Numerical Simulation of Flow Over Rectangular Broad Crested Weir (Real case study)

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Abstract

In this article FLOW3D Computational model have been used to calculate water flow profile over a rectangular broaded crest weir and in Gharnave check dam in north east of Iran moreover its designed USBR stilling basin capability to damp energy is investigated and finally two different modifications in its stilling basin is proposed and analyzed. Numerical output shows that this commercial software can predict flow profile and hydraulic jump in this hydraulic structure in general.

Keyword: *hydraulic structure, Numerical modeling, FLOW3D software, broad crested weir, hydraulic jump*

1. Introduction

Broad crested weirs are defined as structures where the streamline run parallel to each other over the weir crown, and the crest of the weir is horizontal [1]. In most layouts of broad crested weirs also the hydrostatic pressure is fully accomplished in the middle of crest .However in cases where the weir length is too small it might be that the hydrostatic pressure is not fully accomplished [2]. The broad crested weir is in addition to irrigation systems used for highways, railroad and for hydropower structure. Also an application as a simple discharge measurement structure is possible. An important feature of broaded crested weir is the up and downstream side slope angle, which ay vary between a vertical end (standard embankment weir).Sloping embankment have a higher discharge capacity compared to a traditionally broad crested weir with vertical faces [3]. The discharge characteristics for vertical face weirs with square edge or rounded entrance are extensive analyzed by Azimi and Rajaratnam (2009) [4]. First investigations on discharge capacity of broad crested weir were made by Bazin in 1898 [5]. An extensive series of experiment were conducted by Hager and Schwalt (1994) for evaluating the flow feature over a broad crested weir [6]. Earlier work involving flow modeling over a rectangular broad crested weir has been conducted by Sarker and Rhodes (2004) [7]. who investigated a weir experimentally as well as numerically (the used code Fluent V.4.4.7).Good agreement was found in the above mentioned case for the upstream water level (stated as excellent), whereas all other numerical results, like rapidly varied flow profile over the crest, differ slightly from the results of the physical model study. Hargreaves et al (2007) used the volume of fluid method (Fluent V6.2) to compute the discharge also over a vertical faced broad crested weir [8]. In this work the up and downstream water depths in the model were fixed. This paper shows the application of numerical models as a possibility to support designer, by using a simple test study. Unforeseen conditions during construction, like foundation problems or unexpected properties of the construction material do not include in this investigation. In the current paper, the commercial program FLOW3D V9.3 is used to obtain flow field and pressure distribution over a broad crested weir and stilling basin.

2. Numerical Modeling

A brief introduction of the basic theory for numerical models is given below, including grid types and the calculation of the free water surface.

2.2 Computation of Free Water Surface

The free water surface represents a particular challenge in 2D vertical and also in 3D numerical models. FLOW3D uses the volume of fluid method (VOF) by Hirth and Nicolas (1981) [9]. This is a two phase approach where both the water and the air are modeled in the grid. The method is based on the concept that each cell has a fraction of water (F), which is 1 when the element is totally filled with water and 0 when the element is filled by air. If the value is between 1 and 0, the element contains the free water surface. Therefore an additional transport equation is added (Equation 1)

$$\frac{dF}{dt} + u\frac{dF}{dx} + v\frac{dF}{dy} = 0 \qquad (1)$$

Where u and v are fluid velocity component in the x and y coordinate direction. The local height of the water surface the surface slope and the curvature are calculated for the local column and its neighbors. (Figure 1) . The VOF method requires a fixed grid in FLOW3D.

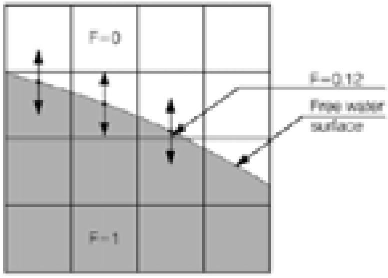

Figure 1 Assessment of the surface according to the VOF method. The arrows show the potential movement of the water surface [10]

Highest grid cell always represents the free water surface. All the cells are thus always completely filled with water. The number of grid cells in the vertical direction depends on the water depth and the initial setting. The verticals movement of the water surface is obtained from the average of the following two methods

1. The first approach is based on the water continuity in the cell closet to the water surface. The continuity defect over a time step divided by the cell area projected in the horizontal plane gives the vertical water surface movement in the same time step

2. The second approach is based on a Marker- and Cell inspired approach.The water surface movement is assumed to follow an imaginary particle in the cell close to the water surface. The average velocity in the surface cell is the same as the particle velocity. Multiplying the vertical water velocity with the time step gives the water surface elevation movement in the time step

The effective vertical water surface movement,ΔZ is thereby given by equation 2

$$\Delta Z = \frac{1}{2}\left(\frac{\Delta V}{A_2} + \frac{\sum_{n-1}^{2} U_n A_n}{A_2}\right)\Delta t \qquad (2)$$

Where $U_n$the velocity in the surface is cell, with component in n direction and A_n is the area component on the top of the surface cell. The horizontal direction is 1, while 2 is the vertical direction.Δt Is the time step and ΔV is the volume flux deficit in the surface cell.

