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Numerical Modelling of Flow over Sharp-Crested Rectangular Contracted Weir

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EXTENDED ABSTRACT

Introduction

Weirs are flow control structures that can be used for flow diversion purposes. They are classified according to section geometry or their length in the flow direction. For sharp-crested rectangular weirs, Rehbock [1] derived stage-discharge equations. In contracted geometries, streamlines curve at the approach flow leading to variations in flow structures. For this case, [2] proposed an equation for discharge as a function of the opening rate at the section (ratio of opening width to total width, b/B). We developed CFD models to test their accuracy in modelling weir flow. For the contracted weir cases, flow structures were visualised upstream of the weir.

Methods and Materials

The interFoam solver of OpenFOAM was selected for modelling because of its ability to handle multiphase flow. It includes forces due to surface tension in the momentum equation to be used at the interfacing cells. The density in each computational cell is calculated considering the ratio of each phase (α) in it. An additional transport equation for α is used to define the interphase. We tested a RANS approach with the eddy viscosity concept for two turbulence models which are k-ε as defined by [3] and [4] and k-ω SST as defined by [5]. Initially, a uniform weir case was modelled by using a two-dimensional approach. Two meshing strategies were applied with varying refinements. For each model, we refined the mesh around the weir structure by defining mesh planes as given in Figure 1 (a). As a result, two different meshes included 4,848 and 19,392 computational cells. The weir height was kept constant (10 cm) and the simulations were conducted for 13 unit discharge values (q) from 0.01 to 0.25 m^2/s. The aims in these simulations were to test the abilities of the turbulence models, to see the effect of different meshing strategies and to test the models at varying discharges.

For contracted weir flow, three-dimensional models were developed. The geometries included various opening rates from 0.05 to 0.9 (Figure 1(b)). Three meshing strategies were applied. Starting with a coarse mesh, refinements were applied in rectangular blocks, first at the interface level, then upstream of the weir. The finest mesh in these simulations contained 672,660 computational cells. Apart from testing the ability of the numerical models by validating them with the relation defined by [2], flow structures were visualised upstream of the weir which are related with the weir coefficient definition. Two unit discharge values were selected as 0.025 m^2/s and 0.050 m^2/s. For the large discharge, 9 opening rates (0.1 to 0.9) were tested. For the small discharge, an additional opening rate of 0.05 was tested.

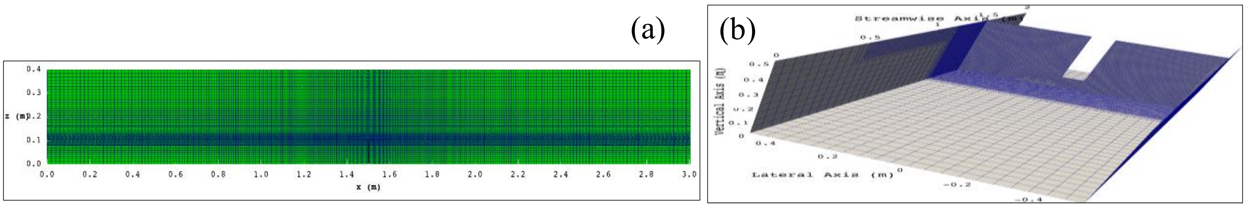

Figure 1. Two of the computational meshes used in the study (a) Fine mesh for 2D simulations (b) Finest mesh for 3D simulations at b/B=0.1

Results and Discussion

We compared the results of the two turbulence models in the 2D approach. The k-ω SST model managed to solve for the nappe shape more successfully than the k-ε model did. Quantifying the results gave close correlations for the dimensions defining the nappe shape as given by [6]. Besides, the comparison of stage-discharge relations obtained from the *k-ω* SST model and the formula of [1] gave better correlations than the *k-ε* model did. The model, independent of the meshing strategy, predicted the stage-discharge relation within a 1% error limit at all tested discharge values. Details of this part are not presented here to save space. With the knowledge from the uniform weir simulations, only the *k-ω* SST turbulence model was used in the contracted weir simulations. We compared the resulting stage-discharge relations with the formula of [2] for varying *b*/*B* and for two discharge values (Figure 2). Even with the coarsest mesh, the model predicted the relation well. The largest deviations are observed at *b*/*B*=0.05 which is out of the range for the empirical formula of [2].

