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Numerical Simulation of the over and through flow Discharge in Broad-Crested Gabion Weirs with side Slopes

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ABSTRACT: During the recent years, Gabion weirs have been taken into consideration due to their compatibility with the environment, positive effect on river's water quality and their simple design and implementation. In this research, the hydraulic parameters of flow around broad crested gabion weirs (BCGW) with various side slopes are investigated. Overall, a number of 21 models comprising 7 various geometries each with 3 different porosities including (43%, 44%, 46%) and in different discharges were simulated and studied. Results indicated that the discharge coefficient (Cd), through flow discharge and energy dissipation increased by increasing the average diameter of particles. In addition, Increasing the area of the porous media by changing side angles from 0° to 60° reduces the discharge coefficient and through flow discharge. At final stage, experimental equations are presented using Nonlinear Multivariable regression analysis in order to calculate the discharge coefficient and through flow discharge of these structures.

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1- Introduction

Weirs are of structures that can be used in order to increase water level or flow measurement. Generally, weirs are constructed of a concrete rigid body but today, the stone made porous structures such as gabions are preferred. Physical and chemical materials such as sediments can pass downstream through the porous body of these structures. It will result in a minimum amount of sedimentation as well as water accumulation behind the weir's body. According to these effects, it could be inferred that gabion weirs are structures with least negative impact on the natural life of the surrounding environment and the quality of river's water flow [1]. Sargison and Percy (2009) studied the effect of upstream and downstream slopes of broad-crested weirs and inferred that increasing the upstream slope may decrease the discharge coefficient [2]. Azimi et al. (2013) studied the hydraulic performance of broad-crested solid weirs with different side ramps. Their results revealed that the discharge coefficient (C_d) for weirs with both side ramps is higher than that for weirs with solely one side ramp [3].

The environment friendly nature of porous gabion structures and the increasing use of them during the recent years show the importance of complete and thorough investigations of such structures. Analyzing the flow through a porous weir requires the hydrodynamics of both flow inside of a coarse-grained porous media and the rapidly varied free-surface flow above the weir. By performing a One-Dimensional non-uniform steady flow analysis, Michioku (2005) inferred that the discharge through porous weirs is a function of geometrical parameters as well as the upstream water head [4]. Mohammadpour et al. (2013) utilized Fluent software along with three variants of the K-ε turbulence models to simulate the flow around a broad-crested gabion weir. The results showed that the standard k-ε model more accurately predicts the flow behavior [5].

The literature review shows that no comprehensive study of the flow behavior around gabion weirs is performed yet. So, the objective of this research is to investigate the hydraulic performance and the ratio of through to total flow discharge for broad crested gabion weirs numerically. The Effect of geometrical parameters and porosity on the discharge coefficient and through flow discharge and flow behavior around the weirs were investigated in detail. Regression analysis was performed to provide functional relations to estimate discharge coefficient and through flow discharge finally.

2- Governing Equations

The Flow-3D software as a commercial 3D CFD code was utilized to solve the flow field around the porous weirs and laboratory flume. Governing equations include continuity and momentum. The Forchheimer saturated drag model was used to simulate the effect of porosity on the flow around weir. This model combines the Darcian and non-Drcian flow losses to describe the drag forces applied to flow from the porous media as follows [6]:

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$$F_d = -\frac{1}{\rho u_{microscopic}} \nabla p = \frac{\mu}{\rho} \frac{1-\phi}{\phi} [A \frac{1-\phi}{\phi} + B \frac{\mathrm{Re}_p}{d_{pore}}] \quad (1)$$

Where A and B are media-specific loss coefficients and could be elicited form experimental data, □ is the porosity, μ is dynamic viscosity of flow and ρ is the fluid density.

3- Mesh domain and Boundary Layer

A structured non-uniform mesh domain was used to simulate the canal and the flow field around the weir. The quality of mesh was improved as it gets closer to the weir. Also, the maximum intensity of mesh is located above the weir in order to provide an accurate estimation of the rapidly varied flow surface above the weir. The size for boundary layer mesh was determined using the (Y+) index. It is proposed that the value for Y+ must remain between 11.25 and 30 [5]. Thus, the preferred height for the boundary layer cell was determined equal to 5 mm.

