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Modeling Scour Downstream of a Levee Using Flow-3D

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Abstract

In this paper, the results of numerical modeling of water flow over a dam and the depth and length of the downstream scour hole are compared with the experimental results of Muhammad Abbas and Tanaka under different hydraulic conditions including two critical depths on the spillway crest (D_c) equal to 0.03 and 0.04 m and two downstream depths (D_p) of 0.07 and 0.09 m. For this purpose, the dimensionless parameters of the flow depths on the crest and downstream, namely $D_c^*=D_c/HE$ and $D_p^*=D_p/HE$, have been used. Also, the dimensionless parameters $Sd^*=Sd/HT$ and $L_s^*=Ls/HT$ have been used for the scour depth and scour hole length. With increasing the dimensionless downstream depth (D_p*), it was observed that with increasing D_c^* and correspondingly the critical flow depth on the spillway crest, the maximum depth and length of the scour hole increase, but with increasing the dimensionless critical depth D_c^*, these values decrease. On average, the difference between the numerical and experimental results is less than 3/75%. 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; Levee; Numerical model; Flow-3D.

1. Introduction

Scour is a phenomenon that occurs due to the interaction between flow conditions and the movement of materials in erodible beds. Bed materials can be non-cohesive, such as gravel and sand. Generally, the rate of scour varies in different materials. Loose granular materials are eroded faster by water flow, whereas cohesive materials exhibit greater resistance to erosion. However, the ultimate scour depth in cohesive materials can be greater than scour in sandy beds (Melville et al.). Under steady flow conditions, the time to reach maximum scour depth is proportional to hours in sandy beds, proportional to days in cohesive materials, and proportional to the material itself in rocky and gravelly beds (Melville et al.). The particle size of the bed and its gradation also influence the extent of scour. The dimensions of the scour hole decrease with an increase in bed particle size. The more uniform the particle gradation, the larger the scour dimensions will be. In sediments with non-uniform gradation, the scour depth is typically less than that in uniform materials [1].
Sá Machado et al (2020) investigated the impact of the projectile ski jump angle on the scour hole downstream of a convergent stepped spillway. The influence of various parameters, including flow rate, tailwater depth, and projectile ski jump angle, on the main scour dimensions was examined under different flow conditions. Longitudinal scour profiles were measured for each experiment, and the results were compared with empirical predictions from previous researchers. The findings indicated a slight discrepancy between the current study's results and those of previous researchers, approximately 12%. Analysis of the projectile angle's effect, specifically for α=20° and α=25°, led to the conclusion that for a 25° angle, the maximum scour depth occurred near the projectile. This observation may be explained by energy dissipation along the jet's path, which reduces its energy at the point of impact [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, 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

Figure (1) illustrates the weir model employed in the present study, which was selected based on the experimental investigations conducted by Muhammad Abbas and Tanaka (2022). Figure (2) presents a comparison between the numerically simulated scour hole profiles downstream of the weir and the corresponding experimental results under various hydraulic conditions. These hydraulic conditions differ in terms of the flow depth over the weir crest and the tailwater depth. It is observed that the trend of scour hole development for all four hydraulic conditions is in good agreement with the experimental data. Specifically, the plunging jet from the weir creates a scour hole, followed by the accumulation of sediment deposits further downstream. For a constant dimensionless tailwater depth (D_p^*)، an increase in the dimensionless critical flow depth (D_c^*) over the weir crest leads to an increase in both the maximum depth and length of the scour hole. Conversely, for a constant D_c^* an increase in (D_p^*)، results in a reduction of the maximum scour depth and length. Figure (3) displays the variations of Sd^* and L_s^* against D_c^* for different tailwater depths, comparing numerical and experimental findings. This plot further confirms that the numerical results closely align with the experimental data, demonstrating the capability of the software in simulating sediment transport processes and downstream scouring. The aforementioned observations regarding the changes in maximum scour depth and length are consistent with the variations in D_c^* and D_p^* observed in this figure.

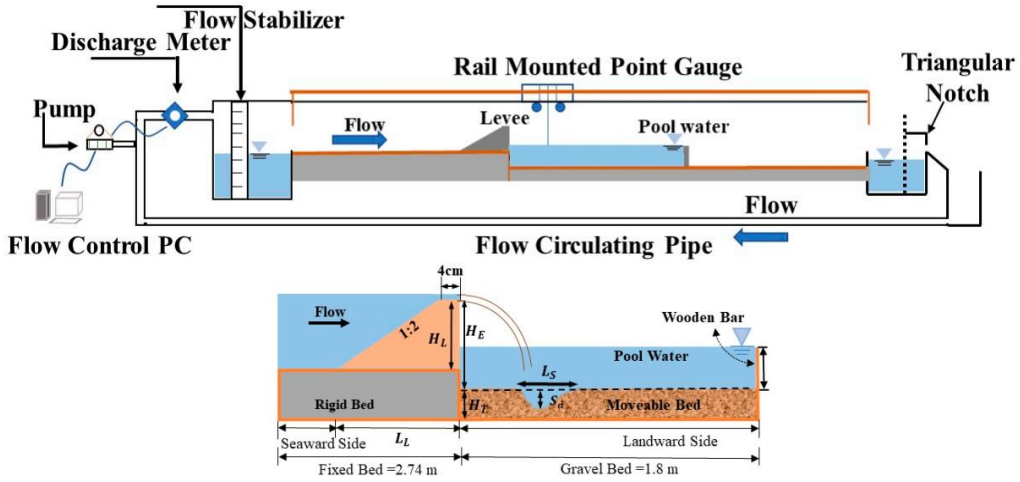


Figure 1. Laboratory channel and dam specifications in experiments Muhammad Abbas and Tanaka (2022)[4]

