Civil Engineering Infrastructures Journal, 46(2): 199 – 207, December 2013
ISSN: 2322 – 2093

Effect of Crest Roughness on Flow Characteristics over Circular Weirs

Ghobadian, R.[1*], Fattahi Chaghabagi, A.[2], Farmanifard, M.[3] and Ahmadi, A.[4]

[1] Assistant Professor, Department of Water Engineering, Campus of Agriculture and Natural Resources, Razi University, P.O Box: 1158, Kermanshah, Iran.
[2] MSc Student, Water Resources Engineering, Campus of Agriculture and Natural Resources, Razi University, P.O Box 1158, Kermanshah, Iran.
[3] Young Researchers and Elite Club, Kermanshah Branch, Islamic Azad University, Kermanshah, Iran.
[4] MSc Student, Water-Civil Engineering, Department of Civil Engineering, Razi University, Kermanshah, Iran.

Received: 16 May 2012; Revised: 11 Nov. 2012; Accepted: 25 May 2013

ABSTRACT: Different construction materials with different roughness used to make circular weirs highly affect surface roughness and, in turn, flow hydraulics passing over these structures. In the present research, numerous experiments under different hydraulic conditions were performed on a physical model to study the effects of roughness on flow hydraulics over a circular weir. The flow hydraulics included velocity profile, discharge coefficient and longitudinal water surface profile. The actual water surface elevation and velocity profile at different cross sections were measured using a point gauge and micro current meter, respectively. About 200 experimental tests were performed on a circular weir made of polyethylene with 29.5 cm height, 30cm wide, and 7.5 cm radius. The results showed that for a constant discharge, as the weir surface roughness increases the upstream water level over the weir increases and the discharge coefficient reduces. The velocity profile at upstream sections of the weir crest is extremely different from that over the weir crest while the velocity profile at downstream sections of the weir crest follows the same pattern as those experienced at the weir crest. Also, the increased roughness makes the velocity profile over the weir more uniform, with a higher average velocity. Finally the effects of roughness on velocity values are less near weir in comparison with water surface.

Keywords: Discharge Coefficient, Experimental Test, Relative Roughness, Velocity Profile.

INTRODUCTION

Weirs are among the oldest man-made hydraulic structures used with different dimensions, shapes and applications including measurement and the control of discharge and the water surface regulation in irrigation networks. Rectangular, triangular, and trapezoidal weirs are known as the oldest types of weirs used. With regards to the crest type, circular weirs have many advantages compared to sharp- and broad-crested ones. The advantages include their potential in flow passage with a stable

* Corresponding author E-mail: rsghobadian@gmail.com

pattern as regards sharp-crested types, their potential for passing floods and floating debris easily and safety, their simplicity of their structural and hydraulic designs, their lower costs compared to other weirs, as well as their high capacity for flow drainage (at a fixed water head).

Circular weirs have many applications in irrigation networks, water and sewage systems, and transfer, drainage, and/or diffusion. Among structures associated with circular weirs elastic dams and cylindrical sluice gates can be named. Prior to the introduction of ogee overflows, circular weirs were common in the late 19th and early 20th centuries. During the 19th century, efforts made to increase the drainage capacity of overflows. These efforts resulted in the design of circular weir designs; Bazin's work in France (1898) can be mentioned as an example of that. Bazin's work on weirs is well-known for his attention in observing broad-crested weirs, which, later, was used by Creager (1917) to develop the profile of ogee spillways. Creager also conducted some research on the profile of circular weirs, where his findings were applied to design the French Put dam. Much of researches on circular weirs have been undertaken by Rehbok (1929), Fawer (1937) and Sarginson (1972). These researches indicated that the discharge coefficient (C_d) is equal or higher than one. And, the discharge coefficient is a function of $\frac{H_W}{R}$, where H_w is the total head over a weir and R is the arc radius of a weir.

