Numerical investigation of scour downstream of piano key Weirs using Flow-3D software

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ABSTRACT

In this research, the numerical simulation of the scouring of the downstream bed of two types of trapezoidal and triangular piano key series in the same geometric and hydraulic conditions has been done using the Flow-3D numerical model. To carry out the calibration process of the desired numerical model, the laboratory study of Ghodsian et al. (2021) was used in the conditions of sediment transfer. After the software calibration, the accuracy of the R^2 criterion for the longitudinal profile of scour and the maximum depth of scour downstream of the weir was equal to 0.9338 and 0.873, respectively. Eighteen numerical simulations for scour downstream of two types of trapezoidal and triangular piano key weirs were carried out under the conditions of changes in discharge and depth of abutment, and the local changes of scour in a trapezoidal piano key weir at a depth of 0.05, 0.075 and 0.1 meters and all three The flow rate of 25, 35 and 45 liters second was observed less than the weir of the triangular piano key. By doubling the depth of the weir in the trapezoidal weir up to 29% and in the triangular weir up to 26.6%, the scour depth decreases. Also, with a 44% decrease in discharge at a constant depth of aquifer, a 40% and 37.4% decrease in the maximum scour hole depth was observed in the trapezoidal and triangular weir, respectively. The increase in the depth of the floodplain causes the loss of energy of the falling jets from the weir, and by reducing the capacity of the bed sediments carried by the water flow, it causes a decrease in the maximum scour depth downstream of the desired weirs. It was observed that with the increase of the flow through both types of trapezoidal and triangular piano key weirs in the condition of constant depth of the abutment, the scour rate in the sedimentary bed for both types of weirs approaches.

KEYWORDS

Triangular piano key weir, Trapezoidal piano key weir, scour hole, Numerical simulation, Validation of Flow-3D software.

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Introduction

For the passage of excess water and floods from the upstream to the downstream of dams, weirs are of high importance, which form one of the important structures of any dam. Weirs should be both in terms of strong devices and in terms of design in such a way that they have the ability to transfer water to the required amount [1]. One of the types of weirs are piano key weirs, these types of weirs are a new form of long crest non-linear weirs [2]. In addition to the greater water-passing capacity that piano key weirs have compared to simple weirs, they are also economical [3]. Other advantages of piano key weirs include: increase in flow rate per unit of width passing through the weirs up to 100 cubic meters per second per meter, at least 4 times increase in flow rate compared to linear weirs and lower maintenance cost [4]. These features make piano key weirs efficient structures. This type of weirs is mainly used with the purpose of increasing the water-passing capacity of existing structures and also as a control structure in newly built weirs [5]. In dams, due to the relatively high hydrostatic pressure exerted by the water in the reservoir on this structure, it is necessary to control the stability of the structure in addition to controlling the hydraulic conditions. Local erosion is one of the important issues in river engineering and flow hydraulics in alluvial beds. If in a studied period, the amount of sediment entered is less than the amount of sediment left, the erosion of the river bed occurs and the river bed is gradually hollowed out. Among the effects of river bed hollowing in the downstream, we can mention the disruption of the hydraulic jump in the upstream and the transfer of the hydraulic jump to the downstream. With the increase of the hydraulic gradient, which ultimately leads to the increase of the lifting pressure and the phenomenon of seepage, the scouring risks in the structure are increased. Therefore, scouring phenomenon in structures is very important and it is necessary to predict it before building the structure [2]. The very high costs of building energy-consuming structures such as absorption ponds, relaxation ponds, etc., have caused an increase in scour investigations in the river bed and its greater protection.

Methodology

In this research, the experiments of Ghodsian et al. (2021) have been used to calibrate the numerical model, the experiments were carried out in a flume with a length of 10 meters and a width of 0.75 meters with a height of 0.8 meters. In order to determine the scour rate of the downstream bed of the piano key weir, uniform sand with an average diameter of d50=1.64mm and a standard deviation of σg=1.24 was used. The length of the downstream erodible bed is 200 cm, and the width and depth of the sediment layer are 75 and 42.5 cm, respectively. The weir used for validation in the present study was selected from the trapezoidal type weir in the experiment of Ghodisian et al [6]. Due to the nature of the current research, which is related to the depth and longitudinal profile of the scour pit, in the numerical simulations, half of the length of the erodible bed, i.e. the first 100 cm of the erodible bed, was examined and the rest of the length of the sedimentary bed was omitted in the modeling. Because the purpose of this research is only to numerically investigate the scour downstream of the piano key weir and considering that in the laboratory study of Ghodsian et al. The last 1 m of sediment bed for the numerical simulation does not make a difference in the scour pit results and only causes a huge increase in the simulation time. In the numerical studies carried out to validate the software used (Flow-3D), due to time and hardware limitations, only 20 minutes of the scouring process of the study of Ghodsian et al. The time has happened, so the numerical modeling done was compared with the first 20 minutes of the laboratory results.