2.3 Grid Type

FLOW3D uses a structured and orthogonal grid with rectangular (2D) and hexahedral cells (3D). The non adaptive cell grid is fixed and does not move during the calculation. The border between the geometry and the water is defined by the Fractional Area Volume Obstacle Representation (FAVOR) method. Figure 2 shows a longitudinal profile of the grid used in FLOW3D.

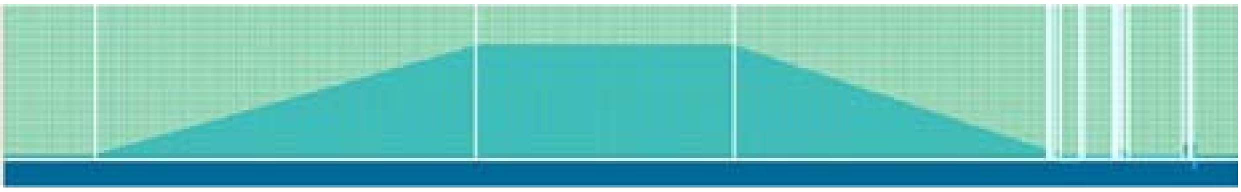

Figure 2 Sketch of the orthogonal, structure and non adaptive grid

2.4 Grid Generation

The weir setup in FLOW3D was performed by inserting an STL (stereolithography) file. In STL files solid object surface are approximated by triangles. Most CAD programs are able to convert solid models into an STL format. To save computation time, an initial water body in front of the weir was inserted. The cell size is set to 14 cm in the all direction.

2.5 Time Step

A courant type stability criterion is used in FLOW3D to calculate the maximum allowed time step size. The courant Number tells how fast the fluid passes through a cell. If the courant Number is greater than 1, the velocity of a particle is so high that it passes through a cell in less than one time step. This lead to numerical instabilities. The stability criteria in FLOW3D lead to time steps between 0.4 and 0.004 seconds.

2.6 Boundary Condition

A constant volume flow rate is used as inflow boundary in FLOW3D. In FLOW3D the grid covers the whole flume, so the inflow would be distributed over the whole flume depth. That is not correct, so the area of the inlet above the expected water surface was blocked out to specify the inflow height. Otherwise the inflow would produce waves in the upstream part of the weir which would influence the result. The outflow condition was chosen as outlet boundary condition.

2.7 Convergence Criteria

The solution in FLOW3D converges if the viscous and pressure iterations have converged. The convergence criteria are the same for the pressure iteration as for the explicit viscous algorithm. They are set automatically during the calculation and may vary between time steps.

3. Designed Weir

the designed weir with a width (b) of 6 m a height (h) of 6 m and total length (l) of 98 m and a slope angle of 0 degree. The designed weir has A (1:3.5) is the upstream and B (1:3) in the downstream slope. Figure (3) shows the designed and simulated structure. As this figure show the structure support with USBR IV stilling basin type for energy damping in its chute downstream.

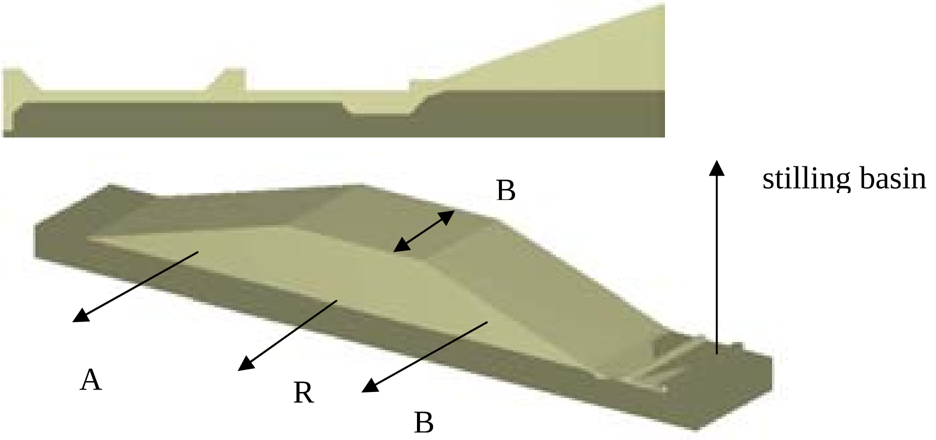

Figure 3 Longitudinal cross section of the investigated broad crested weir. The water flow is from left to

4. Result

Results of the calculated water surface elevation for given condition shows in the figure 4. As this figure shows the predicted water profile at spillway and stilling basin agree with the general water profile in this kind of structure.