The effects of aeration and no aeration on the discharge coefficient have been studied by Escande and Sananes (1959) and Rouve and Indlekofer (1974). The results of these researches showed that under no aeration condition, no flow separation was created and the discharge coefficient increased by 15% to 20%.

Using Dressler's theory, Ramamurthy et al. (1993) obtained the velocity distribution over the crest of a circular weir and presented a dimensionless equation for the flow coefficient. Chanson and Montes (1998) studied the effect of upstream conditions on flow characteristics over a circular weir under different conditions. The results of their experiments showed that $\frac{P}{R}$ and upstream slopes of weir have no effect on the discharge coefficient, flow depth at the overflow weir, and energy loss. In contrast, flow conditions at the upstream influence the characteristics of flow over the weir. Compared to sharp- and broad-crested weirs, circular weirs have a higher discharge capacity for a certain head. Also, Chanson and Montes (1998) provided an equation to calculate the discharge coefficient for a circular weir under developed flows at upstream conditions.

Using flow function over or around a cylinder, Heidarpour et al. (2002) determined the velocity distribution over a weir and presented a mathematical model in order to determine discharge coefficients at a circular weir. Heidarpour et al. (2006) studied hydraulic characteristics such as the discharge coefficient, water depth on weirs, and energy loss at a circular weir. The results of their experiments showed that for cylindrical and circular weir overflows, the discharge coefficient increases as the water load increases and that energy loss is higher at cylindrical overflows than at the circular-crested weir

Esmaili et al. (2010) compared the values of pressure and velocity measured in laboratory with values simulated by the fluent model. The results showed that there exists good agreement between the on-the-weir flow patterns measured in laboratory and simulated by the model. They also observed that the formation of critical depth prior to the weir crest as well as the flow separation from the top of the weir takes place at its terminal area.

Raupach et al. (1991) studied the effects of wall roughness on the average velocity profile despite difficulties in determining a linear scale specifying the roughness dimension and geometry.

Using five physical models, Tahmassebii (2010) worked on the effects of roughness on the dimensions of the separation region for broad-crested weirs. The results of this research indicated that the separation height to the water height ratio over a weir decreases as the roughness of the weir increases.

Othman et al. (2010) examined the effects of three different roughness sizes and three different diameters of a cylindrical weir on the conditions of passing flows. Their results demonstrated that the coefficient of discharge and discharge passing over the weir increase as cylinder diameters decrease. In addition, the results showed that an increase in the roughness size of the weir surface leads to a significant decrease in the discharge coefficient, and that the effect of $\frac{H}{R}$ on the discharge coefficient increases as the diameter of cylinder increases. Othman et al. (2010) finally presented an experimental equation to estimate the flow drainage under different cylinder sizes and weir roughness.

The review of researches undertaken on circular weirs shows that the effects of upstream flows and weir dimensions on the discharge coefficient have been adequately considered, Despite this, less attention has been paid to the effects of roughness on velocity profiles as well as the discharge coefficient of circular weirs. This study aims to evaluate the effects of different roughness sizes at the body and crest of a circular weir on flow hydraulic parameters.

MATERIAL AND METHODS

Applying the dimensional analysis theory the following non-dimensional equation can be developed in which the discharge coefficient, is a function of eight various parameters.

$$f_1(C_d, q, H_W, P, K_S, R, \alpha, \beta, g, \mu, \sigma, \rho) = 0 \tag{1}$$

$$C_d = \frac{q}{\frac{2}{3}\sqrt{\frac{2}{3}g}H_w^{1.5}} = f_2\left(\frac{H_w}{R}, \frac{P}{H_W}, \frac{K_s}{H_W}, F_r, R_e, W_e, \alpha, \beta\right) \tag{2}$$

where, C_d= Discharge Coefficient, R = Radius of circular weir, P = Height of weir crest, K_S = Roughness size of crest and body of weir (D_{50}), H_w= Total head above weir, q = Discharge per unit width, g = Acceleration due to gravity, α = Weir's upstream face angle, β= Weir's downstream face angle, $F_r = \frac{q}{\sqrt{gy^3}}$ Froude number, $R_e = \frac{2R\sqrt{2gH_W}}{\nu}$ Reynolds number, and $W_e = \frac{RH_W^2}{\sigma}$ Weber number of the approach flow.