Results and Discussion

The values related to the maximum scour depth per minute until the end of the simulation and the scour longitudinal profile for each of the modeling performed in Tecplot software were called and compared in the form of graphs with similar laboratory results. Also, the measures of root mean square error RMSE, mean absolute value of error MAE and coefficient of determination R^2 were obtained for each of the performed simulations and compared to select the optimal mesh and suitable disturbance model. The most appropriate measures of root mean square error RMSE, mean absolute magnitude of error MAE and coefficient of determination R^2 obtained in software calibration were obtained in table (1) for medium mesh size meshing and K-Ɛ turbulence model.

Table 1. The measures of root mean square error RMSE, mean absolute value of error MAE and determination coefficient R^2 extracted for the selected numerical model

Parameter	dsm	Profile of Scour
RMSE	3.77	0.2056
MAE	3.15	0.168
R^2	0.8731	0.9338

To investigate and compare the scour downstream of the triangular and trapezoidal piano key weirs with Flow-3D software, among the selected characteristics are the type of grid, the size of the meshes in the modeling and the turbulence model, which gives the closest results to the desired laboratory study (results mentioned in table 1) provided to us was used. According to the obtained results, the largest local decrease in the bed level in all three flow rates of 25, 35 and 45 liters per second and the depths of 0.05, 0.075 and 0.1 meters occurred in the downstream of the triangular piano key weir. According to the results obtained from the numerical modeling of scour downstream of piano key weirs, the local changes of the downstream bed level in the trapezoidal piano key weir for all modeled hydraulic conditions are lower than the triangular piano key weir and it varies between 12% and 25%.

By examining the longitudinal profile of the scour downstream of the trapezoidal piano key weir, it was found that at a flow rate of 45 liters per second, the increase in the depth of the weir does not cause a noticeable change in the distance of the maximum depth of the scour hole from the base of the weir, and it only affects the dimensions of the scour hole. This is despite the fact that at a flow rate of 25 liters per second and a water depth of 0.05 meters, the difference between the maximum scour depth and the maximum bed depth at the edge of the weir base is less than 0.003 meters, and it can be said that the maximum scour depth has occurred at the edge of the weir base. Is.

In the investigation of the longitudinal profile of the scour downstream of the weir, a triangular piano key was observed, respectively, at constant depths of 0.05, 0.075 and 0.1 meters with a 40% increase in the flow rate, changes in the maximum depth of the scour hole to the base of the weir in all three depths. The catchment is 5% and with an increase of 80%, the flow through the weir is 5%, 5% and 10%, respectively. Therefore, the two parameters of discharge and depth of the weir have a direct relationship with the distance of the maximum depth of the scour hole from the base of the weir.

Conclusion

In general, it can be said that if the sediment characteristics are constant, such as the average diameter of the sediment particles, the geometric standard deviation of the particles, and the density of the sediments, among the factors influencing the transfer of sediments downstream of the trapezoidal and triangular piano key weirs, according to the results obtained from the numerical simulation, the depth of the reservoir and The flow is the passage of the weir. In this way, the increase in the depth of the aquifer in the condition of a constant flow rate causes more energy loss of the falling jets from the weir keys of the piano key, and with the reduction of the impact force on the sedimentary bed, the dimensions of scouring are reduced. This reduction in the dimensions of the scour hole with the increase in the depth of the abutment includes a decrease in the length of the scour hole, a decrease in the maximum depth of the scour hole, a decrease in the depth of the scour hole at the foot of the weir, and a decrease in the maximum distance of the depth of the scour hole from the base of the weir. According to the variability graphs of scour hole characteristics in exchange for changes in the depth of aquifer, it can be concluded that approximately with the increase of the depth of aquifer, the characteristics of the scour hole changes with a constant trend as a numerical progression. Also, flow rate changes change the geometric dimensions of the scour hole; However, unlike the weir depth, the increase in flow through the weir in both trapezoidal and triangular piano key weirs causes an increase in the depth of the scour hole and an increase in the length of the scour hole, an increase in the maximum depth of the scour hole, an increase in the scour depth at the weir foot and an increase in the maximum distance. The depth of the scour hole is from the base of the desired weirs. In general, all the dimensions of the scour hole are similar to the flow passing through the weir and the depth of the weir for the triangular piano key weir, except for the length of the scour hole and the maximum distance of the scour hole depth from the base of the weir, it is greater than the trapezoidal piano key weir.

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