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Assessment of Scour Depth Downstream of Sharp Crested Weirs: An Experimental Study

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ABSTRACT

Weirs are hydraulic structures built across open channels to measure the flow and raise the water level. A sharp-crested weir is one type of weir of different configurations. Local scour at the downstream of hydraulic structures is a problem that affects their safety and stability. The credibility of the estimation of maximum scour depth is debated in many published studies. In this study, an experimental work was conducted to investigate the impact of flow rates on maximum scour depth downstream of a sharp-crested weir. The weir model was calibrated before it was used in the discharge measurement. The value of the weir coefficient of discharge was found to be 0.633. The experiments were conducted on a plexiglass model of a sharp crested weir, which was tightly fixed at the middle of a laboratory flume. The weir had a crest height of 15 cm above the flume bed. In the experiments, a non-uniform sediment was used with a median diameter (d_{50}) of 0.72 mm; it was placed downstream of the weir within the working section at a depth of 6.5 cm. The scour depths at an interval of 4 cm were measured by a point gauge. The measurement covered the resulting scour hole. The maximum recorded scour depth of 6.2 cm was observed approximately at the center of the flume width, with a Froude number of 0.0313. The measured maximum scour depths were found to agree with those published by other studies.

Keywords: Local scour, Hydraulic sructures, Sharp crested weir, Non-uniform sediment, Scour depth.

1. INTRODUCTION

Weirs are hydraulic constructions built across rivers, streams, or channels to control water flow. Their principal purpose is to regulate water levels and flow rates, so maintain stability in water distribution for many applications like irrigation, water supply, and flood management. Scouring is the process of sediment erosion and removal caused by the hydrodynamic forces of flowing water, typically occurring around hydraulic structures such

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as weirs. The interaction between turbulent flow and sediment in a mobile bed downstream of the weir location results in sediment removal and leads to the formation of scour holes. The phenomenon is a major concern in water resource management, as excessive scouring can compromise the stability and functionality of hydraulic structures, including weirs. To mitigate this issue, several studies have been undertaken to diminish the scour downstream of these structures.

Various experimental investigations using weir-type structures have been performed to improve hydraulic and aeration efficacy **(Cassidy et al., 1985; Kim et al., 2016)**. **(Chen et al., 2005)** studied scouring at the downstream of weirs and found that the length of the scour hole is affected by the geometric characteristics of the weir, the size of the bed material, and the Froude number of the flow. The length of the scour hole increases with increasing Froude number of the flow that results from the difference in water levels upstream and downstream of the weir. **(Verma and Goal, 2005)** studied scouring at the downstream of a sluice gate, and they focused on gate opening, apron length, and submergence depth. They showed that the scour depth increases with shorter aprons. An experimental study on scouring below a high vertical drop in a flume with a cross-section of 0.3 m width and 0.7 m depth **(Dey and Raikar, 2007)**. The researchers used three sizes of gravel (d_{50} = 4.1, 5.53, and 7.15 mm) for the bed material and six sizes of sand with median sizes of 0.26, 0.49, 0.81, 1.86, 2.54, and 3 mm. It was found that the scour depth increases as the Froude number increases. Conversely, the scour depth reduces as the tailwater depth and sediment size increase. **(Bhuiyan et al., 2007)** examined the impact of a W-weir (without upstream or downstream apron) on downstream sediment transport, with a focus on scour hole formation. The greatest scour depth was observed a short distance downstream of the weir, regardless of boundary conditions. **(Chinnarasri and Kositgittiwong, 2008)** executed 105 experiments to examine the maximum scour depth downstream of sills utilising a V-notched weir. It was found that scour depth increases with time, with 80% of the scour occurring within 20% of the duration necessary to achieve equilibrium, after which the increase slowed. **(Hamed and Mirdan, 2009)** studied the influence of oblique and V-notch weir angles on scour parameters. It was found that scouring dimensions increased with the Froude number and deflection angle, with a 120° angle reducing scouring dimensions compared to smaller angles. **(Amini et al., 2012)** carried out an experimental study to examine scour around pile groups in shallow-water flow. The effects of pile spacing, submergence ratio, and arrangement on scour depth were analyzed. It was found that scour depth increases as pile spacing and submergence ratio reduce. **(Scurlock et al., 2012)** collected bathymetry data downstream of A, U, and W-shaped weir models that were placed on a weak mobile bed. The data allowed them to estimate the maximum depth of scouring that would occur under equilibrium conditions.

(Al-Mashhadani, 2014) investigated how screen walls could reduce the scouring downstream of weirs. He extrapolated two empirical formulas to calculate the ratio of scour depth to length using dimensionless parameters. **(Ahmed Amin, 2015)** found that reducing the Froude number led to a decrease in both the maximum depth and length of scouring, as well as a move in the location of the maximum scour depth towards downstream. **(Irzooki and Yass, 2015)** found that the discharge coefficient (C_d) increased with greater weir height (P) and decreased with larger upper face angles (θ), while triangular face angles have minimal effect. **(Ibrahim, 2015)** examined a compound sharp-crested V-notch weir, designed with two triangular sections to manage normal and peak discharges. Forty-eight experimental runs were performed with variations in weir geometry (combination of notch angles), water levels, and bed materials. Regression equations were developed to predict local scour downstream based on the experimental data. No significant difference in scour was observed between the compound and classical V-notch weirs, but the compound design was recommended for improved handling of high discharges. **(Jüstrich et al., 2016)** investigated scour formation and sediment deposition downstream of piano key weirs (PKW) using physical model tests. The results demonstrate that maximum scour depth and associated sediment movement can be predicted based on jet-induced processes, emphasizing the importance of designing effective energy dissipation structures for PKW foundations. **(Pagliara and Kurdistani, 2017)** investigated scour phenomena downstream wooden stream restoration structures and concluded that log-frame deflectors provided better riverbank protection compared to log deflectors.