In the present research upstream/ downstream face angles has been set as right angles. At high discharges the effect of surface tension will be neglected so the effect of the Weber number was neglected given the range of flow depth over the weir. Because the flow is subcritical and turbulent, therefore, the effects of Froude and Reynolds numbers had been neglected. So, only the effects of the first three parameters of the above equation have been considered. It can be seen other parameter from Figure 1.

The experiments were carried out in a 9 m long horizontal channel (channel slope equal to zero) that is 0.3 m wide and 0.5 m height (see Figure 2).

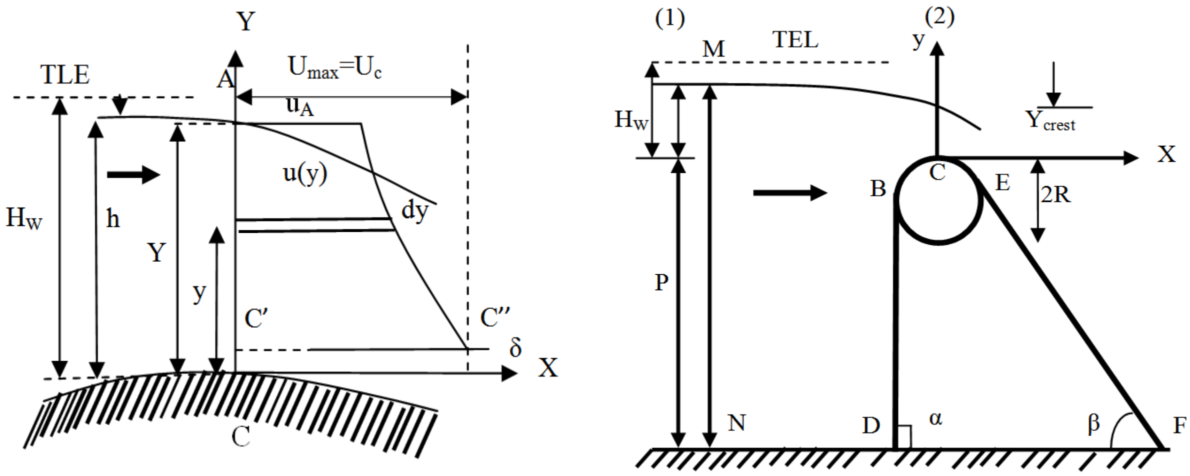


Fig. 1. Flow over the weir, velocity distribution, and boundary layer on the crest of a circular weir.

