. This can be related to the strong vortices produced near the slit weir (for slit located in the center). This was observed with all tests except tests of slit weirs with the slit opening located at the side. The size of bed material directly affects sediment transport, and it is a significant factor contributing to the scour process, dimension of scour hole, and maximum scour volume. The maximum scour depth and scour area was decreased when the median size,  $D_{50}$ , and geometric standard deviation  $\sigma_g$  were increased. For all experiments, the bed material used in this study were nonuniform sediments with  $\sigma_g = 1.6$  for  $D_{50} = 0.3$  and  $\sigma_g = 1.58$  for  $D_{50} = 0.7$ . This type of nonuniform sediment resulted in an armoring layer formed in scour hole that prevents the progress of scour or the transport of sediments. **Table 2.** shows the experimental data collected on scour depth for  $D_{50} = 0.3$ , while **Fig. 8** shows the impact of sediment size on maximum scour depth.





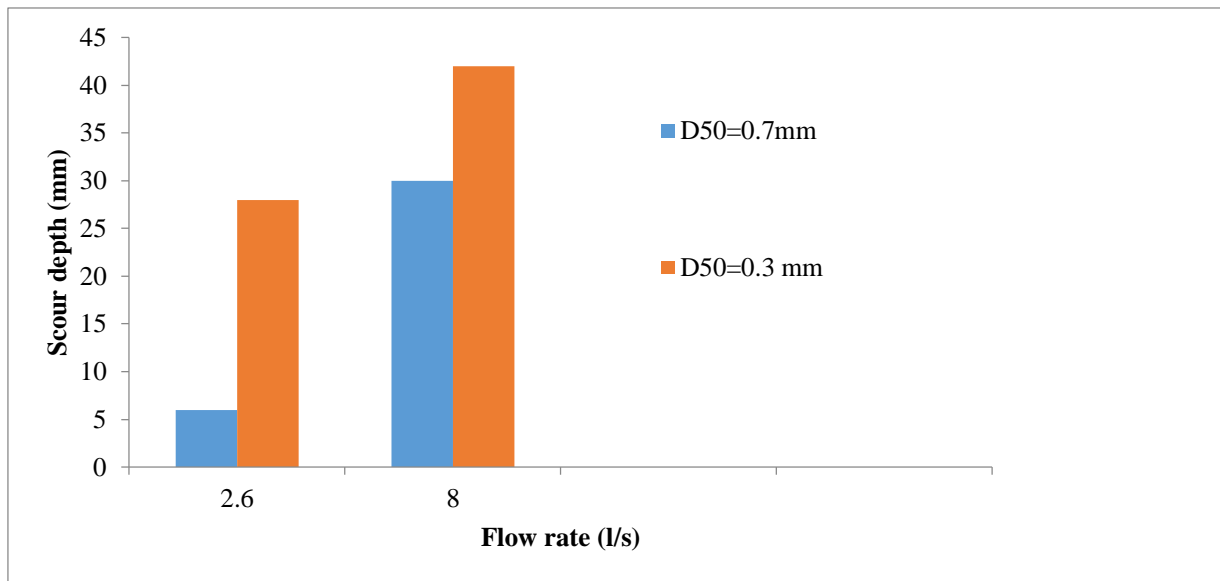
**Figure 7.** Variation of maximum scour depth with slit height for different flow rates with central position slit weir opening.

### 4.2 Impact of Sediment Size on Maximum Scour depth

The bed material size has directly affected the transport of sediments. It is a significant factor that contributes to the scour process, dimension of scour hole, and maximum scour volume. The maximum scour depth and scour area was decreased when the median size,  $D_{50}$ , and geometric standard deviation  $\sigma_g$  were increased.

