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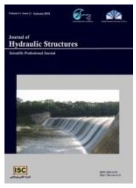

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Experimental Study of Discharge Coefficient of Combination Labyrinth Weirs

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Abstract

Labyrinth weirs are one of the kinds of nonlinear crest weirs causing the increase of discharge capacity for specified height of water level in canals and dams. In this study, the effects of dentate and orifice labyrinth weirs on increasing the discharge capacity were investigated. Experiments were conducted in a laboratory flume with length of 12 m and width of 0.8 m. The nine experimental models with 15 cm height were used. The results showed that for L/W=2 and H/P=0.2, the discharge coefficient of the orifice-dentate labyrinth weir and the dentate labyrinth weir are 75.6% and 17.5%, more than the simple labyrinth weir, respectively. However, dent and orifice may decrease their efficiency in high heads and the discharge coefficient will be close to simple labyrinth weir. The reason for these changes was increasing the flow interference in downstream of labyrinth weir between dents, orifices and weir with increasing discharge. Also, the result showed the efficiency of orifice and dentate on labyrinth weirs will decrease with increasing the weir magnification (L/W) and they lose their effect.

Keywords: Orifice, Dentate, Magnification Ratio, experimental model.

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1. Introduction

Labyrinth weir is one of the non-linear weirs which is used for water surface level control and the flow discharge control in reservoirs of dams, rivers and canals. For a given width, this kind of weirs has longer weir crest in compared to linear weirs. Therefore, they are capable to transfer more water to the downstream in comparison with linear weirs. These weirs are in different types, including triangular, trapezoidal, rectangular, and arch. Hay and Taylor [7] studied on the labyrinth weirs in semi-circular and sharp-crest labyrinth weir. They showed that the labyrinth weir efficiency in low heads at upstream was appropriate and pass more discharge compared

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with linear weirs. Emiroglu et al. [5] experimentally investigated the labyrinth weir and concluded that the discharge coefficient was 1.5 to 4.5 times the rectangular side weirs. Tullis and Crookston [12] examined the triangular labyrinth weir with two cycle types and different apex angles and concluded that in low flow discharge, the discharge coefficient was more than the linear weir. By increasing the flow discharge, the flow interference will increase and the discharge coefficient gets closer to the linear weirs. Christensen [3] studied the effect of cycle number on labyrinth weir efficiency. The results showed that the discharge coefficient decreases by increasing the number of cycles. Seo et al. [10] compared the labyrinth and linear weir (Ogee) and found that the flow discharge through labyrinth weirs is about 71% more than flow discharge in Ogee weir. Meshkavati et al. [9] investigated discharge coefficient at trapezoidal labyrinth weirs. The results showed the upstream water depth of linear weir is about 2.8 times more than the labyrinth weir. Also they provided a relationship for the trapezoidal labyrinth weir discharge coefficient. Dabbling and Tullis [4] investigated the flow upstream of the labyrinth weir with different approach flow angles (0, 15, and 45 degree). Their results showed that the weir efficiency in approach flow angle of 15-degree has no sensible change compared to the angle of zero-degree; however, in the approach flow angle of 45-degree the weir efficiency decreased by 11%. Ahmadi et al. [1] compared simple labyrinth with dentate labyrinth weir and orifice labyrinth weir with one-cycle. The results demonstrated that orifice weir has more discharge capacity than simple and dentate weirs. Ghaderi et al. [6] studied the geometric parameters effect in the trapezoidal triangular labyrinth weirs. The results showed by decreasing the sidewall angle the discharge coefficient decreases due to the collision of the falling jets in the high value of H/P. Bahreh Bar et al. [2] investigated on trapezoidal-orifice, square-orifice and triangular-orifice labyrinth weirs in the laboratory. The results showed that the triangular-orifice labyrinth weir had the highest discharge rate. The aim of the present study is to examine the effect of the use of dent and orifices in the labyrinth weir in comparison with the simple one on the discharge coefficient. The reason for using dentate and orifice is to lower the water level in floods. This happens by opening the dentate and orifice in this situation. Also, having two-cycles of weirs will better show the effect of flow interference on the discharge coefficient.

2. Material and Methods

The experiments of the present study were performed in a glass-wall flume of 12 m length, 80 cm width, and 100 cm height at the Arak University. The maximum flow rate was 90 lit/s. An ultrasonic flow meter was used with an accuracy of 0.01 lit/s. The water elevation measured with a manual point gauge. Figure 1 shows a schematic of the laboratory channel.

