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Modeling of Scour Downstream of the Triangular Labyrinth Spillway Using Flow-3D Software

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Abstract

In this paper, the results of scour depth (Ds) and scour pit length (Ld) are compared with the experimental results conducted by Elnikhely and Fathy at 4 different discharges, 0.007, 0.008, 0.009, and 0.010 m³/s. The dimensionless parameters are the ratio of scour depth to the depth of the outfall (Yt), i.e., Ds/Yt, and the ratio of scour pit length to the depth of the outfall, i.e., Ld/Yt. It is observed that with increasing discharge, the maximum values of the dimensionless ratios Ds/Yt and Ld/Yt have a decreasing trend. This is because with increasing discharge, the depth of the outfall increases. This research showed that the numerical model has a good ability to simulate the sediment transport and scour process downstream of the triangular convoluted spillway. The numerical results are in good agreement with the experimental results, and the rate of change of the scour pit at the bottom of the spillway is close to zero. With increasing discharge, the maximum values of the depth and length of the scour pit have decreased. On average, the difference between the numerical and experimental results is less than 5%. It can be concluded that there is a good agreement between the results. Numerical simulation of physical phenomena allows for a more detailed study of the flow field, velocity vectors, and pressure contours, which is also discussed in this article.

Keywords

Local scour, Energy dissipation, Jump characteristics, flow-3D.

1. Introduction

Although the subject of scour has a long history in the field of hydraulics, it remains a focal point for researchers in hydraulics and river engineering due to its unique conditions and complexities, as well as the absence of a comprehensive relationship capable of accounting for all scenarios. Hydraulic structures acting as obstructions to water flow alter the flow pattern in their vicinity, inducing scour in these areas. The significance of investigating the scour phenomenon becomes particularly apparent when the scour depth reaches a magnitude that damages the foundations of river structures, threatens their stability, or even leads to their failure. Empirical relationships or physical models are typically employed to determine the depth of scour. Despite extensive research into estimating local scour around various hydraulic structures, no universal or comprehensive relationship has yet been established to calculate local scour depth for these structures. Furthermore, it should be noted that the theoretical and empirical foundations underlying different methods may vary; consequently, the local scour depth values calculated using diverse approaches may not be identical or even closely aligned [1]. Badaghi et al. (2023) experimentally investigated and evaluated the downstream scour of a Type A trapezoidal Piano Key Weir (PKW) under both free and submerged flow conditions. The experiments were conducted using a flume measuring 10 meters in length, 0.75 meters in width, and 0.8 meters in height. Experiments were conducted with flow rates ranging from 30 to 70 liters per second, particle Froude numbers between 0.029 and 0.058, and tailwater depths of 0.13 m for free-flow conditions, as well as 0.23 m and 0.29 m for submerged-flow conditions. The bed material downstream of the spillway consisted of uniformly graded sand with a mean particle diameter of 2.2 mm, a layer thickness of 0.425 m, and a length of 2 m. The results indicated that, compared to submerged-flow conditions, bed changes occur more rapidly under free-flow conditions, resulting in greater depth and length of the scour hole. With a 77% increase in tailwater depth, the relative scour depth decreases by 42%, 45%, 21%, 28%, and 27% for particle Froude numbers of 0.029, 0.037, 0.045, 0.052, and 0.058, respectively; with a 123% increase in tailwater depth, these reductions are 95%, 92%, 90%, 75%, and 68%, respectively. Furthermore, an 18% increase in the submergence ratio at a particle Froude number of 0.029 and a 96% increase in the submergence ratio at a particle Froude number of 0.058 result in a decrease in the maximum relative scour depth by 92% and 56%, respectively. For tailwater depths of 0.13, 0.23, and 0.29 m, the location of the maximum scour depth occurred at distances of 0.18–0.30 m, 0.18–0.36 m, and 0.03–0.30 m from the toe

of the spillway, respectively. As the particle Froude number increased, the relative length of the scour hole also increased [2].

2. Methodology

The erosion model in FLOW-3D software simulates the transport, erosion, and deposition, as well as the state change of sediment settlement caused by fluid flow. This model is definable for all materials with specific physical characteristics. It utilizes two fields: suspended sediment concentration and bed load. The movement and lifting of suspended sediments by the fluid are driven by local pressure gradient changes. These suspended sediments can originate from the inflow containing suspended particles or from bed erosion. Bed sediments are constrained by adjacent particles and thus are not easily displaced. They only move if they transform into suspended load through erosion at the bed-fluid interface. Suspended load converts to bed load when the settling velocity exceeds the bed erosion rate [3]. Considering the simulation of scour downstream of the spillway, in the present study, as well as in the results of investigations by other researchers on scour and sediment transport, it was determined that the k-ε (RNG) turbulence model provides more accurate results compared to laboratory data. Furthermore, this model simulates the scour phenomenon in less time compared to the LES turbulence model. Therefore, the k-ε (RNG) turbulence model was employed to solve for turbulence in the modeling of flow and scour downstream of the spillway.