**Table 2.** Maximum scour depth for different slit weir dimensions and flow rates.

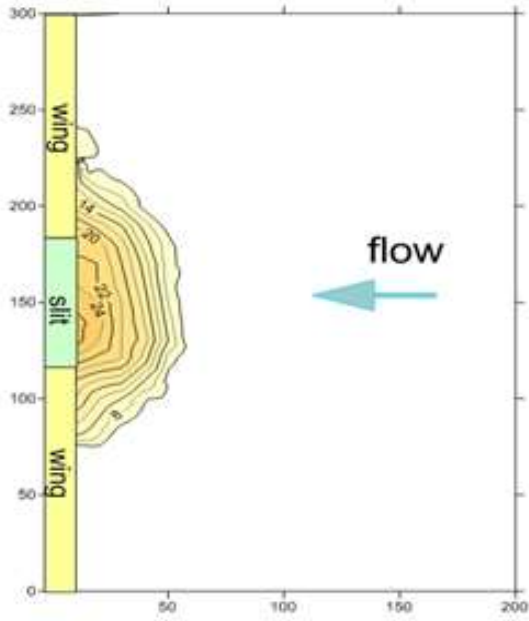
For $D_{50} = 0.3$ mm for bed materials						
flow rate( l/s)	Maximum scour Depth (mm)					
	Slit Height = 110 mm center opening	Slit Height = 100 mm center opening	Slit Height = 90 mm center opening	Slit Height = 80 mm center opening	Slit Height = 70 mm center opening	Slit Height = 110 mm side opening
2.6	38	28	9	0	0	38
6	40	42	15	8	3	36
7	42	48	25	10	8	34
8	42	72	26	18	10	32



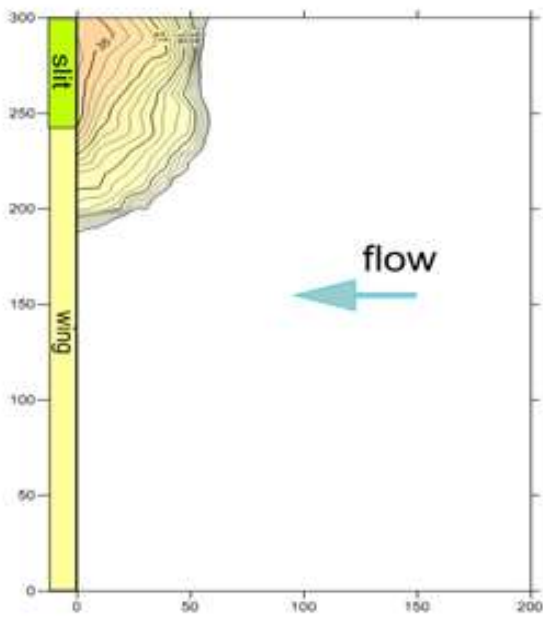
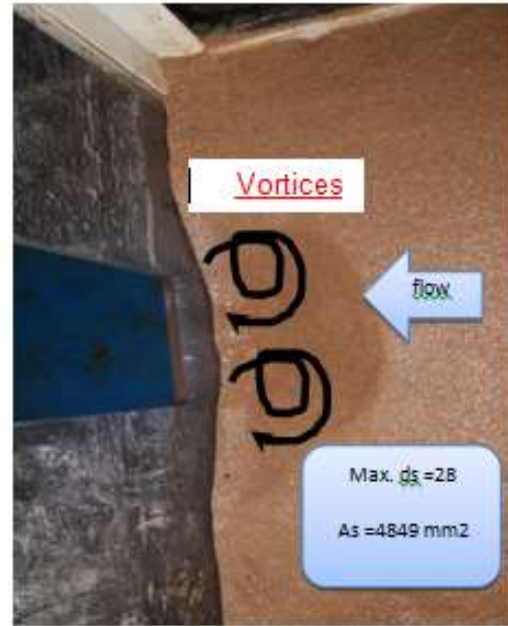
**Figure 8.** The impact of sediment median size on scour depth upstream of slit weir (slit opening located at the center).

#### 4.3 Impact of Slit Weir Location and Flow Rate on Surface Scour Area

**Fig. 9** shows the impact of the slit position in the weir on the scour area. For a flow rate of 2.6 l/s, the scour area was bigger when the slit opening was located at the side of the weir. This comparison was made with the same flow condition and weir dimensions but when the slit opening was in the weir's center. For the other cases, the scour area's behavior under increasing flow rate was found the same. **Table. 3** shows the variation of scour area for different slit weir dimensions and flow rates, while **Fig. 10** shows how the scour area increases with the flow rate for slit weirs located at the center and at the side of the weir.



A. Slit in the center of the weir



B. Slit in the side of the weir



**Figure 9.** Contour lines and actual scour at upstream of slit weirs with dimensions of 110x60 mm.



Table 3. Scour area for different slit weir dimensions and flow rates.