(Al-Thamiry and AbdulAzeez, 2017) analyzed riverbank erosion in Nu'maniyah City using experimental tests and numerical modelling. The study found that high water velocities near the right bank caused severe erosion. Among mitigation methods, riprap proved the most effective, reducing velocity by up to 85% and being more cost-efficient than gabions. **(Alsawaf et al., 2019)** studied the impact of spur dikes on flow concentration in multithreaded channels using experimental models. Results showed that a spur dike occupying one-third of the channel width maximized flow diversion, increasing discharge in the active branch and altering sediment transport. **(Kareem and Al-Thamiry, 2019)** studied scouring in the Galal Badrah River using HEC-RAS modelling. Results showed high velocities exceeding safe limits, leading to severe bank erosion. Stacked boulders were recommended as protection, reducing velocities by up to 65.23%. Flood embankments were also suggested to prevent rising water levels. **(Alhealy and Hayawi, 2019)** studied scouring at downstream weirs with different circular holes in their surfaces. It was shown that the scour volume increases with the increase in discharge, and the maximum depth of scour was reduced by the use of circular holes in the weir surface. **(Al-Husseini et al., 2020)** executed a numerical and experimental study to examine local scour around submerged sharp-crested weirs. Different weir configurations, such as inclined and arch weirs, were tested and contrasted with a traditional sharp-crested weir. It was found that the inclined weir with a 120° angle significantly reduced scour depth. **(Farsirotou et al., 2020)** examined local scour development downstream of sharp-crested weirs using flume experiments. Measurements of scour depth and bed level variation were validated with empirical equations and numerical models. The findings confirmed the reliability of experimental methods for improving sediment transport simulations in rivers.

(Ben Meftah and Mossa, 2020) investigated scour downstream of a grade-control structure (GCS) in alluvial channels. Extensive laboratory experiments were performed in a rectangular channel with a non-uniform sediment bed. (**Abed and Majeed, 2020)** used CFD simulations to study scouring around bridge piers. They found that increasing the spacing between piers reduced scour depth. Circular piers caused the deepest scour, while triangular-nose piers caused the least. The spacing ratio had a significant impact, with no noticeable effect when the ratio exceeded 4.6. **(Ghaderi et al., 2020)** carried out an experimental study on scouring downstream of a stepped spillway. The deepest scouring was seen when the flow was skimming, and it got shallower as the step height went up. The deepest scouring was seen near the walls and higher in the middle. Increasing the depth of the tailwater while keeping the other hydraulic properties the same would make the scour hole smaller. **(Majeed et al., 2021)** used a CFD simulation to study the effects of gate openings on sediment transport and scour at the Al-Hay Regulator. They found that the scour depth and sediment removal increased with higher Froude numbers. Additionally, asymmetrical gate openings caused more sediment movement compared to symmetrical operations.

(Alhassani and Mohammed,2021) examined the impact of slit weir dimensions, location, and flow intensity on upstream scour. Through 48 laboratory experiments, they found that maximum scour depth and area occurred with a centrally located 110 mm slit weir at an 8 l/s flow rate. Finer sediments increased scour, while coarser ones reduced it by forming an armouring layer. **(Obaida et al., 2022)** studied scouring at the downstream of the piano key weir type C, where the height of the weir, width of the keys, and apron solid were changed. Furthermore, decreasing the height of the weirs leads to a decrease in scour depth. The equation that includes the governing variables was proposed using SPSS software. **(Chooplou et al., 2022)** showed the significant impact of the densiometric Froude number on longitudinal bed profiles downstream of the outlet keys. Increasing the densiometric Froude number caused an increase in the scour hole area. **(Hamdan et al., 2022)** studied scour volume upstream of a slit weir for sediment release. Experiments showed that fine, uniform sediments caused larger scour, increasing up to four times with higher flow rates. **(Abd alakhwa and Mohammed, 2023)** studied scouring at the Kufa Bridge, evaluating the accuracy of three bridge scour estimation formulae (HEC-18, Forehlich, and Johnson) using field data from multiple locations. Statistical analysis showed that the Johnson formula provided the most accurate predictions. **(Obaida et al., 2023)** proved that the use of a solid apron leads to a decrease in both the depth and length of the scour hole. Two empirical formulas were extrapolated to estimate the maximum depth and length of the scour hole. **(Al-kmoly and Majeed, 2024)** examined how blockage affects scour at box culvert inlets. Increased blockage raised water depth by 30%-50% and reduced scour depth. Higher discharge intensified scouring. **(Ahmed et al., 2025)** used Ansys Fluent to simulate scour at culvert outlets. It found that increased flow rates, higher inlet blockages, and larger sediment sizes led to greater scour depths. The RNG turbulence model provided more accurate results, especially under 40% blockage. According to the literature review, scouring downstream is the major problem encountered with hydraulic structures.

This study included experimental work to investigate the effect of flow rate on the maximum scour depth as well as to calculate the value of the discharge coefficient.