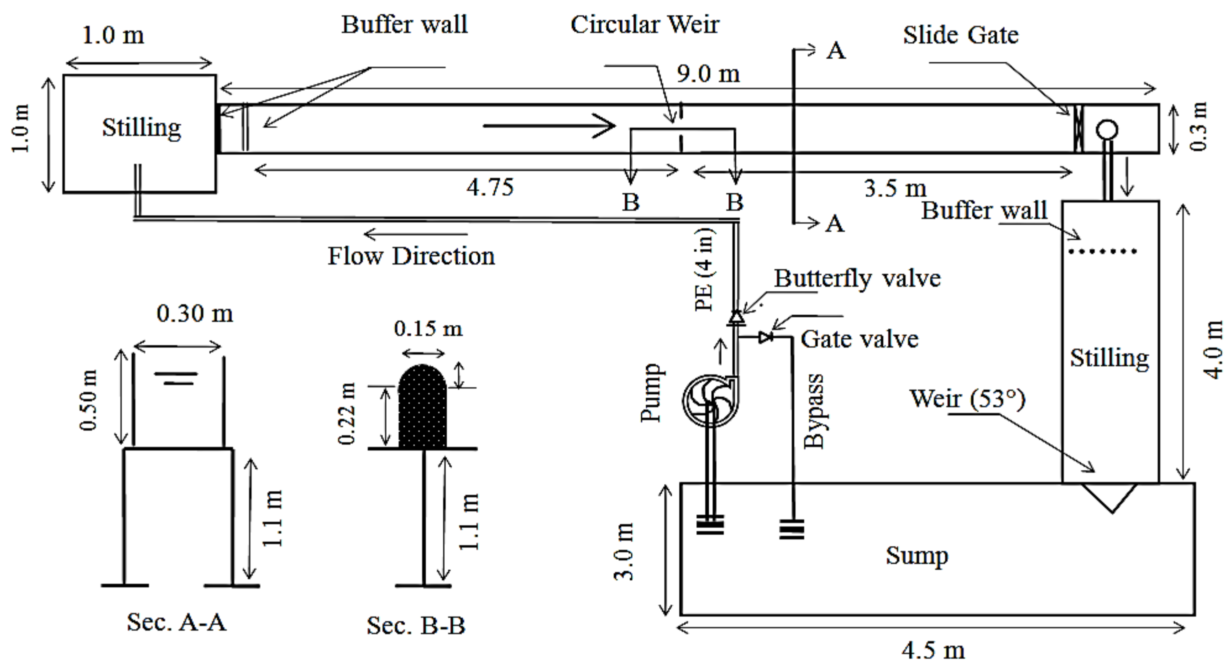


Fig. 2. Plan view of experimental setup (Unit: m).

The channel is made of glass walls and floor. A movable point gauge is mounted on rails at the top of channel sides (see Figure 3). Several experiments were performed on a physical model under different hydraulic conditions in order to study the objectives of the current research.

(a) (b)

Fig. 3. Views of weirs:
a) With roughness D_{50} = 1.18mm; b) With roughness D_{50} = 0.8mm.

A physical model of the intended weir with 29.5 cm high; 30 cm wide and 7.5 cm radius were made of Plexiglas, having three different roughness sizes of 0.8, 1.18, and 2.36 mm, as shown in Figure 3. To roughen the crest, upstream and downstream faces of the weir, and sand particles with special glue was placed on the weir.

In hydraulics Laboratory of Water Engineering Department of Razi University, Kermanshah, about 200 experiments were conducted under different discharges in the flume. Water surface elevations and velocity profiles were measured at different cross sections using a point-gauge (with precision of 0.1 mm) and mini current meter (Nixon model with precision of 0.1 cm/s), respectively. The flume discharge was measured after the flow was drained into a cubic metal tank equipped with a 53° triangle weir. A pumping system that could supply a maximum discharge of 20 L/s was used. Figure 2 shows the experimental setup.

RESULTS AND DISCUSION

Based on experiments undertaken, the effects of body and crest roughness's of the weir on flow hydraulics the circular weir were analyzed and following results were obtained:

Water Surface Profile

At site of weir up to its 70 cm distance towards upstream, the water level profile was collected for different roughness sizes (Figure 4). As seen in Figure 4 it is observed that for a certain discharge, increased roughness size causes that the water surface profile ascend to upper level.