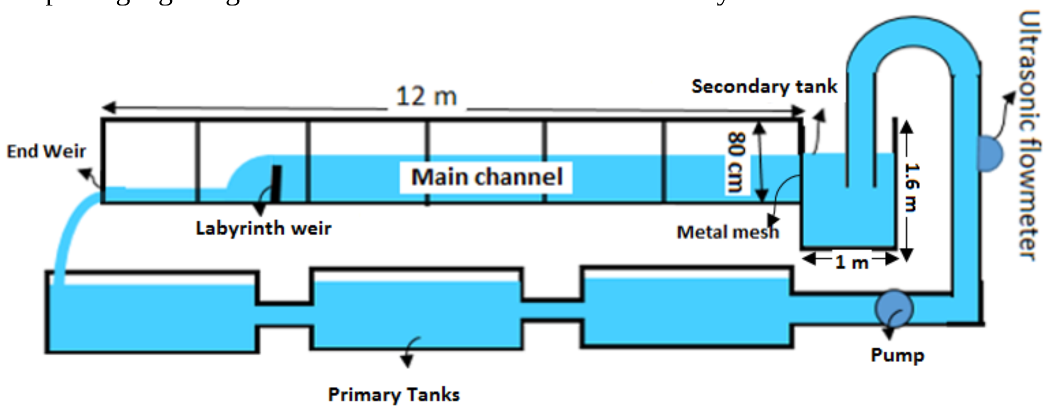

Figure 1.A schematic of the laboratory channel

All models were made in two-cycle with the cycle width of 40 cm and the height of 15 cm. The material of all models was Plexi-glass with thickness of 3 mm which indicates a sharp crested weir. Three types of labyrinth weirs were modeled (Fig. 2), including a simple labyrinth weir, a dentate labyrinth weir and an orifice-dentate weir. Dents and orifices with the width and length of 2 cm were set on the weir with a distance of 2 cm.

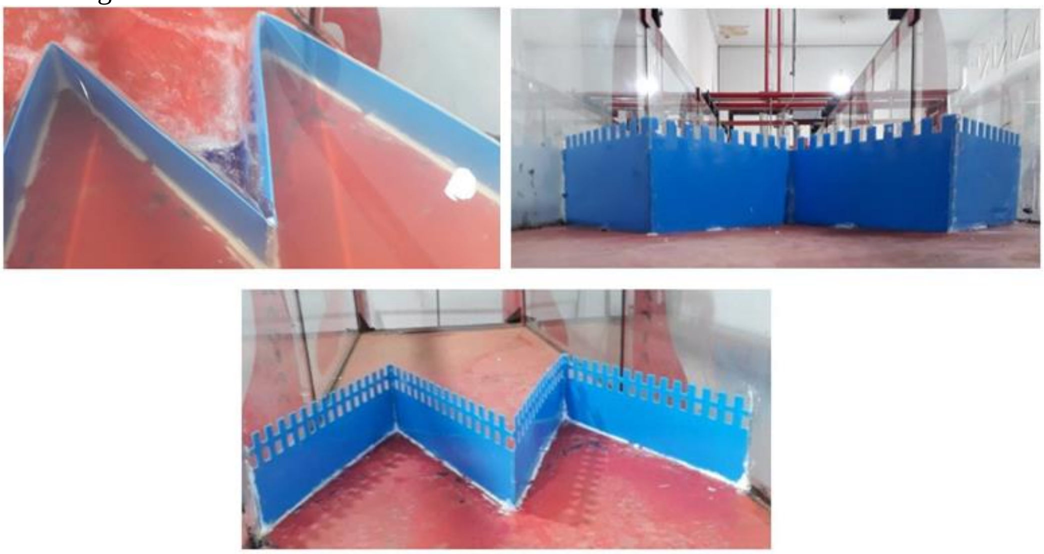

Figure 2. Schematic view of simple, dentate and orifice-dentate labyrinth weir

Considering effective variables, Q as the discharge of labyrinth weir is defined by the function:

$$Q = F(A, L, W, D, P, R, T, H, Hd, g) \tag{1}$$

The parameters in above function are shown in Figure (3) that include half apex length (A), crest length (L), cycle width (W), downstream height of the weir wall (D), upstream height of the weir wall (P), weir crest curvature radius (R), wall thickness (T), total upstream head (H) and downstream water depth (H_d).

By dimensional analysis the discharge can be written as follows [8]:

$$Q = CWH\sqrt{gH} \tag{2}$$

That C is the discharge coefficient. In labyrinth weirs C is a function of H/P (headwater ratio) and L/W (weir magnification).