2. MATERIALS AND METHODS

2.1 Laboratory Flume Model

In this study, the experiments were carried out using a physical model in the hydraulic laboratory of the Ministry of Water Resources, Baghdad, Iraq. The flume is 4 m long, 0.60 m wide, and 0.20 m deep. It is manufactured in three sections: the flow stilling section, the flume section, and the outflow stilling tank. The apparatus is made of fiberglass reinforced plastic by ARMFIELD Company Ltd., UK, as shown in **Fig. 1**. The flume was modified to include a 2 m working section in the middle of the flume. The working section was filled with sediment to a depth of 6.5 cm. The heads of water above the weir and scour depth were measured using a point gauge with an accuracy of ±1 mm. After every experiment, the working section was leveled and prepared for the next experiment.

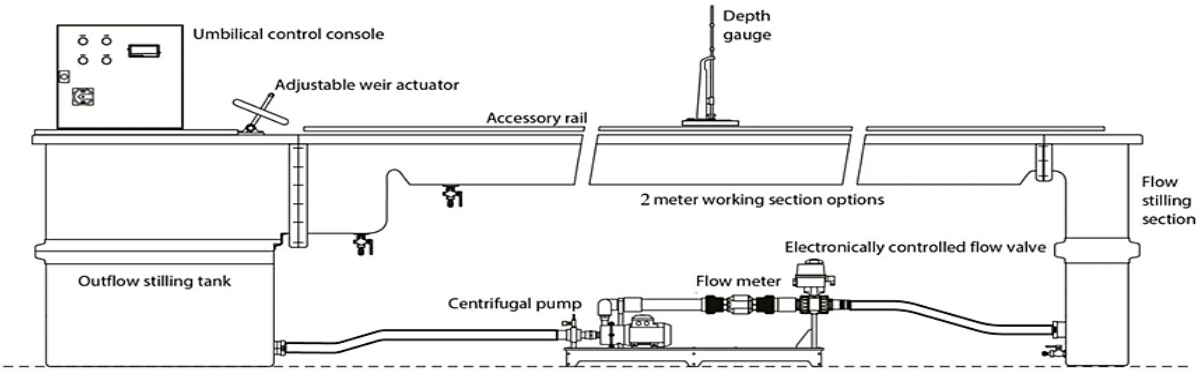

Figure 1. The elevation view of the flume laboratory

2.2 The Weir Model

The weir model used in this study was made of plexiglass with a height of 15 cm, a width of 60 cm, and a thickness of 0.6 cm, as shown in **Fig. 2**. To prevent the leakage of water underneath the weir models, they were fixed to the flume bed using glue.

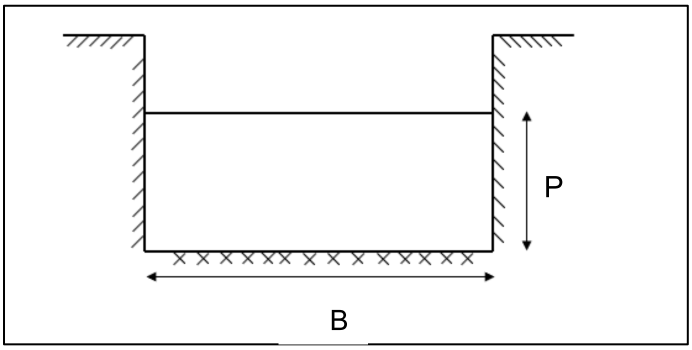

Figure 2. The weir model

2.3 The Bed Materials

A sample of 0.5 kg was taken for sieve analysis, which was conducted to find the median particle size of the sediment, and this was done by mixing various sizes of sand particles. The percentage passing and size of the sediments were determined from sieve analysis, as shown in **Fig. 3.** In this study, non-uniform sediment with a median diameter of d_{50} = 0.72 mm was used in the working section. The geometric standard deviation σ_g of the sand size is equal to 1.44. Therefore, the geometric standard deviation for non-uniform sediments should be more than 1.3, and it was calculated using the following Eq. (1) **(Melville and Coleman, 2000):**

$$\sigma_g = \sqrt{\frac{d_{84}}{d_{16}}} \tag{1}$$

Where sediment sizes with diameters of d_{84} and d_{16} were determined from the grading curve of sediment as shown in **Fig. 3.**

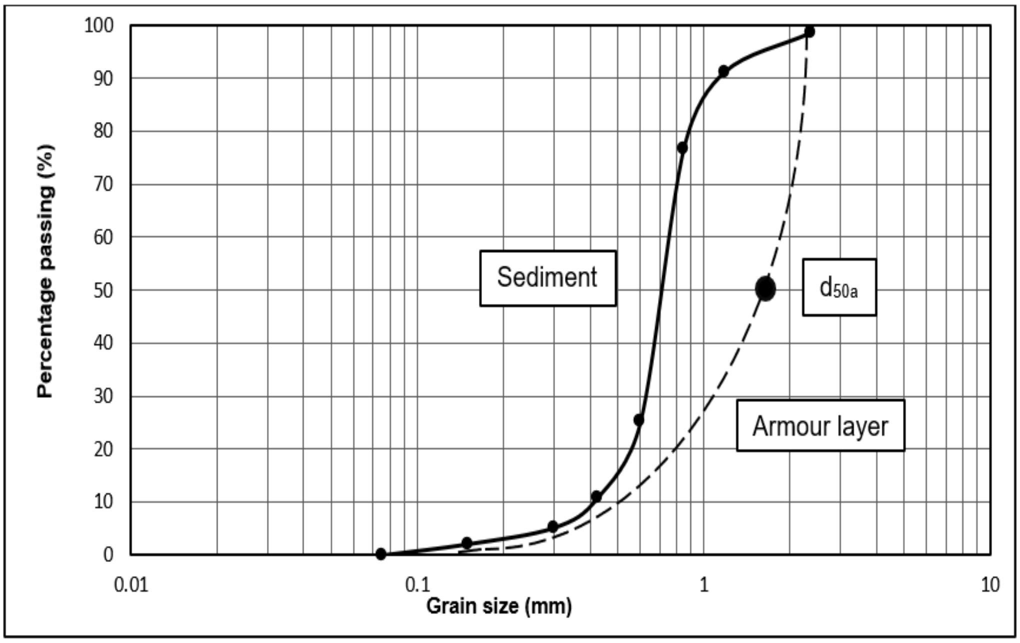

Figure 3. Grain size distribution curve for sediment used in the working section.