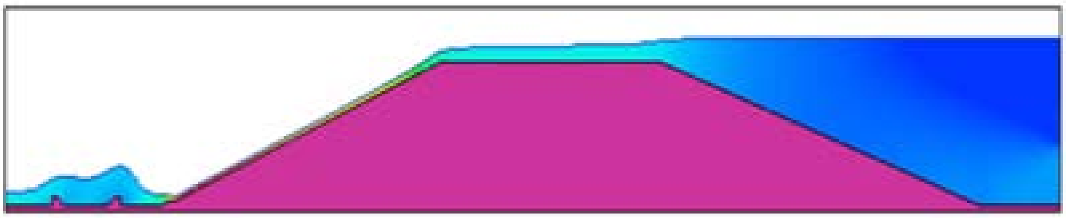

Figure 4 water surface profile in the proposed domain

As this Figure shows the USBR proposed stilling basin can damp energy with hydraulic jump. To figure out the end sill layout effect on hydraulic jump character two kind of modification in end sill is done. Figure (5) shows this two kind of modifications in end sill and its predicted effect on hydraulic jump.

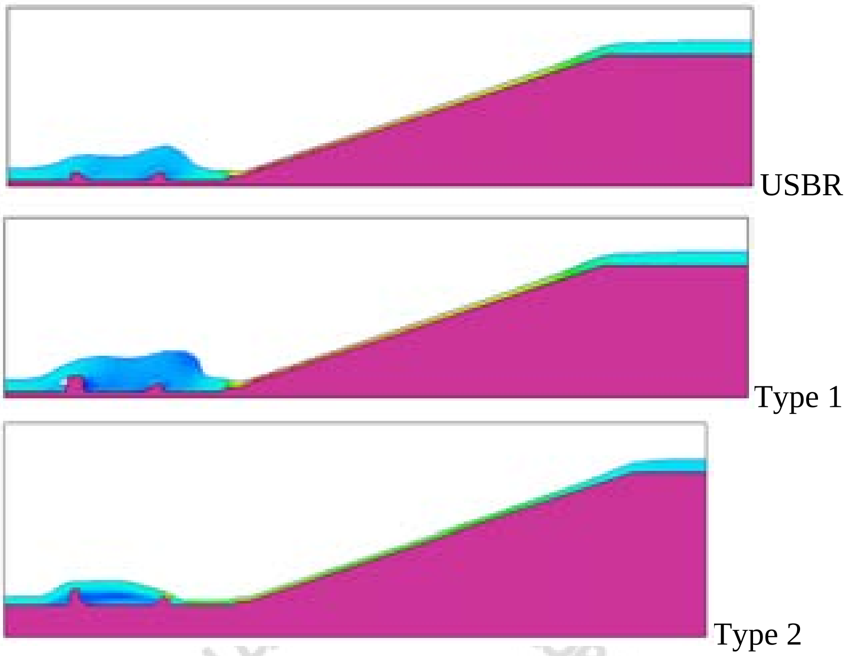

Figure 5 flow profile in stilling basin in different case

Figure (6) shows flow vector in this different case. As this figure shows flow field in the stilling basin greatly depend on sill layout. Flow field around end sill shows that upstream slope conduct flow and control velocity in the stilling apron while its height increase (Type 1) change its role in flow field and increase alternative depth and shift hydraulic jump to chute outlet region. To maintain the advantage of velocity control and hydraulic jump translation another modification in end sill layout is done (Type2).

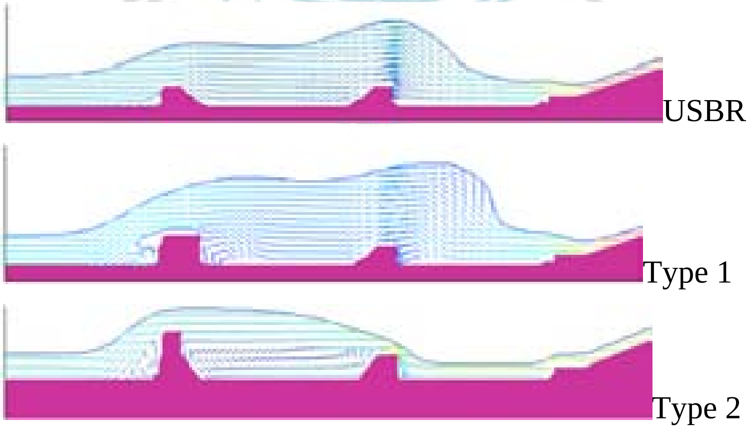

Figure 6 flow vector in in stilling basin in different case

Numerical simulation shows that this kind of modification can greatly improve energy damping process. Numerical output shows that this modification decrease hydraulic jump length in the stilling basin but inlet chute length increase.

5. Conclusion

The objective of this study was to evaluate the flow over a broad crested weir and stilling basin. This task is done by using FLOW3D numerical model. Numerical modeling shows that FLOW3D predicted flow pattern agree with the general flow profile in the weir and stilling basin and this numerical software can predict hydraulic jump. To ensure hydraulic energy damping and increase hydraulic jump quality two different modifications in end sill layout has done. This modification show that end sill play important role in flow pattern in stilling basin and end sill height increase can shift hydraulic jump to chute outlet region while its height increase plus maintaining its upstream slope can decrease hydraulic jump length

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