For D <sub>50</sub> = 0.3 mm for bed materials						
Flow rate (l/s)	Surface area (mm <sup>2</sup> )					
	Slit Height = 100 mm center opening	Slit Height = 110 mm center opening	Slit Height = 90 mm center opening	Slit Height = 80 mm center opening	Slit Height = 70 mm center opening	Slit Height = 110 mm side opening
2.6	3390	4849	1212	0	0	6707
6	10561	15518	3200	4458	1870	8645
7	14321	18032	5010	4890	2297	10654
8	28564	32357	5200	5500	2800	12054

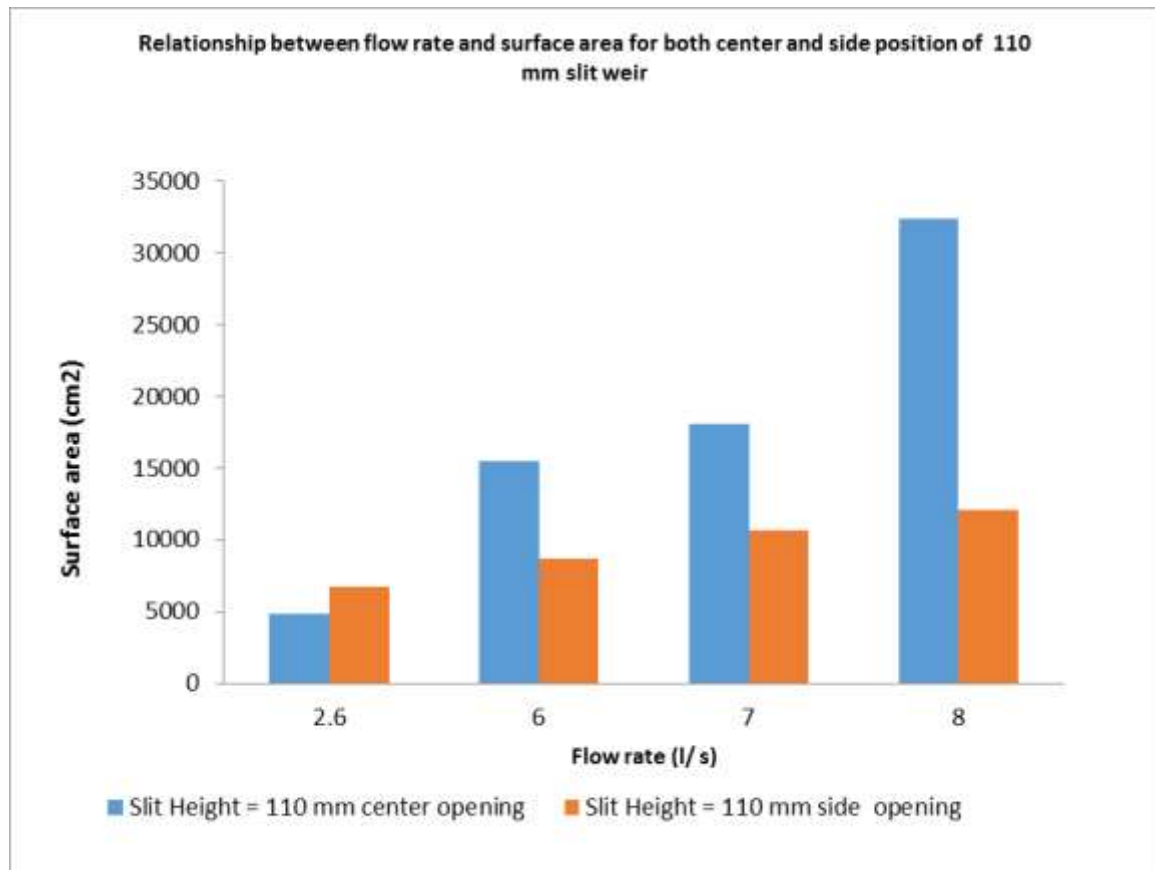


Figure 10. Scour area for different slit weir dimensions and flow rates.

Fig. 11 shows the impact of the slit weir dimension on scour area for different flow rates. It gives important information about expansion of the scour hole in horizontal direction. This is one of the



main parameters which affect the scour at upstream of slit weir site. In addition, it can be noticed that the slit weir dimensions significantly affect scour area.

The flow rates of 6 and 7 l/s gave approximately the same results when the slit weir has dimensions of 60 x 100 mm ( width x height), but it was changed with the other values of flow rates and slit weir dimensions. Although the scour depth didn't increase, scour area was expanded due to vortices' effect in x-y directions.