2.4 Flow Intensity Determination (V/V_c)

Clear water scour occurs when the water flow fails to transport sediment or bed particles from upstream. In this condition, shear stress remains equal to or below the critical shear stress required for sediment movement, and the flow velocity (v) does not exceed the threshold velocity (v_c). According to **(Melville and Coleman, 2000)**, clear water scour conditions are defined by a flow intensity ratio of $v/v_c < 1$ for uniform sediment when $\sigma_g < 1.3$. For non-uniform sediment ($\sigma_g > 1.3$), the condition is expressed as $(v - (va\text{-}vc)) / v_c < 1$. Under these conditions, the presence of an armor layer reduces scour depth, and the flow intensity ratio is adjusted to v/v_a. The critical velocity for sediment entrainment and the armor peak velocity are determined using the Shield diagram **(Nakad et al., 2022)**, as represented in Eqs. (2) and (3):

$$v_c = 0.049 + 0.053d_{50}^{1.4} + (0.066 + 0.072d_{50}^{1.4})log\frac{y}{d_{50}} \qquad for\ 0.1\ mm < d_{50} < 1\ mm \qquad (2)$$

$$v_a = 0.039 + 0.018d_{90}^{1.4} + (0.052 + 0.025d_{90}^{1.4})log\frac{y}{d_{90}} \qquad for\ 0.1\ mm < 0.55d_{90} < 1\ mm \qquad (3)$$

Where v_a is the armour peak velocity, d_{90} is used in place of d_{max}, and y is the flow depth.

3. EXPERIMENTAL DESIGN

The experiments were carried out in the laboratory, with the examined variables summarized in **Table 1.**

Table 1. Details of the weir model

Weir type	Weir height (cm)	Weir width (cm)	Size of bed material (mm)	Flow rate (l/sec)	Froude number (dimensionless)	$(v - (v_a - v_c)) / v_c$
Sharp-crested weir	15	60	0.72	0.9	0.0189	0.2646
Sharp-crested weir	15	60	0.72	1.2	0.0240	0.2734
Sharp-crested weir	15	60	0.72	1.5	0.0286	0.2822
Sharp-crested weir	15	60	0.72	1.7	0.0313	0.2875

4. EXPERIMENTAL WORK PROCEDURE

The experiment procedure comprised:

1. The working section was filled with sand with a length of 2 m and a thickness of 6.5 cm.
2. The sand layer's surface was leveled and tested with a point gauge.
3. To prevent the leakage of water underneath the weir model, the weir model was fixed to the flume bed using glue.
4. The pump was turned on and the control valve opened according to the required discharge, and then the height of the water above the weir was measured.
5. After some time had passed from the start of operation and after making sure that the scouring had stopped and the bed materials were not moving, the pump stopped operating and waited until the water in the channel was removed.
6. The dimensions of the scouring hole were measured by a point gauge at the corners of 4x4 cm to the end of the scouring hole.
7. After the maximum scour depth was achieved, scour contours for the working section were prepared by using the Surfer Program (version 20). In addition, the capabilities of the Surfer program were used to estimate the scour volume downstream of the weir.
8. These steps were repeated for all experiments.

All experiments were conducted under clear water scour conditions. In addition, the flows were steady and subcritical.

5. RESULTS AND DISCUSSION

5.1 Calibration of the Weir Model

The values of discharges and heads over the weir model were measured to determine the coefficient of discharge of the weir model. The data were plotted on a log-log scale as shown in **Fig. 4**. The plot on a log-log scale was used to convert the nonlinear parabolic relationship between the discharge (Q) and the head over the weir (H) to a linear relationship. The standard parabolic relationship between Q and H for a weir is given by the following general equation:

$$Q = K\,H^n \tag{4}$$

Where K is a constant and n is an exponent.

The standard value of the exponent n is 1.5, while the value of K is varied depending on hydraulic factors as well as the geometry of the weir. However, K can be described as

$$K = \frac{2}{3}\, C_d \sqrt{2g}\, B \tag{5}$$

Where: Q is the discharge over the weir (m^3/sec), C_d is the discharge coefficient (dimensionless), g is the acceleration due to gravity (m/sec^2), and B is the weir crest length (m).
The values of K and n can be determined from the log-log plot (K is the intercept, while n is the slope of the line, **Fig. 4**. After knowing the values of constant K and crest length for the weir model, the value of C_d can be determined from the following equation:

$$C_d = \frac{3K}{2B\sqrt{2g}} \tag{6}$$

Table 2 shows the average values of K, n, C_d, and the equation of the weir after calibration.