3. Discussion and Results

The triangular labyrinth weir model used in the present study was selected from the experimental studies of Elnikhely and Fathy (2020) (Figure 1). The experiments were conducted in a flume 15.70 m long, 0.30 m wide, and 0.58 m high. The labyrinth weir with an apex angle of 60° was placed on a trapezoidal weir having a crest length (b) of 0.134 m, a height (H1) of 0.30 m, a side slope of 1:1 (horizontal to vertical), and a width equal to the flume width (B). Downstream of the labyrinth weir and following a simple stilling basin of length (Lb) of 1.20 m, a sediment recess was filled with sandy sediment particles having a median diameter of d50 = 0.75 mm, a thickness of 0.05 m, a length of 1 m, and a specific gravity of 2.65. Figure (2) illustrates the variations of Ds/Yt and Ld/Yt against discharge (Q) obtained from numerical and experimental results. As shown in this chart, the numerical results are in close agreement with the experimental data, indicating that the software is capable of simulating sediment transport and downstream scour processes caused by the triangular labyrinth weir.

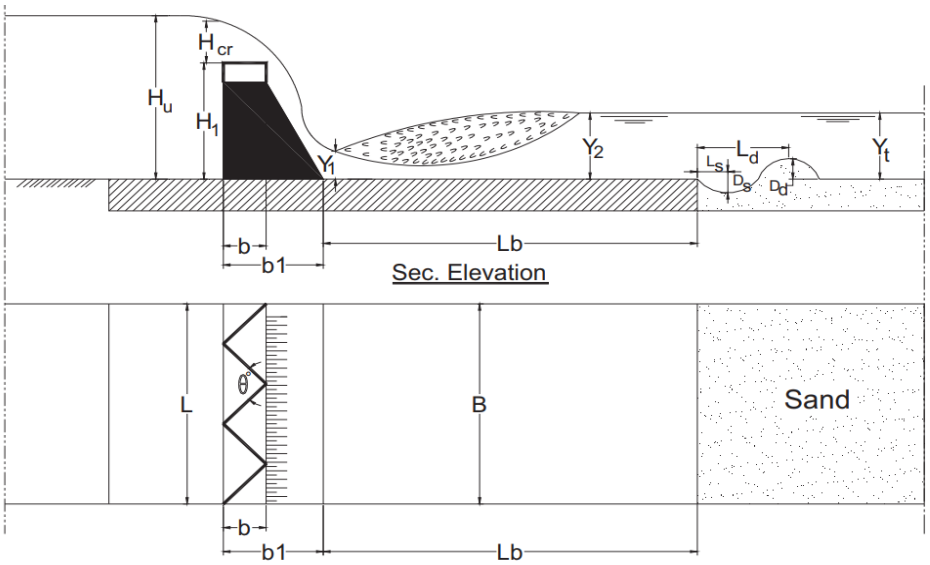


Figure 1- Laboratory channel and dam specifications in experiments Elnikhely and Fathy (2020)[4]

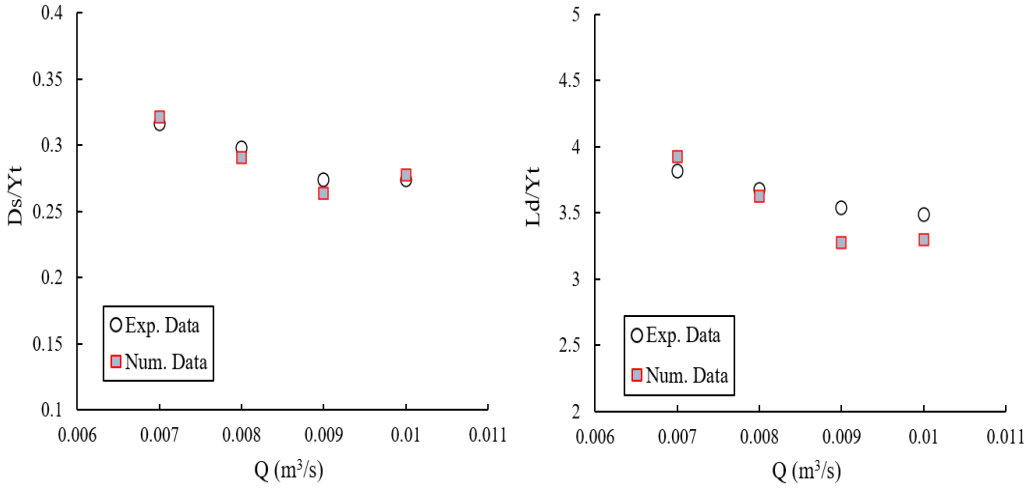


Figure 2 - Comparison of numerical and experimental

4. Conclusions

In this study, the experimental model conducted by Elnikhely and Fathy (2020) [4] was numerically modeled under various conditions with four discharges of 0.007, 0.008, 0.009, and 0.010 m3/s. For better comparison, the dimensionless parameters of the ratio of scour depth to tailwater depth (Yt), namely Ds/Yt and the ratio of scour hole length to tailwater depth, namely Ld/Yt were utilized. Furthermore, during this time interval, the rate of change of the scour hole downstream of the weir was approximately close to zero. Figure (2) illustrates the variations of Ds/Yt and Ld/Yt versus discharge (Q) obtained from both numerical and experimental results. As evident from the diagrams and figures, the numerical results are nearly identical to the experimental data, indicating that the software is capable of simulating sediment transport and downstream scour processes caused by the triangular labyrinth weir. The variations in the maximum depth and length of the scour hole in the numerical and experimental results demonstrate that with an increase in discharge, the maximum values of the dimensionless ratios Ds/Yt and Ld/Yt follow a descending trend. This is because an increase in discharge leads to an increase in the tailwater depth, thereby decreasing the values of Ds/Yt and Ld/Yt.

5. References

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