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Numerical analysis of subcritical flow over two-cycle trapezoidal labyrinth side weir

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ABSTRACT

The side weirs are basic and effective hydraulic structures utilized commonly in irrigation, flood management, drainage and wastewater systems. The labyrinth side weirs have developed in recent years as more effective and efficient mechanism than conventional side weirs. The multi-cycle trapezoidal labyrinth side weirs could increase the side weir performance. The hydrodynamics of these weirs are considerably sophisticated due to the turbulent flow and vortices in the cycles. This paper presents the hydrodynamic behavior of the side weir with two cycles using Computational Fluid Dynamics (CFD) method. The grid convergence index (GCI) was used to demonstrate the mesh sensitivity in the results, and a fine mesh (9 mm) selected relatively among the used meshes was applied to computational volume for more accuracy. As the turbulent model, Reynolds Stress Model (RSM) model, which requires more computation effort, was implemented to consider turbulence effects in more detail. Additionally, certain experimental results were used for verification of the numerical results, and the CFD results were considerably consistent with experimental observations. The detailed hydrodynamic results, which were too hard to determine experimentally, were presented to describe the flow properties of this weir. The results indicated that the discharge coefficient decreased with an increase in Froude number. The best performances were obtained with side weir angle, $\alpha = 30°$ and weir height, $p = 20$ cm among tested values. The results encouraged the use of computational fluid dynamics methods for the further analyses.

1. Introduction

Side weirs are commonly used to protect a system against overflows. These structures can be also used to control the water level and to get the desired amount of water in the system. Traditional side-weirs are placed in the wall of a channel with a sharp crest parallel to the flow direction. There are several studies on side weirs, especially broad-crested side weirs conducted during the past years. De-Marchi [1] established the key for side weirs analytically, solving the spatially varied flow equation [2]. Then, several researchers, e.g. El-Khashab and Smith [3], Borgehi et al. [4], Emiroglu et al. [5], have studied conventional sharp-crested side weirs based on De-Marchi's approach until today.

As a new idea, an effective way of increasing the flow rate of a weir is to increase the crest length for a constant opening. During recent years, the researchers came up with the labyrinth side weirs, inspired by this idea. Labyrinth side weirs were initially comprehensively investigated by Emiroglu et al. [6]. They conducted 2830 laboratory tests to define discharge efficiency of these weirs, and they found that the performance of labyrinth side weirs were 1.5–4.5 times higher than traditional side weirs for the same weir opening. Similarly, Borghei and Parvaneh [7] experimentally investigated a new type called oblique side weir to increase the discharge with the constant channel opening. They studied the hydraulic characteristics of this side weir in subcritical situation, and found that the discharge efficiency of the oblique weir is a maximum of 2.33 times better than that of conventional one, as well. Although the conventional method to investigate side weirs, similar to other hydraulics structures, is to use physical laboratory tests, recently numerical method use has increased along with computational advancements. Aydin [8] used the CFD simulation to determine the free surface flow characteristics of triangular labyrinth side weirs. Using volume of fluid method, the author concluded that the simulation results quite agree with the experimental results. Aydin and Emiroglu [9] also used the CFD simulation to obtain labyrinth side weir discharges. They compared the CFD results with experimental observation, and their numerical results were consistent with empirical results in terms of

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discharge capacity. Borghei et al. [10] conducted an experimental study to determine discharge performance of labyrinth side weirs using one and two triangular cycles. Their results demonstrated that the efficiency of the labyrinth side weirs with multi-cycles, which was defined by discharge coefficients of the weir, were higher than conventional side weirs for same flow and geometric conditions. Recently, Emiroglu et al. [11] also conducted an experimental study on labyrinth side weirs with two trapezoidal cycles in subcritical flow condition. They proposed two new equations to determine De-Marchi coefficient for one and two cycles, respectively. In the study, the discharge efficiency of single and multiple cycles were compared for a constant opening and crest lengths, as well. In other studies, Zahedi Khameneh et al. [12] investigated the effect of the number of cycles in the labyrinth side on the performance of labyrinth side weir. Their results indicated that an increase in the number of cycles led to the reduction of flaws such as eddy flows. They also pointed out that while the weirs with one and two cycles had a higher discharge performance, the labyrinth weir with four cycles presents lower performance in comparison with two others. Aydin [8] used different turbulence models to test the sensitivity of the turbulence models related to free surface profiles over a triangular labyrinth side weir. He found that the RSM is the best suitable turbulence model for simulation of the waves and vortex on the free surface flow over the side weir. Rahimzadeh et al. [13] also tested several turbulence models on the simulation of flow over the circular spillways, and they stated that the RSM turbulence model gave the best results among all turbulence models. Aydin et al. [14] examined hydrodynamic characteristics of a self-priming siphon side weir using CFD simulations along with laboratory test results. As another approach to determine the discharge efficiency, Dursun et al. [15] used an adaptive-neuro fuzzy inference system to estimate the discharge coefficients of semi-elliptical side weirs with 675 laboratory test results. Their results showed that the ANFIS method could be successfully used for estimating the discharge coefficient.