Finally, In order to evaluate the discharge coefficient (C_d) of labyrinth weir, the following equation is used [11]:

$$Q = \frac{2}{3} C_d L \sqrt{2g} H^{\frac{3}{2}} \tag{3}$$

Therefore, the discharge coefficient is defined as follows:

$$C_d = \frac{Q}{\frac{2}{3}L\sqrt{2g}(H)^{\frac{3}{2}}} \tag{4}$$

where H is total head over the weir (m).

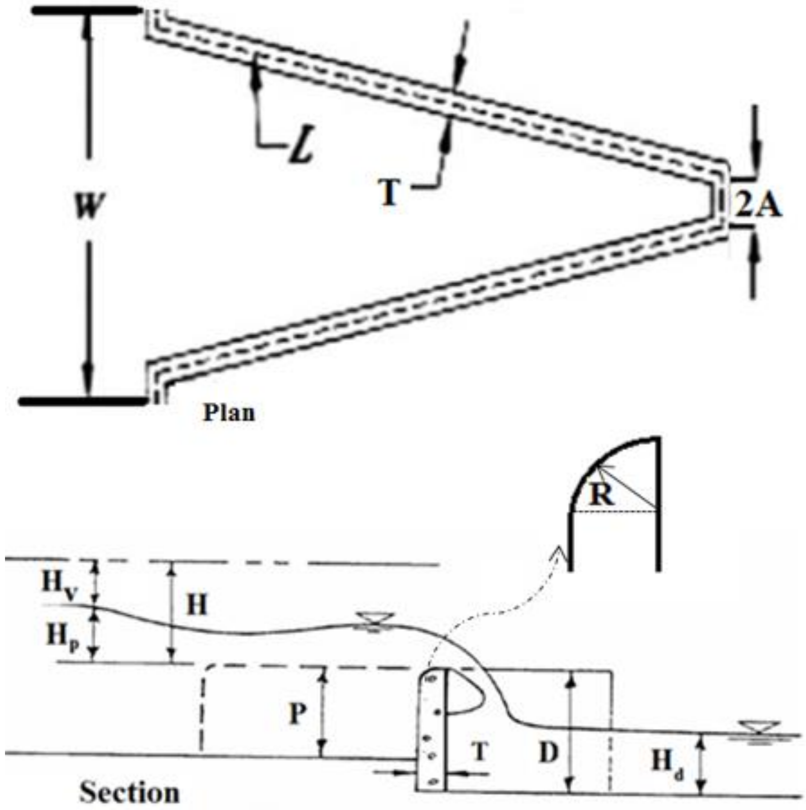

Figure 3. Longitudinal section of simple labyrinth weir

In orifice-dentate labyrinth weir regarding to passing water from the orifice the function of orifice should be considered.

$$Q = C_d A\sqrt{2gh} \tag{5}$$

where, Q is flow discharge through the weir, C_d is discharge coefficient, A is orifice area and h is the total water head from the orifice center. Therefore, by combining Eqs. 3 and 4, the discharge coefficient of orifice-dentate labyrinth weir can be calculated as follows:

$$C_d = \frac{Q}{\frac{2}{3}L\sqrt{2g}H^{3/2} + A\sqrt{2gh}} \tag{6}$$

The discharge coefficient calculated by Eq. (5) was compared with that of the Eq. (3) and it was found that difference between both equations is slight. For example, for H/p = 0.4, the discharge coefficient calculated by Eq. (3) is 0.9 and by Eq. (5) is 0.894. Similarly, for H/P = 0.6, these amounts are respectively 0.681 and 0.68. Therefore, this slight difference illustrates that by using Eq. (3), the effect of orifice can be obvious and so it will be used.

3. Results and Discussion

At first, the simple labyrinth weir was examined. Table 1 shows the results of experiments for this model. In this table, Q is flow discharge (lit/s), P is weir height (m), V is flow velocity (m/s), $V^2/2g$ is dynamic head (m), Hp is upstream water depth, H is total water head (m), H/P is the relative water head and C_d is the discharge coefficient.

Table 1. The discharge coefficients for simple labyrinth weir in L/W = 2.

