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CFD simulation of free-surface flow over triangular labyrinth side weir

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ABSTRACT

Side weirs are extensively used in the hydraulic and environmental engineering applications. The modeling of free surface flow over a labyrinth side weir is a sophisticated problem in the hydraulic engineering. The water surface profiles over the triangular labyrinth side weirs were investigated by many of the researchers experimentally and theoretically. In this study, the free surface flow over the triangular labyrinth side weir was modeled by using Volume of Fluids (VOF) method to describe the flow characteristics in subcritical flow conditions. A valid method, Grid Convergence Index (*GCI*) was used to determine the numerical uncertainty of the simulation results. The simulation results were compared with experimental observations, and good agreements were obtained between the both results.

1. Introduction

Labyrinth side weirs can be used more efficiently than conventional side weirs for flow diversion in irrigation, land drainage, urban sewage systems and also in intake structures. Recently, Emiroglu et al. [1–3], Bilhan et al. [4] investigated labyrinth side weirs experimentally and numerically. The surface levels over side weirs play important role to determine discharge amount along the side weir. Many researchers investigated the surface levels profiles theoretically, experimentally or numerically. Before the description of the flow characteristics of a triangular labyrinth side weir, the main flow characteristics over the side weir must be understood clearly. The flow over a side weir is a typical case of spatially varied flow with decreasing discharge. The governing differential equation for such a flow is [5]:

$$\frac{dy}{dx} = \frac{S_0 - S_f - \frac{Q}{gA^2}\frac{dQ}{dx}}{1 - \frac{Q^2T}{gA^3}} \tag{1}$$

in which S_0 is the channel bed slope, S_f is the friction slope, Q is channel discharge, g is the gravitational acceleration. A is flow area, dQ represents the partial flow passing through a spatial strip dx along the side weir and T is the top flow width. The water level rises from upstream end of a side weir toward the downstream end of the side weir in the main channel, according to Eq. (1) for subcritical flow conditions in the main channel. However, Subramanya and Avasthy [6] and El-Khashab [7] pointed out that the water level drops slightly at the upstream end of a weir. This has been attributed to the side weir entrance effect at the upstream end. This formation does not extend to the centerline of the main channel, and it forms only near the side weir. The change in the water level is not noticeable in nearly at the last third of the weir length, where the water surface is almost horizontal. Agaccioglu and Yüksel [8] also described similar water surface profiles along a side-weirs placed on a curved channel. Khorchani and Blanpain [9] used a video observation technique to determine water surface profiles over side weirs. The observed data were transformed in numerical data. Emiroglu et al. [1] and Emiroglu and Kaya [2] investigated hydraulic characteristics of the labyrinth side weir located on a straight channel. They measured the water surface levels both along the centerline and weir-side of main channel to describe the flow structures in the main channel. They found in their experimental runs that the water depth in the upstream of the side weir is lower than water depth in the downstream end of the side weir. The water level along the side weir drops slightly at the upstream of the weir due to the side weir entrance effect at the upstream end, as the results of Agaccioglu and Yüksel [8]. Consequently, in the literature, the free surface profiles over side weirs can be defined as the following forms depend on main channel flow condition:

(a) The critical flow condition occurs close to upstream end of the side weir, and the flow is supercritical along the side weir. In this situation, the water level rises along the side weir.
(b) The flow depth is higher than critical flow depth at the upstream end of side weir. As the flow along the side weir is subcritical, the water level rises along the side weir.

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Nomenclature

A	flow area
b	width of the main channel
dQ	partial flow passing through a spatial strip dx along side weir
e	approximately relative error
E	energy height
F	body force
F_1	upstream Froude number in main channel
f_1, f_2, f_3	key variables which is important to objective of simulation study
g	gravitational acceleration
GCI	Grid Convergence Index
h_1	depth of flow on upstream end of side weir in centerline
h_2	depth of flow on downstream end of side weir in centerline
L	width of side weir
$\dot{m}_{pq}$	mass transfer from phase p to phase q
$\dot{m}_{qp}$	mass transfer from phase q to phase p
N	number of cell
P	apparent order
p	height of weir crest
P_{ave}	average apparent order
P_s	pressure
Q	channel discharge
S_0	channel bed slope
S_f	friction slope
T	top flow width
u	velocity vectors
x	longitudinal direction
z	distance from channel bottom
α_q	qth fluid's volume fraction in a cell
θ	side weir included angle
λ	representative grid size
μ	dynamic viscosity of fluid
ρ	density of fluid
ΔV_i	volume of ith cell

(c) The flow level, which is subcritical in the upstream end of the side weir, drops approximately to critical depth, then it again turn into subcritical flow condition due to energy losses, and after that the flow depth increases after the critical depth.

