The Eurasia Proceedings of Science,
Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 2018

Volume 2, Pages 361-367

ICRES 2018: International Conference on Research in Education and Science

Evaluation of Flow behavior over Broad-Crested Weirs of a Triangular Cross-Section using CFD Techniques

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Abstract: Weirs are barriers placed across a river and designed to control the flowing water in order to prevent floods, make waterways operable for inland navigation and measure flow discharge. Although there are many types of weirs, mainly used ones are sharp-crested, circular-crested (cylindrical), broad crested and ogee weirs. In the present study, triangular broad-crested weirs are numerically investigated under different flow conditions. Different interior angles of 90^o, 100^o, 110^o and 120^o are included for the opening of weirs. The flowing water over weirs is simulated using CFD techniques and evaluated at different flow regimes with inlet discharges of 0.012 m^3 s^{-1}, 0.036 m^3 $s^{-1}$and 0.06 m^3 s^{-1}. The simulation results have shown that the water level upstream the weir is inversely proportional to the opening angle, where an increment of 10^o in the opening angle leads to a drop in water level about 1.5 cm. In addition, applying a discharge of 0.012 m^3 s^{-1}, an uncovered region with water is created downstream the triangular broad-crested weirs, while the bed downstream of the rectangular broad-crested weir is covered with a thin layer of water at the same flow discharge. The aforementioned results are compared with a comparative data and show good agreement. By using triangular broad-crested weirs, it is important to measure the wake region and the hitting point of falling water downstream the weirs where this area must be strengthened well in order to resist water power and reduce the risk of drift.

Keywords: Weir, CFD, V-notch, Broad-Crested weir, Turbulence model

Introduction

Weirs are simple hydraulic structures used for flow measuring. They work as overflow dams to control water level in open streams (Lodomez et al. 2014). Weirs are classified according to the geometrical shape into different types such as rectangular, triangular, trapezoidal and cylindrical shapes. They are classified also according to the type of weir crest into two types, sharp-crested and broad-crested weirs (Hoseini et al. 2013). These structures are featured by their ease in design and low cost in maintenance. Investigating the flow behavior over weirs was interested by many researchers where many kinds of physical and numerical models are evaluated in term of their performance. Naghavi et al. (2011) evaluated experimentally and numerically the performance of circular weirs. Their results have shown that nappe separation significantly depends on the overflow discharge. Afshar and Hooman (2013) investigated experimentally and numerically the flow behavior over rectangular broad crested weirs. Computational fluid dynamics techniques are used with three turbulence models of RNG k-ε, standard k-ε and large eddy simulation LES in order to determine the water surface profile over the weir. The simulation results were agreed with the experimental work. Moreover, Namaee in (2014) studied numerically the performance of side weirs with an inclined ramp. He used ANSYS-FLUENT software with the standard k-ε turbulence model his results show that placing an inclined ramp decreases the lateral outflow. Yuce et al. (2015) have shown in the numerical study performed to evaluate the flow behavior over oblique cylindrical weirs that the flow over weirs is affected by the geometrical shape of the weir. They used CFD techniques with the SSG Reynolds stress turbulence model, where the simulation results have shown that the increasing the angle of obliqueness increases the flow velocity at the downstream face of the weir In the

- Selection and peer-review under responsibility of the Organizing Committee of the Conference

present study, the flow behavior over triangular broad-crested weirs is numerically investigated under different flow regimes using CFD techniques.

Numerical model

In fluid dynamics, the turbulence phenomena was the main subject considered by many researchers where it influences significantly on the hydraulic structures. Recently, different models have been developed in order to describe how the turbulence occurs. Each turbulence model used to describe a specific flow regime. Flow regimes of low turbulence are described by simple models such as k-ε and k-ω models while flow of high complexity, which includes rotating objects and large vortices, is described well by developed models such as Reynolds stress models. In the present study, because that no flow region of high complexity is expected, k-ε turbulent model is dependent to evaluate the flow behavior over rectangular and triangular broad-crested weirs (ANSYS user's guide).