As mentioned above, several approaches have been used to determine the side weir discharge efficiency. However, the conventional methods do not provide sufficient detail about hydrodynamic flow behavior over the side weir. Hydrodynamic characteristics of free surface flows, such as the flow over side weirs could be successfully detailed by CFD models. In the present study, the labyrinth side weir with two trapezoidal cycles was analyzed using CFD method in order to obtain the hydrodynamic and discharge characteristics of the weir, which was experimentally investigated by Emiroglu et al. [11] previously. The 3D numerical solutions were conducted by ANSYS-Fluent (v.13) [16] code, which is recognized worldwide in CFD studies. In order to verify and calibrate the results of CFD analysis the laboratory test observation of Emiroglu et al. [11] were used. Emiroglu et al. [11] concluded that unlike labyrinth spillways, due to spatially varied flow along the side weir, the labyrinth side weirs requires a different equation and separate effort for each number of cycles. More cycles than two couldn't be also applicable for side weirs in practice owing to space restriction in the side wall. On the other hand, as mentioned by Zahedi Khameneh [12], the effective length of the weir diminishes for more cycles because of the collision of the jet passing over the crest at the cycle's connection points. For this reasons, only two cycles was considered in the study.

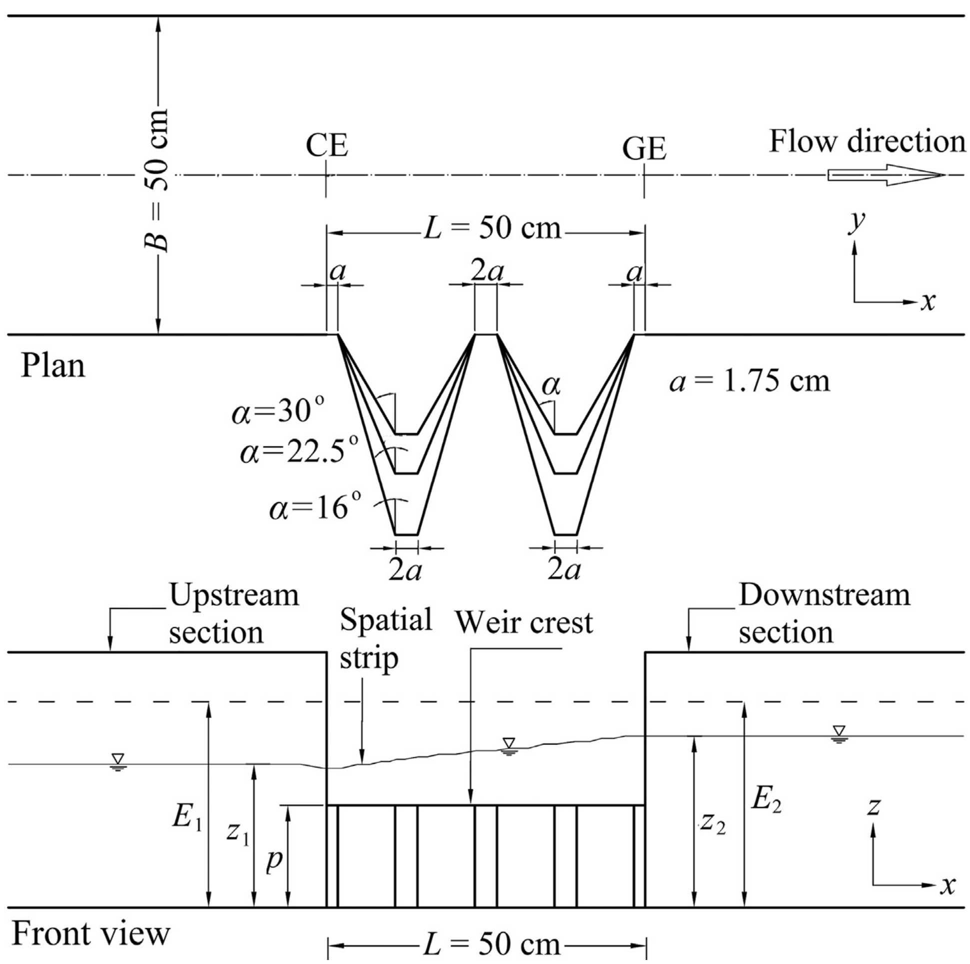

Fig. 1. The sketch of trapezoidal side weir with two cycles [11].