(d) The flow at the upstream end of the side weir is supercritical and the water level is below the critical flow. The flow is supercritical along the side weir.

This study presents an investigation of the water surface profiles over the triangular labyrinth side weirs in order to describe flow characteristics in the subcritical flow condition, by using CFD simulations with Fluent code. A verification method proposed by Celik et al. [10] was applied to determine discretization errors of the CFD model. The simulation results were compared with the experimental results.

2. Experimental study

Emiroglu et al. [1] performed a comprehensive experimental study on a large scale model to determine the discharge capacity and surface profiles of the labyrinth side weirs. The experimental data used in this study are based on the study of Emiroglu et al. [1]. The experimental set-up is demonstrated in Fig. 1. A rectangular weir was placed at the end of collection channel to measure the discharge of the side weir. A digital point gauge with ±0.01 mm sensitivity was fixed further 0.40 m from the weir to measure water surface levels. Labyrinth side weirs were produced by sharp edged steel plates. Experiments were performed for subcritical flow, stable flow conditions and free overflow conditions. According to Novak and Cabelka [11], minimum nape height should be higher than 30 mm because of the surface tension. Therefore, the minimum nape height is also considered as 30 mm in this study. The typical hydraulic profile and plan views of a triangular labyrinth side weir are shown in Fig. 2. In this figure, Q_1 and Q_2 are water discharges of main channel in the upstream and downstream of side weir respectively, p is crest height, b is width of the main channel, L is width of the side weir, h_1 and h_2 are depths of flow at the upstream and downstream end of side weir in centerline respectively, and E is energy height.

3. CFD simulation

The Fluent is general-purpose CFD code, which is used by several researchers worldwide. Fluent implement the surface capturing approach by using the VOF scheme for general multiphase flow modeling. The VOF model is ideally suited to applications involving free-surface flows. This involves defining a volume fraction function for each of the fluids throughout the domain and then convecting the volume fraction of each fluid with the average fluid flow. The interface between the two fluids is then reconstructed from the volume fraction function for each of the fluids in the

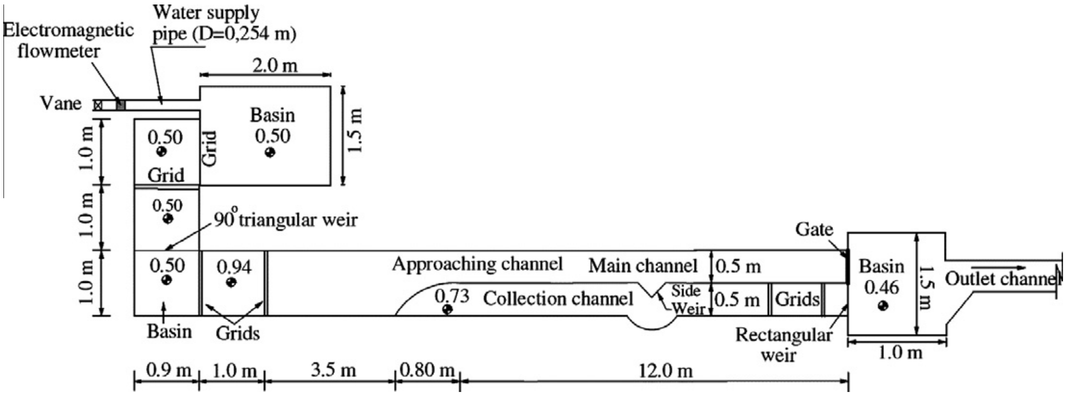

Fig. 1. Experimental arrangement [1].