The transport equations in the realizable k-ε model are:

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_j}(\rho k u_j) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\rho_k}\right)\frac{\partial k}{\partial x_j}\right] + G_K + G_b - \rho\varepsilon - Y_M + S_k \quad (1)$$

and

$$\frac{\partial}{\partial t}(\rho\varepsilon) + \frac{\partial}{\partial x_j}(\rho\varepsilon u_j) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] + \rho C_1 S\varepsilon - \rho C_2\frac{\varepsilon^2}{k+\sqrt{\nu\varepsilon}} + C_{1\varepsilon}\frac{\varepsilon}{k}C_{3\varepsilon}G_b + S_\varepsilon \quad (2)$$

Where

$$C_1 = max\left[0.43, \frac{\eta}{\eta+5}\right], \eta = S\frac{k}{\varepsilon}, S = \sqrt{2S_{ij}S_{ij}} \quad (3)$$

Where; G_k, G_b are the turbulent kinetic energy created by mean velocity gradient and buoyancy,Y_M indicates the fluctuation in turbulence relative to the dissipation rate,σ_k and σ_ε represent the turbulent Prandtl numbers for kinetic energy and dissipation rate, S_k and S_ε are terms of user-defined source,C_1 and C_2 are constants.

Model Setup

In the present study, water flow over triangular broad-crested weirs is numerically investigated under different conditions. An open channel of 5 m length and 0.6 m width and 0.8 m height is included in the numerical models. Triangular broad-crested weirs with different opening angles are investigated under different flow regimes. The performance of weirs is evaluated under three different Froude numbers of 0.28, 0.85 and 1.4. The weir models are designed with four different opening angles of 90^o, 100^o, 110^o and 120^o (Figure 1). The triangular weirs are broad-crested with a length of 0.5 m and placed at 1.0 m from the inlet. The channel inlet and outlet were given a pressure inlet and pressure outlet, respectively. The channel sides, bottom and weir models were smooth walls. The upper face of the domain is subjected to atmospheric pressure (Figure 2).