4- Model Simulation and Validation

The numerical model was validated and calibrated using the laboratory results of [7] performed in the hydraulic laboratory of Shahid Chamran University of Ahvaz. The laboratory flume with 0.3 m width, 0.5 m height, and 10 m length was modeled in the software along with the broad-crested gabion weirs with various geometrical shapes in different discharges from 3 to 30 L/s. Three different aggregations were investigated as described in Table 1

Table 1: Aggregation and porosity of simulated weirs

Average diameter d50(cm)	Porosity
3.13	43%
2.2	44%
1.75	46%

Turbulence simulations were performed using three turbulence models of K-ε standard, RNG, and K-ω. The K-K-ε standard turbulence model was opted as the optimum model based on more accurate results and less convergence time compared to other models. Figure 1 shows the validation of results provided by different turbulence models for water surface profile of weirs with 46% porosity.

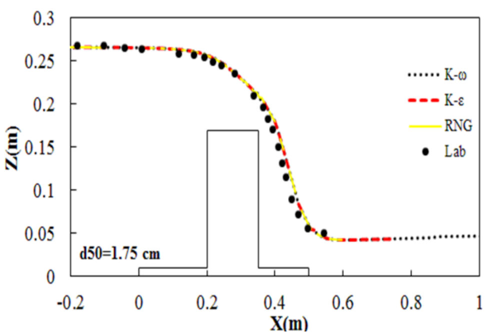

Figure 1: Numerical model validation for water surface profile

5- Results and Discussion

The discharge coefficient (C_d) for rectangular porous weirs were calculated numerically and compared to that of laboratory test in Figure 2. Results show adequate concordance between numerical and lab results. It could be inferred that increasing the size of filling materials may result in the increase of C_d. The discharge coefficient for weirs with side slopes of 60 and 45 were calculated. Results for C_d of weirs with solely downstream slope of 60 and 45 are compared to each other in Figure 3. It could be inferred that increasing the angle of side slope decreases the discharge coefficient. Values of the ratio of the through flow discharge to total flow discharge for all weirs were elicited from the software. Figure 4 shows a comparison between the weirs with both upstream and downstream side slopes. It is indicated that increasing the materials size increases the through flow discharge. Also increasing the angle of side slopes reduces the through flow discharge.

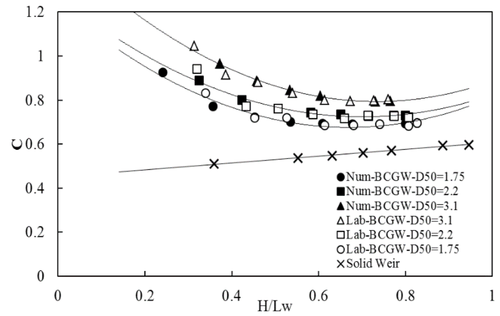

Figure 2: Numerical C_d vs. laboratory C_d

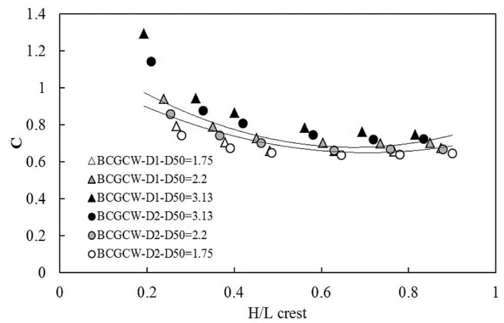

Figure 3: C_d for weirs with different downstream slope

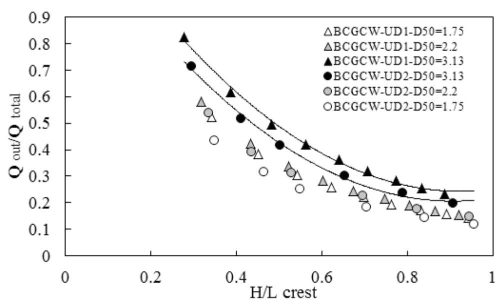

Figure 4: Through flow discharge for weirs with both upstream and downstream side slopes

6- Conclusions

Results indicated that increasing the size of filling materials may result in the increase of the Cd and the through flow discharge. Also, increasing the angle of side slopes decreases the Cd as well as through flow discharge and increases the upstream water head.

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