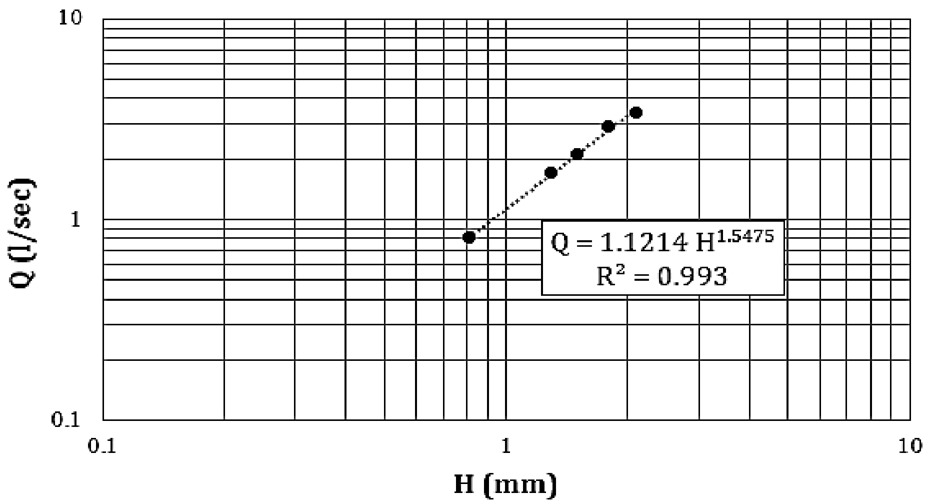

Figure 4. The linear relationship between the head and discharge of the weir model

Table 2. The discharge coefficient for the weir model

Weir type	Weir's Equation	K = 2/3 C_d × B × $\sqrt{2g}$	C_d	n
Sharp-crested weir	$Q = 1.214H^{1.5475}$	1.1214	0.633	1.5475

The discharge coefficient (C_d) for a sharp-crested weir typically ranges between 0.6 and 0.65, depending on factors such as the weir geometry, approach velocity, and flow conditions. A value of 0.633 falls within the acceptable range, making it reasonable and valid. This value aligns with the range reported by **(Johnson, 1996)**, confirming its consistency with established empirical data. In addition, the value of n for the tested weir was found to be 1.5475, which is close to the standard value of the exponent given in the weir's equations.

5.2 Impact of Flow Rate on The Maximum Scour Depth.

The flow conditions were found within the clear water scouring since the range of the flow intensity was between 0.2646 and 0.2875. As mentioned earlier, the clear water conditions exist when the value of flow intensity $((v - (v_a - v_c)) / v_c)$ is less than 1. The experimental results demonstrate a direct relationship between flow rate (Q) and maximum scour depth (S_d) downstream of the sharp-crested weir. As the discharge increases, the scour depth also increases, indicating the intensified erosive impact of the flow. This can be attributed to the higher velocity and shear stress exerted on the bed material, which increases sediment entrainment and deepens the scour hole.

The data demonstrate that when the discharge increased from 0.9 l/s to 1.7 l/s, the scour depth increased from 5 cm to 6.2 cm, representing a 24% increase in scour depth due to the higher discharge rate. The plotted relationship in **Fig. 5** shows a positive correlation between discharge and scour depth, where even a modest increase in flow rate results in a significant increase in erosion due to amplified turbulent intensity and vortex formation. These findings align with established hydraulic principles, confirming that higher flow rates generate greater scouring effects due to increased energy dissipation and flow-induced bed scouring.

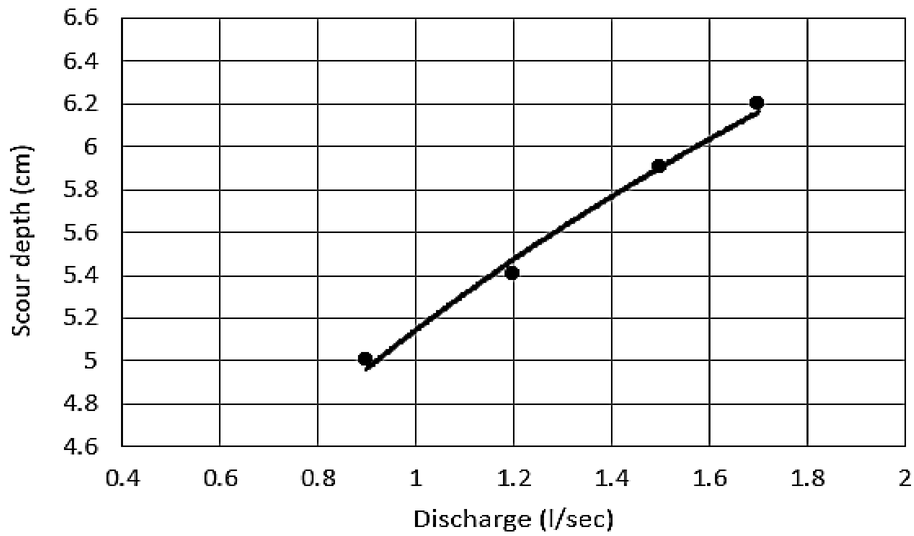

Figure 5. Scour depth for sediment downstream of a weir model

Non-uniform sediment consists of particles of different sizes, where larger particles form a protective (armouring) layer that reduces the exposure of smaller particles to erosion. This diversity enhances particle interlocking and cohesion, increasing the resistance of the sediment to scouring forces. Additionally, non-uniform sediment has lower hydraulic conductivity, limiting the seepage forces that could weaken the bed. **Fig. 6** shows a sample of contours for scour holes measured after 4 hours from the commencement of the experiments for the weir model. The measured maximum scour depth downstream of the sharp-crested weir model was found to be 6.2 cm. However, the maximum scour depth measured by (**Dehghani et al., 2010)** downstream of a hydraulic structure model was found to be 5.5 cm. This confirmed that the results of the present study are in agreement with those obtained by **(Dehghani et al., 2010).**