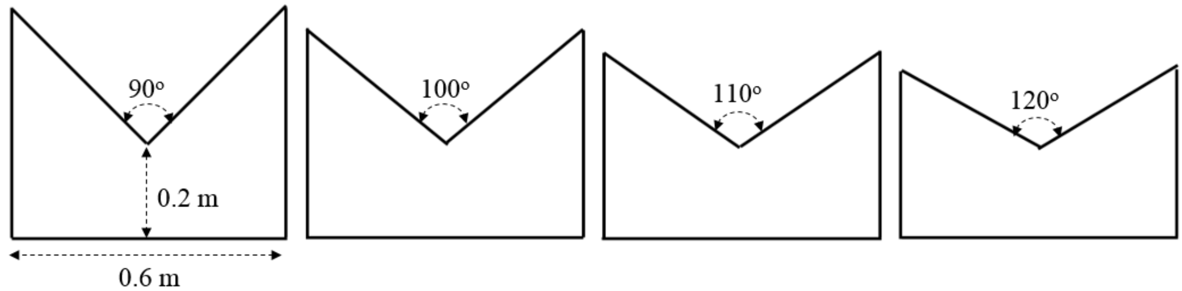


Figure 1. Triangular broad-crested weirs

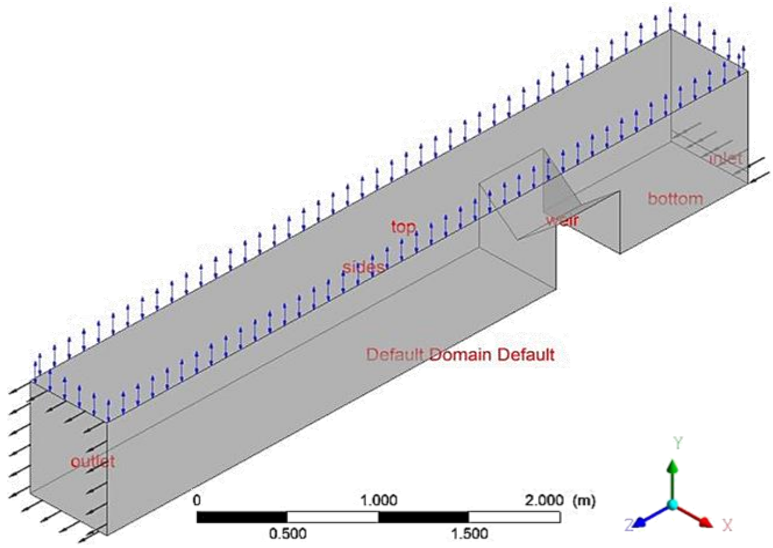


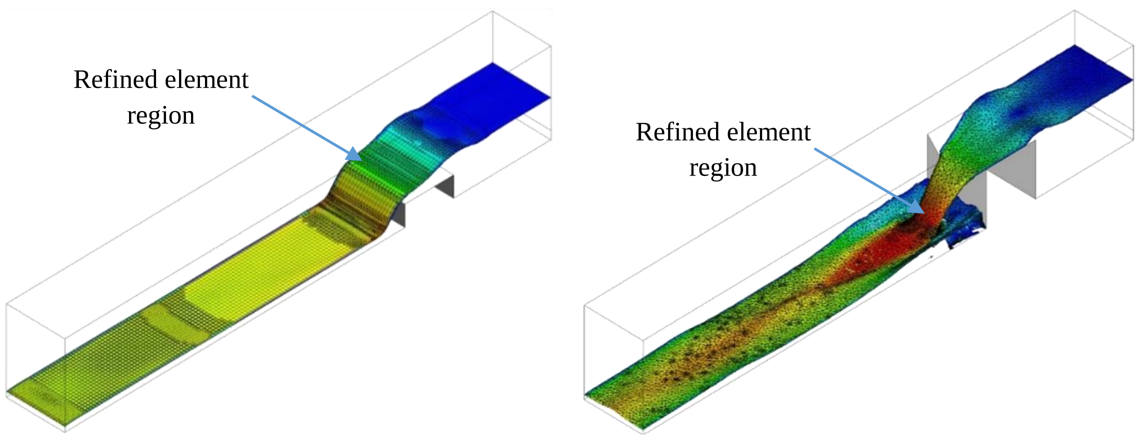
Figure 2. Channel domain and weir position

Simulation Results

In this study, computation fluid dynamics simulations have been performed in order to evaluate the flow behavior over triangular broad-crested weirs. A constant crest width of 0.5 m is used for triangular broad-crested models and the latter are designed with different opening angle of 90^o, 100^o, 110^o and 120^o. Three different Froude numbers are dependent to monitor the water level upstream the weir and the flow velocity downstream it.

Mesh Refinement

In CFD analyses, the solution progress is significantly depending on how the mesh is fine enough to avoid creation of folded elements. The accuracy of results is directly proportional to the mesh quality (Almohammadi et al. 2013). In the present study, the mesh refinement technique, which is provided by ANSYS package, is used in order to refine the mesh elements and reach the desired results (Yuce et al. 2015). Two levels of mesh refinement are performed for all models, where the refinement techniques senses turbulence regions, refines the elements depending upon the level of refinement as shown in figure 3.



(a) Rectangular broad-crested weir

(b) Triangular broad-crested weir

Figure 3. Mesh refinement

Effect of the Opening Angle

The simulation results have shown that when a flow discharge of 0.012 $m^3\ s^{-1}$ is given to the inlet, an uncovered region with water is created at the downstream side for all triangular broad-crested weirs (Figure 3.a). Nevertheless, providing the system with a discharge of 0.036 $m^3\ s^{-1}$and 0.06 $m^3\ s^{-1}$ results in increasing the velocity of dropping water (Figure 3.b, c). Regarding the water level (h_u), the opening angle of triangular broad-crested weirs is inversely relative to water level upstream the weirs, whereas the opening angle of v-notch weirs increases 10^o, the water level slightly decreases about 1.5 cm for the same discharge.

In the rectangular broad-crested weir, the simulation results have shown that there is no uncovered region with water is created at the downstream side and the water falls smoothly over the crest. The water level upstream the rectangular broad-crested weir was 0.27 m when a discharge of 0.012 $m^3\ s^{-1}$ is applied. Frequently, providing a discharge of 0.036 $m^3\ s^{-1}$ increases the water level at the upstream side about 0.04 m and also for the discharge of 0.06 $m^3\ s^{-1}$ (Figure 4).

Consequently, the pressure exerted by falling water (p_{dw}) with a discharge of 0.012 $m^3\ s^{-1}$ on the downstream side of the weir with an opening angle of 90^o to 110^o is increased about 120 Pa, in average, and about 43 Pa for the weir of 120^o angle. In addition, increasing the discharge to 0.036 $m^3\ s^{-1}$ causes an increment in the pressure at the downstream bed about 2.4 KPa, 2.0 KPa, 1.5 KPa and 1.0 KPa for the weirs of 90^o, 100^o, 110^o and 120^o, respectively. Moreover, at a discharge of 0.06 $m^3\ s^{-1}$, the increment of the pressure was about 0.9 KPa, 0.98 KPa, 1 KPa and 1.1 KPa for the triangular broad-crested weirs of an opening angle of 90^o, 100^o, 110^o and 120^o.