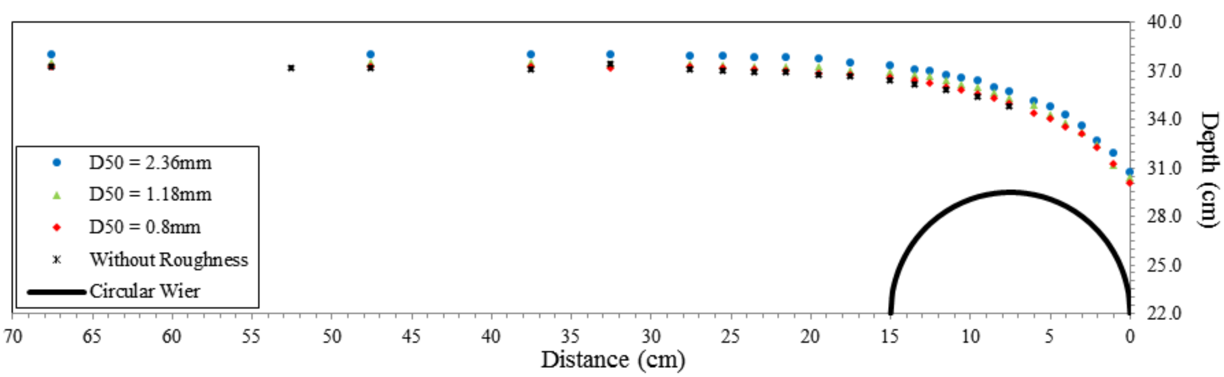


Fig. 4. Diagram of water surface profile over circular weir for different roughness sizes (Q = 14 l/s).

To better understand, the variation of water surface elevation under different roughness sizes relative to a non- roughness weir are provided in Table 1 at different cross sections at the upstream of the weir.

As seen in Table 1, the roughness size at a cross section near the weir crest has more influence on the water surface elevation. By getting away from the weir crest differences in the water surface elevation are reduced.

Stage-Discharge Relation over Weir

Figure 5 illustrates the effect of roughness size on the weir stage-discharge relation. As expected, Figure 5 shows that for a certain discharge, increased roughness size increases the level of water over the weir,; similarly for a certain stage on the weir an increase in the size roughness reduces the discharge passing over the weir, indicating an increase in the flow discharge coefficient.

Weir Discharge Coefficient

By measuring water depth and discharge passing over the weir, the discharge coefficient, C_d against relative roughness, $\frac{D_{50}}{H_w}$, were obtained while other conditions being kept constant, as shown in Figure 6. The results showed that the more increase in the weir relative roughness the more reduction in the discharge coefficient and that the effects of relative roughness on the discharge coefficient are more pronounced with lower relative roughness. Also, a relation was obtained between the weir discharge coefficient and relative roughness as follows in Eq. (3):

$$C_d = 0.605\left(\frac{D_{50}}{H_w}\right)^{-0.202}$$
$$0.001 \le \frac{D_{50}}{H_w} \le 0.1 \qquad (3)$$
$$R^2 = 0.828$$

Table 1. Variation of water surface elevation (cm) for different roughness relative to non- roughness weir in different cross section upstream of weir.

Roughness size (mm)	Cross section distance from weir crest (cm)					
	0.0 (on crest weir)	10.0	14.0	20.0	25.0	30.0
D_{50} = 0.80	0.16	0.15	0.10	0.06	0.03	0.02
D_{50} = 1.18	0.47	0.11	0.17	0.28	0.27	0.23
D_{50} = 2.36	0.93	0.59	0.76	0.77	0.82	0.72

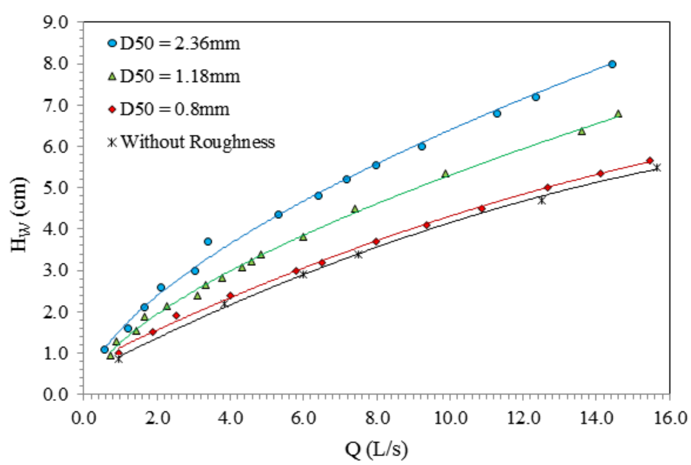


Fig. 5. - Stage-Discharge relation on weir for different roughness sizes.