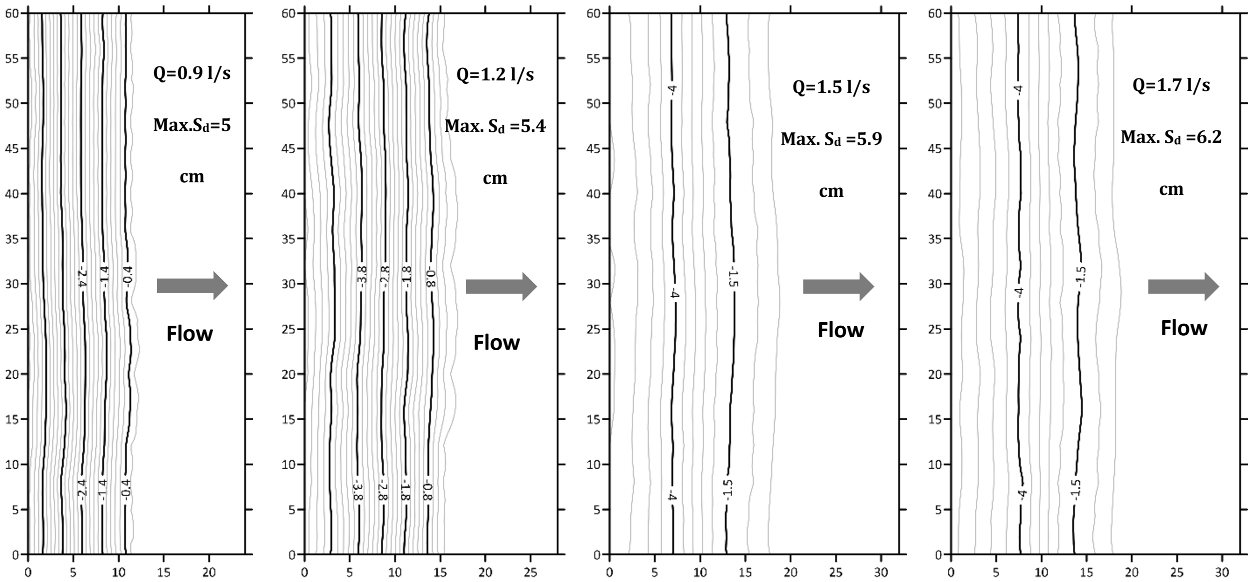

Figure 6. Scour contours for different flow rates of a weir model

6. CONCLUSIONS

In this study, the impact of flow intensity on the maximum scour depth at the downstream of a sharp crested weir was investigated using a weir model that was fixed in a laboratory flume with a non-uniform sediment of medium diameter of 0.72 mm and geometric standard deviation (σ_g) of 1.44. From the observations and the data collection, the following conclusions can be drawn:

1. The maximum measured scour depth at the downstream of the weir model was recorded with a maximum discharge of 1.7 l/s.
2. The scour depth was reaching an equilibrium state after 4 hours from the commencement of the experiment.
3. Observations on the formation of scour holes at the downstream reveal that sediment pick-up occurred due to the strong vortices resulting from the turbulence of the falling water nappe.
4. For the non-uniform sediment used in the mobile bed downstream of the weir model, an armouring layer was added to control the maximum scour depth.

NOMENCLATURE

Symbol	Description	Symbol	Description
B	The Weir Width, cm.	**P**	The weir height, cm.
C_d	Discharge coefficient, dimensionless.	**Q**	The discharge, m^3/sec.
D_{84}	Sediment size for which 16% of the particles are finer, mm.	**V**	Mean approach velocity, m/sec.
D_{16}	Sediment size for which 84% of the particles are finer, mm.	**V_a**	Peak velocity, m/sec.
D_{50}	Median size sediment, mm.	**V_c**	Critical velocity, m/sec.
S_d	The scour depth, cm.	**Y**	The flow depth, cm.
H	The water depth over the weir, cm.	**Σ_g**	Geometric standard deviation, dimensionless.

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Credit Authorship Contribution Statement

Israa Abdulameer Mohammed J.: Writing –review & editing, Writing –original draft, validation, software. Thamer A. Mohammed: Writing –review & editing, Methodology.

Declaration of Competing Interest

The authors confirm that they do not have any competing financial interests or personal relationships that could have influenced the work reported in this paper.

REFERENCES

Abed, B. S., Majeed, and H. Q., 2020. The behavior of scouring around multiple bridge piers having different shapes. *IOP Conference Series: Materials Science and Engineering*, *745*, P. 012158. https://doi.org/10.1088/1757-899X/745/1/012158

Ahmed Amin, A. M., 2015. Physical model study for mitigating local scour downstream of clear over-fall weirs. *Ain Shams Engineering Journal*, 6(4), pp. 1143–1150. https://doi.org/10.1016/j.asej.2015.03.013

Ahmed, K. O., Majeed, H. Q., Amini, A., and Shafaei, H., 2025. Scour prediction at culvert outlets using ansys fluent: influence of inlet blockage, flow rate, And Sediment Size. *ISH Journal of Hydraulic Engineering*, 31(1), pp. 1–14. https://doi.org/10.1080/09715010.2025.2495789

Al-Husseini, T. R., and Al-Madhhachi, A. S. T., and Naser, Z. A., 2020. Laboratory experiments and numerical model of local scour around submerged sharp crested weirs. *Journal of King Saud University - Engineering Sciences*, 32(3), pp. 167–176. https://doi.org/10.1016/j.jksues.2019.01.001

Al-kmoly, D. A. H., and Majeed, H. Q., 2024. Experimental investigation about the effects of blockage on upstream box culverts. *Journal of Engineering*, 30(1), pp. 140-156. https://doi.org/10.31026/j.eng.2024.01.09.

