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An Experimental Study of the Maximum Scour Depth Due to the Free Falling Jets at the Downstream of the Storage Reservoir

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1- Introduction

When the gates of dam are opened in order to discharge the flood or discharge the required water for the downstream consumptions, the falling jet energy released from the dam gates creates a scour hole at the downstream of the reservoir. The dimensions of the scour hole depend on m**a**ny factors, including the outflow discharge of the gates (Q_j), medium diameter of sediment (D_{50}) and the confluence angle of jets at the horizontal plane (θ), and the characteristics of the river bed, time, and geometry of the structure.

A review of the literature shows that the problem of scouring at the downstream of the structures has attracted the attention of many researchers. Many researchers experimentally examined the effect of parameters on the scour and empirically presented many relationships to estimate the maximum scour depth at the equilibrium condition. These relationships show very different results for the same conditions. Such contradictions in the case of scouring in the vicinity of hydraulic structures call for more research so as to increase knowledge and awareness for the proper design, and the reduction of the damage caused by scouring.

2- Experimental Program

The study of the scour phenomena is a complex problem in the sediment hydraulic engineering because it is affected by many parameters. For this reason, in this study the experimental study was conducted to determine the scour hole dimensions due to the falling jets at the downstream of the storage reservoir. The experiments were carried out at Hydraulic Laboratory of Shahrood University of Technology. The flume has the length of 2.43 m, width of 1 m, and height of 1.11 m. The effect of outflow discharge of gates (Q_j), medium diameter of sediment (D_{50}) and the confluence angle of jets at thw horizontal plane (θ) were investigated. The water jet falls from pipes with the circular section and diameter of 1.25 inch into the downstream pound. The drop height was 95 cm. The downstream pound is filled with non-cohesive sediments with the height of 20 cm and the medium diameter of 1.7, 3.2 and 6.75 mm. Experiments were carried out with different discharges, ranging from1.32 to 5.14 l/s.

Using dimensional analysis with *Buckingham* π theorem, the following equation is achieved to predict d_s/h_{tw}:

$$\frac{d_s}{h_j} = f(\frac{V_j}{\sqrt{g(G_s-1)D_{50}}}, \theta) \quad (1)$$

In Eq.1, d_s is the scour depth, h_j is the height of the jet falling, the θ is the confluence angle of jets at the horizontal plane, G_s is the ratio of sediment density to water density, D_{50} is the mean diameter of non-cohesive sediment. The minimum, maximum, mean, standard deviations and coefficients of variation of the parameters $\frac{d_s}{h_j}$ ،θ ،$F_g = \frac{V_j}{\sqrt{g(G_s-1)D_{50}}}$ are given in Table 1:

Table 1- The statistical metrics of the parameters in Eq.1

Parameter	Min	Mean	Max	Standard Deviation	coefficients of variation
θ(rad)	0.26	0.52	0.79	0.22	41.21
$\frac{V_j}{\sqrt{g(G_s-1)D_{50}}}$	4.98	18.75	38.66	9.65	51.46
$\frac{d_s}{h_j}$	0.80	1.74	2.85	0.53	30.53

3-Results and discussion

The results of this study show that a scour hole created at the downstream of the reservoir in all the experiments and with the increase of discharge, the scour depth (d_s) increased.

In addition, the jet discharge change (Q_j) has the same trend on the creation of the scour hole in all the grain sizes and angles of the jets. The results indicated that when the discharge (Q_j) increased from 1.32 to 5.4 l/s, for a constant sediment size and constant angle (D_{50} = 6.75 mm and θ = 15°), the depth of the scour hole (d_s), the longitudinal extension (L_s), the transverse length of scour hole, and the volume of the scour hole (V_s) increased by 74.58, 58.38, 27.27 and 95.62%, respectively. Additionally, the location of the maximum scours depth from the ends of the gates increased about 82.85 %. Moreover, an increase in the average diameter of sediment size (D_{50}) has a reverse effect on the dimension of the scour hole.

Likewise, with of the increase of the mean diameter of sediment (D_{50}) from 1.7 to 6.75 mm in a constant discharge and constant angle (Q_j = 5.14 l/s, θ = 15°), the maximum scour depth decreased by 27.27 % and its location moved toward the gates by 56.5%. Also, with the decrease of the transverse width of the scour hole, the volume of the scour hole and the height of the protuberance of the sediments at the downstream of the scour hole reduced by around 55.69 and 30.91%, respectively.

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Any increase in the confluence angle of jets at the horizontal plane (θ) has a great effect on the maximum scour depth and the scour hole volume. As, in a constant discharge and constant grain size (Q=5.14 l/s, D_{50}= 6.75 mm), with the increase of θ from 15 to 30 degrees and also from 30 to 45 degrees, the kinetic energy of the falling jet from the gates is depleted, and as a result the amount of d_s decreases by 13.66% and 26.47%, respectively. Also, the amount of scour hole volume in the angle of 15 degrees is 12.95 % higher than the angle of 30 degrees and 30 degrees 16.31% higher than the angle of 45 degrees. Fig. 1 shows the longitudinal profile of the scour change in different discharges for coarse sediment (6.75 mm). Also, in Fig. 2, the longitudinal profile of scour changes in different grades of sediments for discharge of 5.14 l/d is plotted. Fig. 3 indicates the effect of the confluence angle of jets on the scour.