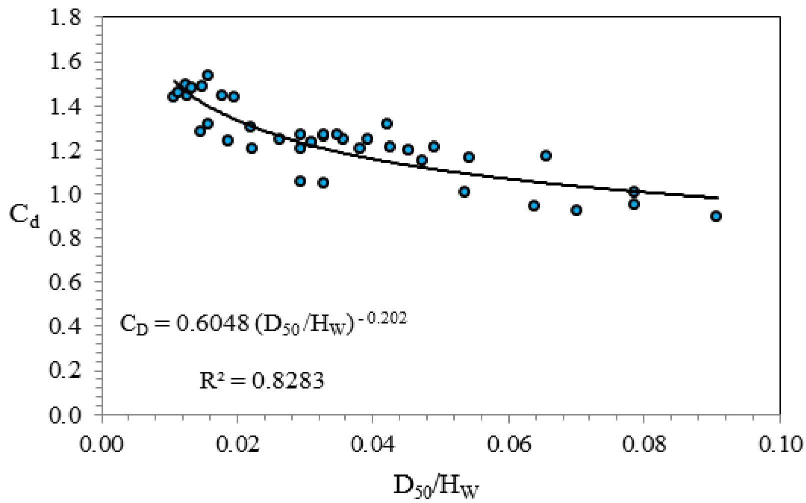


Fig. 6. Discharge coefficient against relative roughness $\frac{D_{50}}{H_W}$

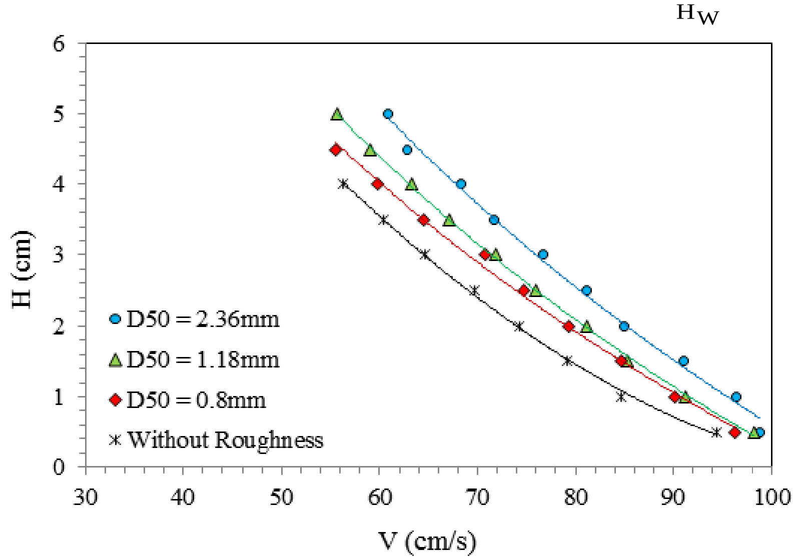
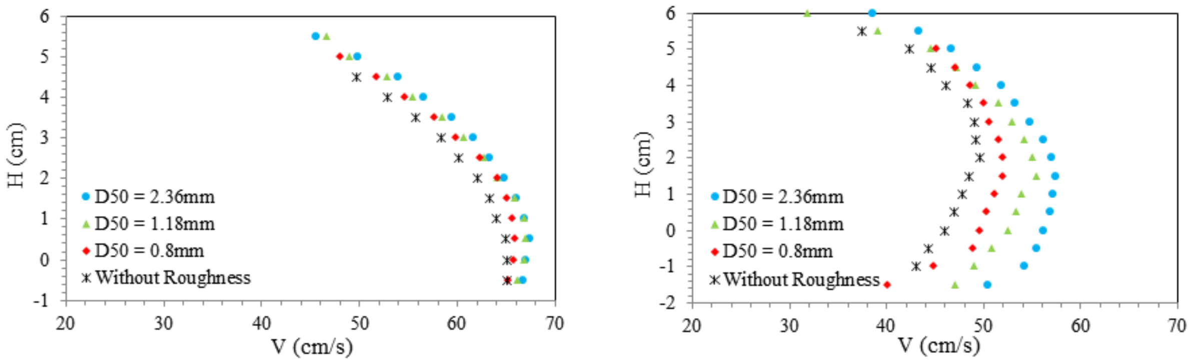