The effective point that the falling water hits (x_e) is located on the bed downstream the weirs at a distance of about 0.66 m, 0.84 m and 0.83 for the three discharge of 0.012 $m^3\ s^{-1}$, 0.036 $m^3\ s^{-1}$ and 0.06 $m^3\ s^{-1}$, respectively (Table 1). The insignificant reduction in the location of hitting point downstream the v-notch weirs between the discharges 0.036 $m^3\ s^{-1}$ and 0.06 $m^3\ s^{-1}$, which is about 0.01 m, is attributed to the occurrence of overtopping flow where it decreases the distance of falling water downstream the weirs.

Regarding the rectangular broad-crested weir, the flowing water passed smoothly over the weir with low water head at the upstream side. These results are well agreed with the numerical study performed by Afshar and Hooman (2013) as shown in figure 5.

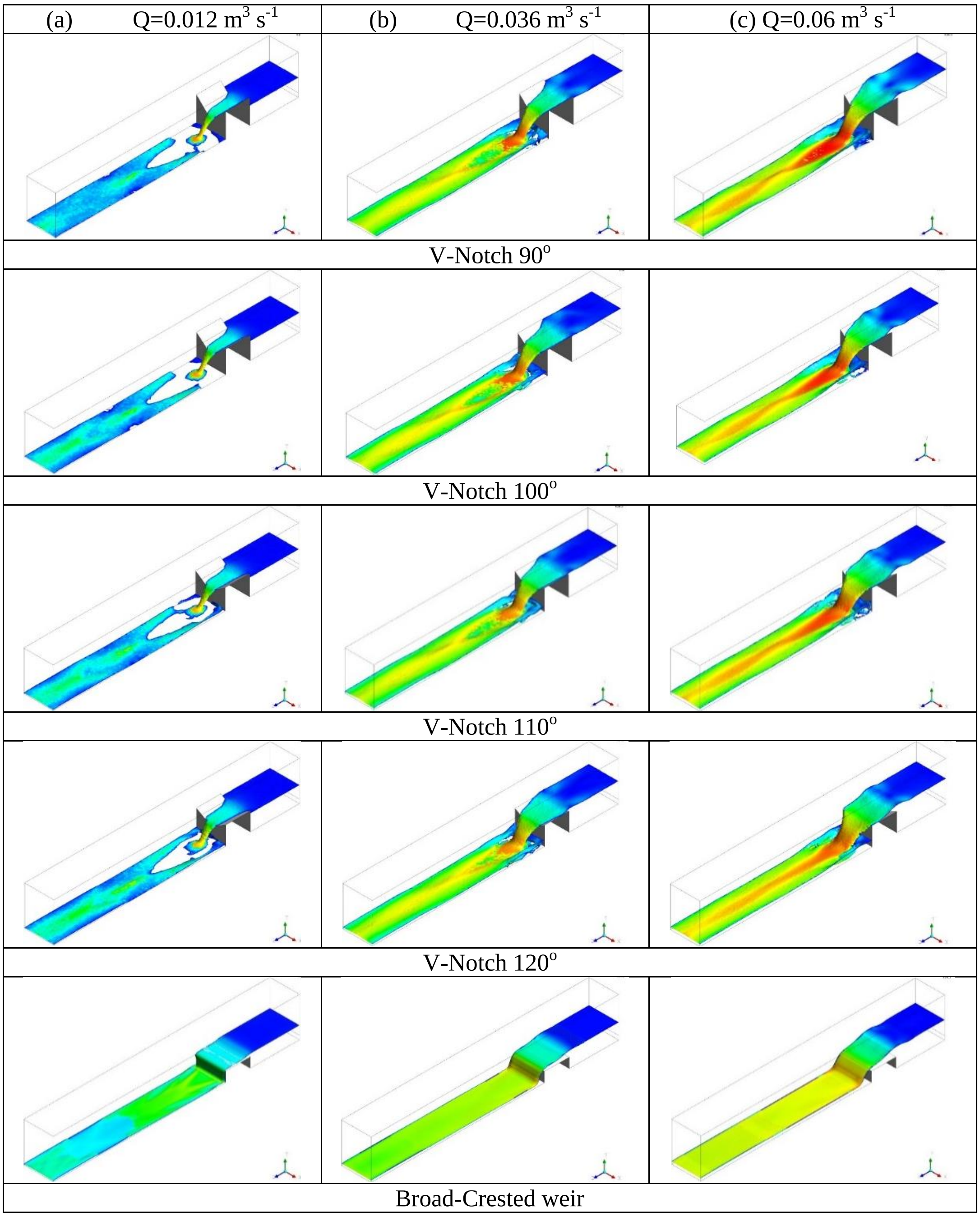