Al-Mashhadani, M. K., and Hayawi, G. A., 2014. Laboratory study to decrease the scour downstream of weirs using screen walls. *Al-Rafidain Engineering Journal*, 22 (5), pp. 47-59.

Al-Thamiry, H. A. K., and AbdulAzeez, T. M., 2017. A two-dimensional mathematical model to study the erosion problem of the Tigris River Banks At Nu'maniyah. *Journal of Engineering*, 23 (1), pp. 112-135. https://doi.org/10.31026/j.eng.2017.01.08

Alakhwa, H. R. A., and Mohammed, T. A., 2023. Checking the accuracy of selected formulae for both clear water and live-bed bridge scour. *Journal of Engineering,* 29 (2), pp. 99-111. https://doi.org/10.31026/j.eng.2023.02.07

Alhassani, N. Z., and Mohammad, T. A., 2021. Impact of the weir slit location, the flow intensity, and the bed sand on the scouring area and depth at the dam upstream. *Journal of Engineering*, 27(5), pp. 49-62. https://doi.org/10.31026/j.eng.2021.05.04.

Alhealy, M. K., and Hayawi, G. A., 2019. Experimental study of the scour depth at downstream weirs with different holes. *Al-Rafidain Engineering Journal*, vol. 24 (1), pp. 18-23.

Alsawaf, M., Ghazali, A. H., Mohammad, T. A., Ghani, A. A., and Yusuf, B., 2019. Movable-bed experiments using spur dike to concentrate flow in one channel of multithreaded channel model. *Journal of Hydraulic Engineering*, 145(5), P. 06019006. https://doi.org/10.1061/(ASCE)HY.1943-7900.0001595.

Amini, A., Melville, B. W., Ali, T. M., and Ghazali, A. H., 2012. Clear-water local scour around pile groups in shallow-water flow. *Journal of Hydraulic Engineering*, 138(2), pp. 177–185. https://doi.org/10.1061/(asce)hy.1943-7900.0000488

Ben Meftah, M., and Mossa, M., 2020. New approach to predicting local scour downstream of grade-control structure. *Journal of Hydraulic Engineering*, 146(2), pp. 1–13. https://doi.org/10.1061/(asce)hy.1943-7900.0001649

Bhuiyan, F., Hey, R. D., and Wormleaton, P. R., 2007. Hydraulic evaluation of w-weir for river restoration. *Journal of Hydraulic Engineering,* 133(6), pp. 596–609. https://doi.org/10.1061/(asce)0733-9429(2007)133:6(596)

Cassidy, J. J., Gardner, C. A., and Peacock, R. T., 1985. Boardman labyrinth-crest spillway. *Journal of Hydraulic Engineering,* 111(3), pp. 398-416. https://doi.org/10.1061/(ASCE)0733-9429(1985)111:3(398)

Chen, Z., Shao, X. N., and Zhang, J., 2005. Experimental study on the upstream water level rise and downstream scour length of a submerged dam. *Journal of Hydraulic Research*, 43 (6), pp. 703-709. https://doi.org/10.1080/00221680509500390

Chinnarasri, C., Kositgittiwong, D., 2008. Laboratory study of maximum scour depth downstream of sills. *Proceedings of the Institution of Civil Engineers: Water Management*, 161(5), pp. 267–275. https://doi.org/10.1680/wama.2008.161.5.267

Chooplou, C. A., Kazerooni, S., Ghodsian, M., and Vaghefi, M., 2022. Experimental study of scouring downstream of type-a piano key weirs. *In Arabian Journal of Geosciences*, 15(23). https://doi.org/10.1007/s12517-022-11001-9

Dehghani, A. A., Bashiri, H., and Dehghani, N., 2010. Downstream scour of combined flow over weirs and below gates. Proceedings of the International Conference on River Flow 2010. *Koll, Germany*, pp. 1201-1205.

Dey, S., and Raikar, R. V., 2007. Scour below a high vertical drop. *Journal of Hydraulic Engineering*,133(5), pp. 564–568. https://doi.org/10.1061/(asce)0733-9429(2007)133:5(564)

Farsirotou, E., Xafoulis, N., and Kotsopoulos, S., 2020. Experimental and numerical simulation of local scouring downstream of sharp-crested weirs in natural rivers. *European Water*, 69(February), pp. 33–44. https://doi.org/10.13140/RG.2.2.35944.44805

Ghaderi, A., Daneshfaraz, R., Torabi, M., Abraham, J., and Azamathulla, H. M., 2020. Experimental investigation on effective scouring parameters downstream from stepped spillways. *Water Science and Technology: Water Supply,* 20(5), pp. 1988–1998. https://doi.org/10.2166/ws.2020.113

Hamdan, R. K., Al-Adili, A., and Mohammed, T. A., 2022. Physical modeling of the scour volume upstream of a slit weir using uniform and non-uniform mobile beds. *Water,* 14 (3273). https://doi.org/10.3390/w14203273

Ibrahim, M. M., 2015. Bed profile downstream compound sharp crested v-notch weir. *Alexandria Engineering Journal*, 54(3), pp. 607–613. https://doi.org/10.1016/j.aej.2015.03.026

Irzooki, R. H., and Yass, M. F., 2015. Hydraulic characteristics of flow over triangular broad crested weirs. *Engineering and Technology Journal,*33(7A), pp. 86–96. https://doi.org/10.30684/etj.33.7a.15

Johnson, M.C., 1996. *Discharge coefficient scale effects analysis for weirs*. Utah State University. https://digitalcommons.usu.edu/etd/7604.