Fig. 7. Velocity profile on weir crest for different roughness sizes (Q=14 l/s)

Roughness Effects on Velocity Profile

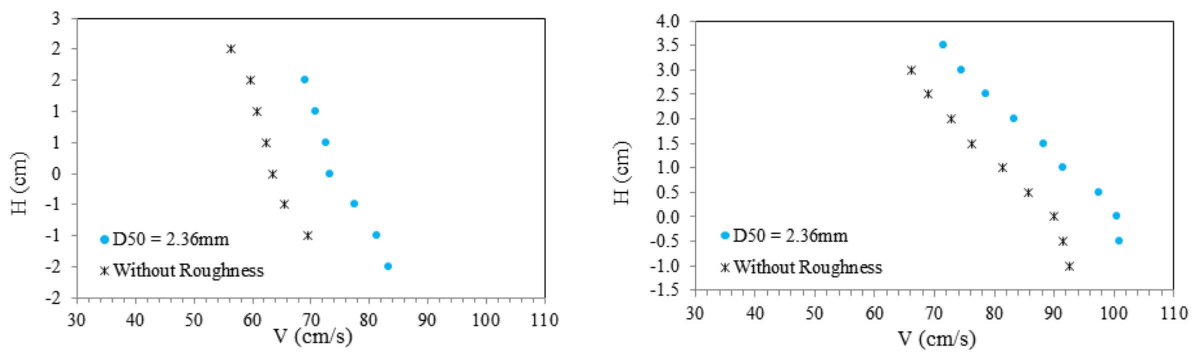
Figure 7 illustrates the velocity profile above the weir crest for different roughness sizes. As seen for all roughness sizes, the maximum value of velocity is observed in depths near the weir crest. The velocity profile becomes more uniform and the average velocity takes higher values as the weir roughness increases. At a certain depth of the weir crest, flow velocity increases as roughness increases. The reason is that flow discharge is constant, and as Figure 4 and Table 1 indicate with increasing surface roughness the water surface elevation increases and therefore the required potential to generate a larger velocity vector at a given depth increases. Also the velocity differences are observed more at points closer to the water surface. In other words, the effects of roughness on velocity values are less near the weir crest compared to the water surface.

Also, Figures 8 and 9 illustrate velocity profiles on sections with a distance of 3cm and 5cm before and after the weir crest, respectively.



a) Section distance to weir crest 3_{cm} b) Section distance to weir crest 5_{cm}

Fig. 8. Velocity profile at different sections before weir crest for different roughness sizes (Q =14 l/s) (H = 0.0_{cm} indicates weir crest elevation).



a) Section distance to crest weir 3_{cm} b) Section distance to crest weir 5_{cm}

Fig. 9. Velocity profile at different sections after weir crest for different roughness sizes (Q=14 l/s) (H = 0.0_{cm} indicates weir crest elevation).

The study of the results also showed that the velocity profile shapes at sections that are at the upstream of the weir crest are extremely different from those on the weir crest while for sections located at the downstream of the weir crest, the velocity profile follows the same trend as that of on the weir crest.