Figure 3. Water surface profile for different triangular broad-crested weirs

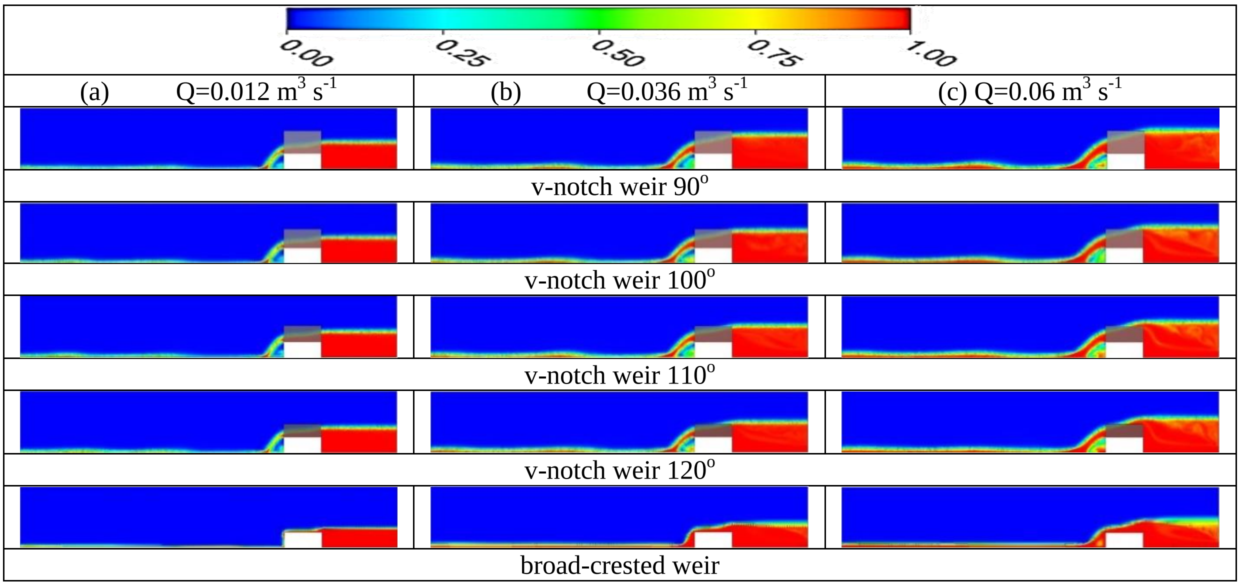
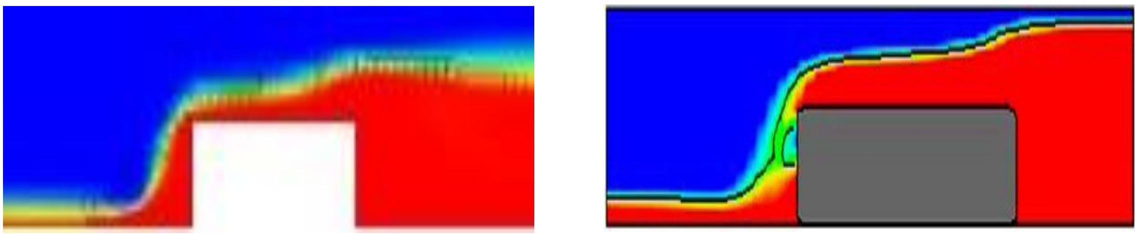


Figure 4. Water volume fraction at different flow conditions

Table 1. The simulation results

Variable	Rectangular broad-crested weir	triangular broad-crested weirs 90^o	triangular broad-crested weirs 100^o	triangular broad-crested weirs 110^o	triangular broad-crested weirs 120^o
h_u (m)	0.27	0.36	0.35	0.35	0.33
P_{dw} (Pa)	1428.28	519.824	629.989	757.163	800.05
x_e (m)	0.5	0.66	0.67	0.67	0.65
			Q=0.012 m^3 s^{-1}		
h_u (m)	0.32	0.45	0.43	0.4	0.4
P_{dw} (Pa)	1357.9	2918.08	2565.91	2224.76	1828.94
x_e (m)	0.65	0.82	0.84	0.84	0.84
			Q=0.036 m^3 s^{-1}		
h_u (m)	0.35	0.5	0.48	0.44	0.44
P_{dw} (Pa)	1884.54	3815.27	3547.65	3225.64	2949.83
x_e (m)	0.65	0.83	0.83	0.83	0.84
			Q=0.06 m^3 s^{-1}		