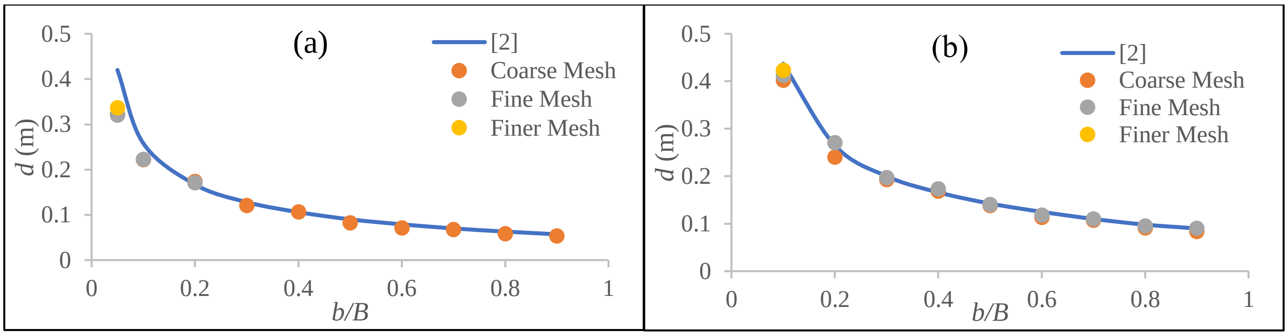

Figure 2. Comparison of the upstream flow depths with [2] for varying b/B (a) for q= 0.025 m^2/s (b) for q= 0.050 m^2/s

At the finest meshes for both discharge values, visualisation of corner vortices upstream of the weir was achieved by using the Q-criterion [7] (Figure 3 (a)). These vortices behaved in a symmetrical manner. Sourced from the sides, they carried mass and momentum to the centre. They were observed close to the bed. The streamlines curve more at the sides compared to the mid portion of the flume as a result of decreasing streamwise velocity at the sides. Figure 3 (b) shows the simulated free surface for *b*/*B*= 0.1 and *q*= 0.050 m^2/s.

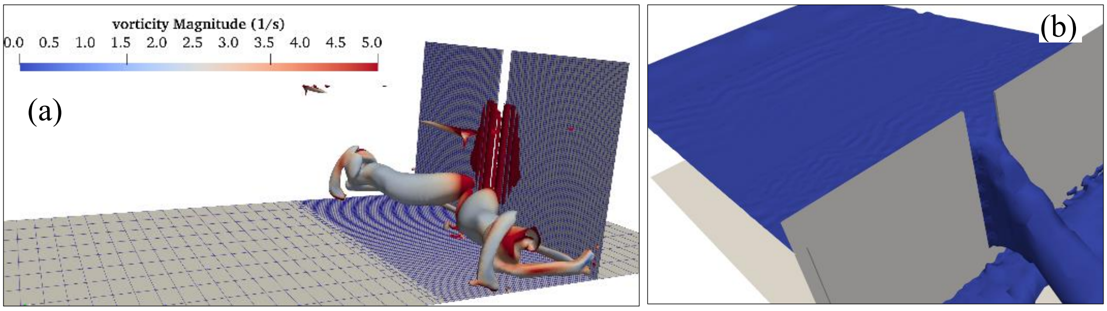

Figure 3. (a) Corner vortices upstream of the weir coloured with vorticity contours plotted over computational mesh for b/B= 0.05 and q= 0.025 m^2/s (b) Simulated free surface for b/B= 0.1 and q= 0.050 m^2/s

Conclusions

CFD modelling by using the interFoam solver of OpenFOAM coupled with a *k-ω* SST turbulence model successfully simulated the uniform and contracted flow over a sharp-crested rectangular weir. Nappe shapes over the crest were reproduced accurately. By using the Q-criterion, we could visualize the corner vortices upstream of the weir that occur due to the flow contraction.

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