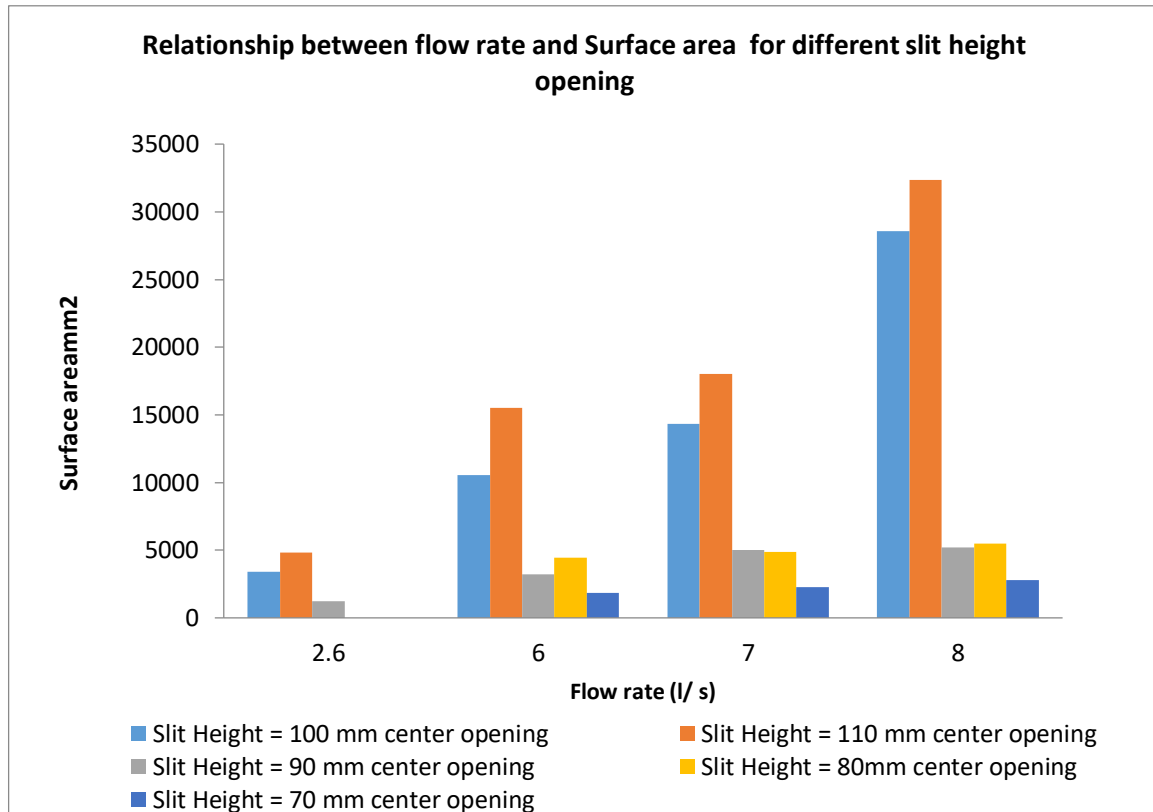


Figure 11. Impact of flow rate on slit weir dimensions on scour area.

### 5. CONCLUSIONS

In this study, experiments were conducted on weir models with different dimensions and locations in the reservoir (center and side) to investigate the impact of flow intensity and sediments coarseness on the maximum scour area and scour depth upstream. From the observations and the data collection, the following conclusions can be drawn:

1. The maximum scour depth and greatest scour area occurred upstream of slit weir with the dimensions of 110 x 60 mm, the flow rate of 8 l/s, and slit weir with slit opening in the center of the weir.
2. The mobile bed with a greater median diameter recorded smaller values of scour area and scour depth.
3. For the lowest flow rate of 2.6 l/s and compared with the weir case with slit at the center, the scour depth and scour area were greatest upstream of the weir with a slit located at the side.



4. Maximum scour depth and scour area is inversely proportional with the nonuniformity of bed material.
5. The scour depth doesn't reach equilibrium after 4 hours from the commencement of the test.
6. Observation of scour progress during the experiments reveal s strong vortices that lift the sediment particles from the mobile bed and carried them with the flow through the slit weir. This was clearly noticed for a slit weir with dimensions of 110 mm x 60 mm (slit, opening in the center) and a flow rate of 8 l/s.
7. Sediment's nonuniformity affects the scour process due to the armoring layer's effect formed in the sediment hole.

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