Jüstrich, S., Pfister, M., and Schleiss, A. J., 2016. Mobile riverbed scour downstream of a piano key weir. *Journal of Hydraulic Engineering,* 142(11), pp. 1–12. https://doi.org/10.1061/(asce)hy.1943-7900.0001189

Kareem, K. A. A., and Al-Thamiry, H. A. K., 2019. Identification of scouring zones in ungauged river by simulation: The case of the Galal Badrah River, Iraq. *Association of Arab Universities Journal of Engineering Sciences*, 26 (3), pp. 57-67. https://doi.org/10.33261/jaaru.2019.26.3.007

Kim, H.S., Kimura, I., and Shimizu, Y., 2016. Experimental investigations of scour pools around porous obstructions. *Water, 8, 498*. https://doi.org/10.3390/w8110498

Majeed, H. Q., Abed, B. S., and Shamkhi, M. S., 2021. CFD simulation for the operation effect of gates openings of Al-Hay regulator on the local erosion. *Journal of Engineering Science and Technology*, 16(2), pp. 1098-1109. https://doi.org/10.20853/16.2.4053

Melville, B. W., and Coleman, S. E., 2000. *Bridge Scour. Water Resources Publication.*

Nakad, N. Z., Mohammad, T. A., and Hamoodi, H. M., 2021. Experimental investigations on scour volume upstream of a slit weir. *Pertanika Journal of Science and Technology*, 30 (3). https://doi.org/10.47836/pjst.30.3.09

Obiada, A. A. R. M., Taha, K. Y., and Hayawi, G. A. M. 2022. Experimental study of scour downstream piano key weir type c with changing height of weir, width of keys, and apron solid. *Al-Rafidain Engineering Journal (AREJ)*, 27 (1), pp. 193-204. https://doi.org/10.33899/rengj.2021.130402.1101

Obaida, A. A. M., Khattab, N. I., and Mohammed, A. Y., 2023. Scour depth downstream sharp-crested weir. *Journal of Engineering and Applied Science*, 70 (23). https://doi.org/10.1186/s44147-023-00192-x

Pagliara, S., and Kurdistani, S. M., 2017. Flume experiments on scour downstream of wood stream restoration structures. *Geomorphology,* 279, pp. 141–149. https://doi.org/10.1016/j.geomorph.2016.10.013

Scurlock, S. M., Thornton, C. I., and Abt, S. R., 2012. Equilibrium scour downstream of three-dimensional grade-control structures. *Journal of Hydraulic Engineering,* 138(2), pp. 167–176. https://doi.org/10.1061/(asce)hy.1943-7900.0000493

Verma, D. V. S., Goel, A., 2005. Scour downstream of a sluice gate. *ISH Journal of Hydraulic Engineering,*11(3), pp. 57–65. https://doi.org/10.1080/09715010.2005.10514801

تقييم عمق التآكل مؤخر الهدار ذي القمة الحادة: دراسة تجريبية

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الخلاصة

الهدارات هي هياكل هيدروليكية مبنية عبر القنوات المفتوحة لقياس التدفق ورفع مستوى المياه الخ. الهدار ذو القمة الحادة هو أحد أنواع الهدارات ذات التكوينات المختلفة. يمثل التآكل الموضعي مؤخر الهياكل الهيدروليكية مشكلة تؤثر على سلامتها واستقرارها. إن موثوقية تقدير أقصى عمق للتآكل محل نقاش في العديد من الدراسات المنشورة .في هذه الدراسة، تم إجراء عمل تجريبي للتحقيق في تأثير معدلات التدفق على أقصى عمق للتآكل مؤخر الهدار ذو القمة الحادة. تمت معايرة نموذج الهدار قبل استخدامه في قياس التصريف. تم تحديد قيمة معامل التصريف للهدار والتي بلغت 0.633. أجريت التجارب على نموذج لهدار ذو قمة حادة مصنوع من الأكريليك الزجاجي، تم تثبيته بإحكام في منتصف قناة مختبرية. كان ارتفاع قمة الهدار يبلغ 15 سم فوق قاع القناة. تم استخدام رواسب غير موحدة بقطر متوسط (d_{50}) يبلغ 0.72 ملم، وُضعت الرواسب عند مؤخر الهدار داخل قسم العمل بعمق 6.5 سم. تم قياس أعماق التآكل بفاصل 4 سم بواسطة مقياس نقطي. غطى القياس حفرة التآكل الناتجة. كان أقصى عمق تآكل مسجل 6.2 سم ويقع تقريبًا في منتصف عرض القناة مع رقم فرود 0.0313. وُجد أن أعماق التآكل القصوى المقاسة تتفق مع تلك التي نشرتها دراسات أخرى

الكلمات المفتاحية: تآكل موضعي، هياكل هيدروليكية، هدار حاد القمة، رواسب غير متجانسة، عمق التآكل.