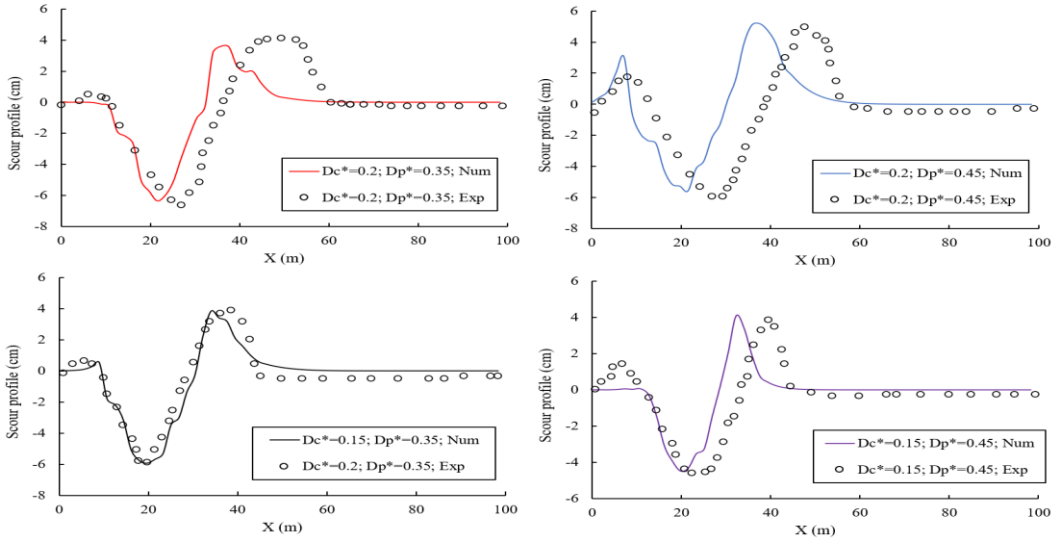


Figure 2 . Comparison of scour pit profile at the bottom of the bracelet, results from the software with laboratory results

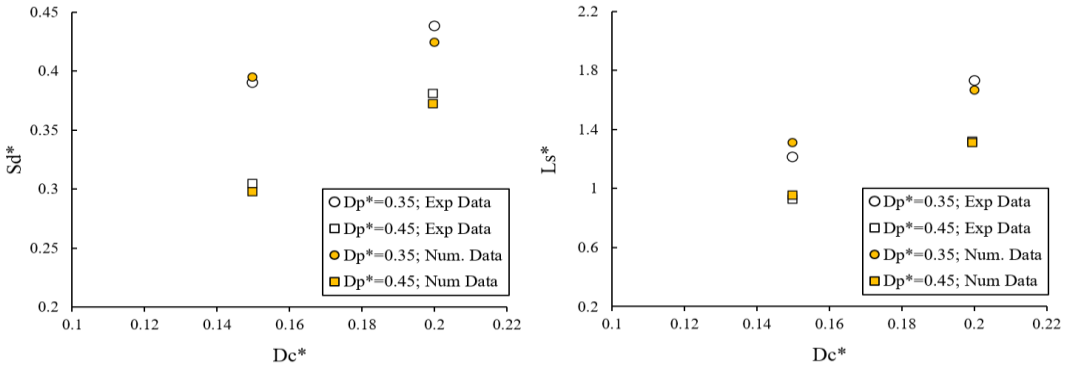


Figure 3. Comparison of numerical and experimental results for changes in Sd* and Ls* versus Dc*

4. Conclusions

In this study, the laboratory model conducted by Muhammad Abbas and Tanaka (2022) under different hydraulic conditions including two critical depths on the spillway crest (Dc) equal to 0.03 and 0.04 m and two bottom depths (Dp) equal to 0.07 and 0.09 m has been numerically modeled. The results related to scour depth (Sd) and scour pit length (Ls) have been compared with the results obtained from the laboratory work. For a better study, the dimensionless parameters of the flow depths on the crest and bottom, namely Dc*=Dc/HE and Dp*=Dp/HE, have been used. Also, the dimensionless parameters Sd*=Sd/HT and Ls*=Ls/HT have been used for scour depth and scour pit length, and it is observed that the scour pit change trend for four different hydraulic conditions is almost the same as the laboratory results Figure (2). As a result of the jet flow passing through the dam, a scour pit is created and some sediments accumulate downstream of the pit. For a dimensionless downstream depth (Dp*), with an increase in Dc* and the corresponding critical flow depth on the spillway crest, the maximum depth and length of the scour pit increase. Also, for a dimensionless critical depth (Dc*), with an increase in Dp*, the maximum depth and length of the scour pit decrease. Figure (3) shows the changes in Sd* and Ls* versus Dc* for different downstream depths obtained from numerical and experimental results. It is also clear from this graph that the numerical results are close to the experimental results. As mentioned in the explanation above, the changes in the maximum depth and length of the scour pit are in good agreement with the changes in Dc* and Dp.*

5. References

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