CONCLUSIONS

About 200 experiments were undertaken on the physical model of a circular weir under different hydraulic conditions in order to study the effects of the roughness of the weir body and crest on flow hydraulics, including velocity profile, discharge coefficient, and water surface profile.

It was observed that for a certain discharge, increased roughness size causes the water surface profile ascend to upper level. Also for a certain stage above the weir an increase in the size of roughness reduces the discharge passing over the weir.
Results also showed that the more increase in the weir relative roughness reduces the discharge coefficient. Also a relation was found between the weir discharge coefficient and relative roughness.

The velocity profile becomes more uniform and the average velocity takes higher values as the weir roughness increases. The effects of roughness on velocity values are less near the weir crest compared to the water surface.

The study of the results also showed that the velocity profile shapes at sections that are at the upstream of the weir crest are extremely different from those on the weir crest while for sections located at the downstream of the weir crest, the velocity profile follows the same trend as that of on the weir crest.

REFERENCES

Bazin, H. (1898). "Recent experiments on the flow of water over weirs", Mémoireset Documents, Annales des Ponts et Chaussées, Paris, France, Sér. 7, 15, 2nd Sem, 151-264.

Chanson, H. and Montes, J.S. (1998). "Overflow characteristics of circular weir: effect of inflow conditions", *Journal of Irrigation and Drainage Engineering, ASCE*, 124(3), 152-162.

Creager, W.P. (1917). *Engineering of masonry dams*, John Wiley and Sons, New York, USA.

Escande, L. and Sananes, F. (1959). "Etudes des Seuils Déversants à Fente Aspiratrice. ('Weirs with suction slots.')", *Journal La Houille Blanche*, Dec., No. Special B, 892-902 (in French).

Esmaili, K., Naghavi, B., KouroshVahid, F. and Yazdi, J. (2010). "Experimental and numerical modeling of flow pattern on circular weir", *Journal of Water and Soil*, 24(1), 166-179.

Fawer, C. (1937). "Etude de quelques ecoulements permanents a filets courbes (Study of some steady flows with curved streamlines)", Thesis, Lausanne, Switzerland, Imprimerie La Concorde (in French).

Heidarpour, M., Afzalimehr, H. and Khorami, E. (2002). "Applied of flow function around cylindrical weir crest", *Journal of Technical and Natural Resource*, 6(3), 51-61.

Heidarpour, M., Chamani, M.R. and Khorami, E. (2006). "Characteristics of circular-crested and cylindrical weirs", *Journal of Agriculture Science and Natural Resource*, 12(6), 21-30

Othman, Kh.I., Tahsen, A.Ch. and Ibrahim, A.I.Al-H. (2010). "Effect of size and surface roughness of cylindrical weirs on overflow characteristics", *Al-Rafidian Engineering Journal*, 19(2), 77-89.

Ramamurthy, A.S. and VO, N.D. (1993). "Characteristics of circular crested weir", *Journal of Hydraulic Engineering. ASCE*, 119(9), 1055-1063.

Raupach, M.R., Antonia, R.A. and Rajagopalan, S. (1991). "Rough-wall turbulent boundary layers", *Applied Mechanics Reviews*, 44(1), 1-25

Rehbok, T. (1929). "The river hydraulic laboratory of the Technical University of Karlsruhe, hydraulic laboratory practice", ASME, New York, N.Y, 111-242.

Rouve, G. and Indlekofer, H. (1974). "Discharge over Straight Weirs with Semi cylindrical Crest", *Der Bauinge nieur*, 49(7), 250-256, (in Germany).

Sarginson, E.J. (1972). "The influence of surface tension on weir flow", *Hydraulic Research Delft*, The Netherlands, 10(4), 431-446.

Tahmassebii, S. (2010). "Experimental Study of effect of weir crest roughness on separation region in broad crested weir", MSc. Thesis, University of Shahid Chamran, Ahvaz, Iran.