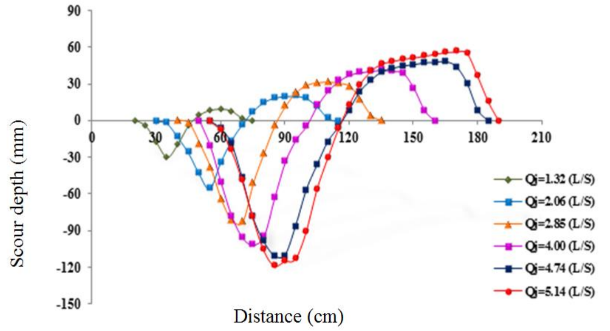


Fig. 1: The longitudinal profile of scour change in different discharges for coarse sediment (6.75 mm)

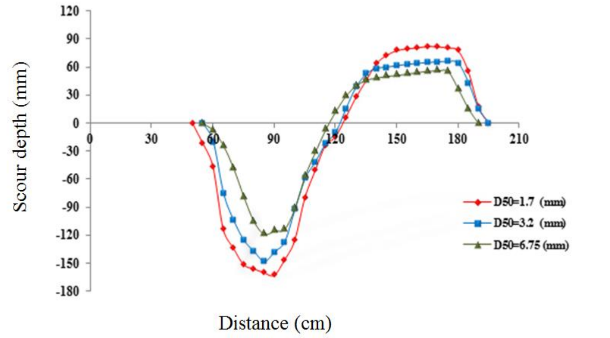


Fig 2. The longitudinal profile of scour changes in different grades of sediments for discharge of 5.14 l/d.

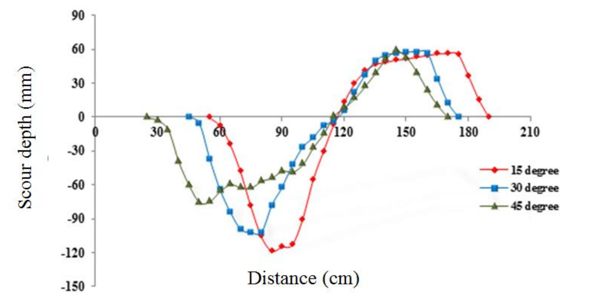


Fig. 3: The longitudinal profile of scour at different of the confluence angle of jets for discharge of Q= 5.14 l/s

Based on the experimental data and according to Eq.1, the following equation is achieved to predict d_s/h_{cw}:

$$\frac{d_s}{h_{tw}} = 2.325 + 0.028F_g - 0.037\theta \qquad (2)$$

Figure 4 shows the calculated d_s/h_{tw} versus the measured d_s/h_{tw} using Eq.2:

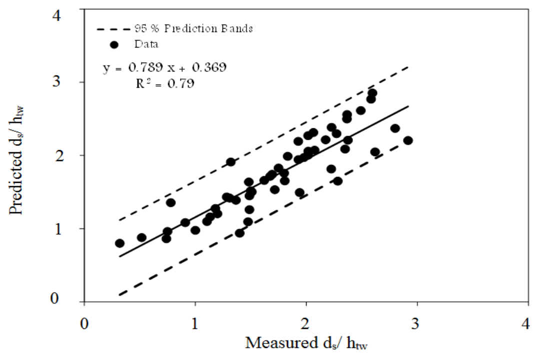
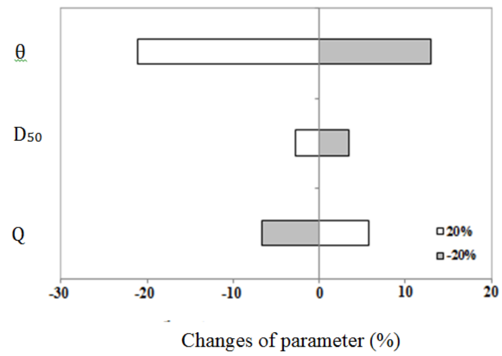


Fig 4. The calculated values of d_s / h_{tw} using equation (2) versus values of d_s / h_{tw} measured in experiments

Sensitivity analysis was done on the Eq. 2 to determine the importance of the parameters on the d_s /h_{tw}. For this purpose, ± 20% changes applied on the parameters of Q_j, D_{50} and θ. The results show that with a ± 20% change of the parameters Qj, D50 and θ, they have 12.33, 6.23, and 34.03 % effects on thed_s/h_{tw}, respectively.



4-Conclusion

The results of the present study on the maximum scour depth due to free-falling jets showed that the falling jets caused a scour hole at the downstream of storage reservoir and its dimensions were related to flow characteristics such as outflow discharge, sediment diameter as well as the confluence angle of jets at the horizontal plane. By impacting the jets from the outlet in the air, before reaching the river bed, the energy of the water flow can be depleted and as a result the scour depth decreased.