Present study

Study of Afshar and Hooman (2013)

Figure 5. A comparison between the present study and the numerical analysis conducted by Afshar and Hoseini (2013) for the rectangular broad-crested weir

Conclusions

This study aims to evaluate the flow behavior over triangular broad-crested weirs under different flow conditions. The effect of opening angle of weirs is numerically investigated and compared with the behavior of rectangular broad-crested weirs. The simulation results have shown that the water level upstream the weir is inversely proportional to the opening angle, where an increment of 10^o in the opening angle leads to a drop in water level about 1.5 cm. In addition, applying a discharge of 0.012 m^3 s^{-1}, an uncovered region with water is created downstream triangular broad-crested weirs, while the bed downstream of the rectangular broad-crested weir is covered with a thin layer of water at the same flow discharge. Consequently, the pressure exerted by falling water of 0.012 m^3 s^{-1} is less than other flow conditions. The difference in pressure exerted by falling water between the opening angles 90^o and 100^o, which is approximately similar to that between the opening angles 100^o and 110^o, was about 120 Pa. In addition, increasing the discharge to 0.036 m^3 s^{-1} causes an increment in the pressure at the downstream bed about 2.4 KPa, 2.0 KPa, 1.5 KPa and 1.0 KPa for the weirs of 90^o, 100^o, 110^o and 120^o, respectively. Moreover, at a discharge of 0.06 m^3 s^{-1}, the increment of the pressure was about 0.9 KPa, 0.98 KPa, 1 KPa and 1.1 KPa for the v-notch weirs of an opening angle of 90^o, 100^o, 110^o and 120^o. By using triangular broad-crested weirs, it is important to measure the wake region and the hitting point of falling water downstream the weirs where this area must be strengthened well in order to resist water power and reduce the risk of drift.

Recommendations

The authors have recommended for future studies to use the same models included in the present study with curved corners and compare the results with the models of sharp edges. In addition, it is recommended to use different turbulence models under constant flow conditions, then compare the results among them.

References

Afshar H. & Hooman H., (2013). Experimental and 3-D numerical simulation of flow over a rectangular broad-crested weir. *International Journal of Engineering and Advanced Technology, 2*, 6, pp. 214-219.

Almohammadi, K., Ingham, D., Ma, L. & Pourkashan, M. (2013). Computational Fluid Dynamics (CFD) Mesh Independency Techniques for a Straight Blade Vertical Axis Wind Turbine. *Energy, 58*, 483–493.

ANSYS user's guide

Hoseini, S. H. Jahromi, S. H. M. & Vahid, M. S. R. (2013). Determination of Discharge Coefficient of Rectangular Broad-Crested Side Weir in Trapezoidal Channel by CFD. *International Journal of Hydraulic Engineering*, 2(4), 64-70. DOI: 10.5923/j.ijhe.20130204.02

Lodomez, M., Erpicum, S., Dewals, B., Pirotton, M. & Archambeau, P. (2014). Comparison between Experimental and SPH Models over a Sharp-crested Weir. *The 5th International Junior Researcher and Engineer Workshop on Hydraulic Structures.* Spa, Belgium.

Naghavi, B., Esmaili, K., Yazdi, J, & Vahid, F.K. 2011. An experimental and numerical study on hydraulic characteristics and theoretical equations of circular weirs. *Canadian Journal of Civil Engineering, 38*(12): 1327–1334. doi: 10.1139/l11-092.

Namaee, M. R. (2014). Numerical Investigation of a Side Weir with an Inclined Ramp. *World Applied Sciences Journal, 31* (10): 1759-1766, 2014, DOI: 10.5829/idosi.wasj.2014.31.10.429

Yuce, M. I., AL-DABBAGH, M. A. & AL-BABELY, A. H. (2015). Flow simulation over oblique cylindrical weirs. *Can. J. Civ. Eng., 42,* 389–407. dx.doi.org/10.1139/cjce-2014-0157

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