Q (lit/s)	P (m)	V (m/s)	$V^2/2g$ (m)	H_p – P (m)	H (m)	H/P	C_d
10	0.15	0.074	0.0002	0.018	0.0182	0.121	0.855
20	0.15	0.135	0.0009	0.34	0.0349	0.206	0.747
30	0.15	0.192	0.0018	0.045	0.0468	0.296	0.695
40	0.15	0.248	0.0031	0.055	0.0541	0.361	0.671
50	0.15	0.297	0.0045	0.60	0.0645	0.430	0.645
60	0.15	0.339	0.0058	0.071	0.0768	0.512	0.595
70	0.15	0.308	0.0073	0.080	0.0873	0.582	0.573
80	0.15	0.418	0.0089	0.089	0.0979	0.652	0.552
90	0.15	0.447	0.0106	0.096	0.1066	0.711	0.546

Figure 4 shows the changes of C_d against the ratio of H/P for simple, dentate and orifice-dentate labyrinth weirs for L/W=2. The discharge coefficient of simple, dentate and orifice-dentate labyrinth weirs for H/P=0.2, were 0.74, 0.87, 1.3 and for H/P=0.6 are 0.57, 0.62 and 0.68, respectively. Therefore, for H/P=0.2, the discharge coefficient of dentate labyrinth weir was 17.5% more than simple labyrinth weir; while, for H/P =0.6 their difference reaches 9.7%. In addition, for H/P=0.2, the discharge coefficient of orifice-dentate labyrinth weir was 75.6% more than the simple labyrinth weir and 49.4% more than dentate labyrinth weir. Also, for H/P = 0.6, these values reached 20.3% and 9.6%, respectively. It is observable that the discharge coefficient of simple labyrinth weir is less than dentate labyrinth weir and the discharge coefficient of dentate weir discharge coefficient is also less than orifice-dentate labyrinth weir. With increasing the ration of H/P = 0.2 to H/P=0.6, the difference between the discharge coefficient of simple and orifice-dentate labyrinth weirs decreases by 55.3%. Slight difference of discharge coefficients for H/P = 0.6 compared to H/P = 0.2 shows that the efficiency of all weirs will be close to each other in high heads. Furthermore, in high head, the discharge coefficient of orifice-dentate labyrinth weir will be higher than two other weirs.

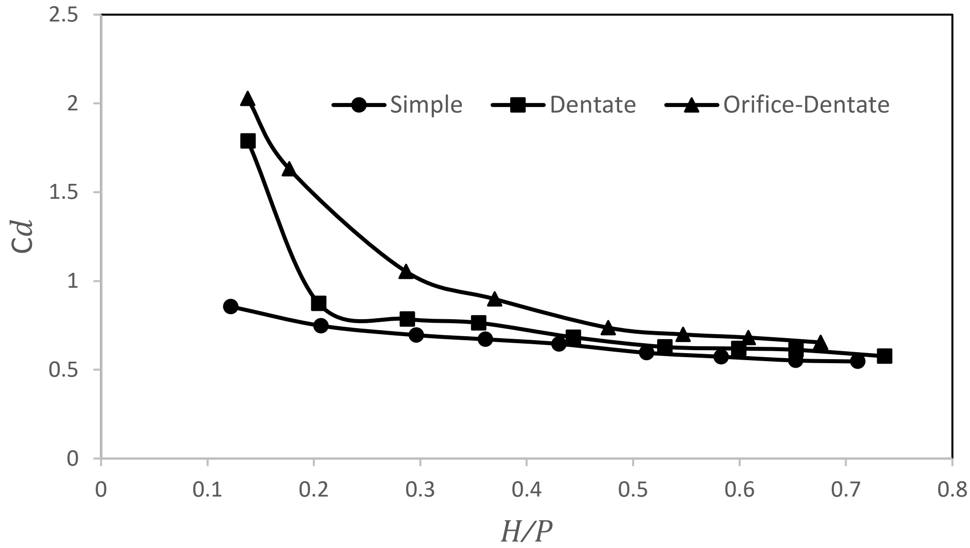

Figure 4. C_d versus H/P with L/W=2 for all models.

Figure 5 illustrates the C_d values versus the ratio of H/P for simple, dentate, and orifice-dentate labyrinth weirs for L/W = 3. As can be observed, for H/P = 0.2, the discharge coefficient of simple, dentate, and orifice-dentate labyrinth weirs were 0.67, 0.85, and 1.1, respectively, and for H/P = 0.6, they are respectively 0.46, 0.47 and 0.51. Therefore, for H/P = 0.2, the discharge coefficient of dentate labyrinth weir was 26.8% more than simple labyrinth weir and for H/P = 0.6 it reaches 2.1%. On the other hand, the discharge coefficient of orifice-dentate labyrinth weir for H/P = 0.2 was 64.1% more than simple labyrinth weir and 29.4% more than dentate labyrinth weir.

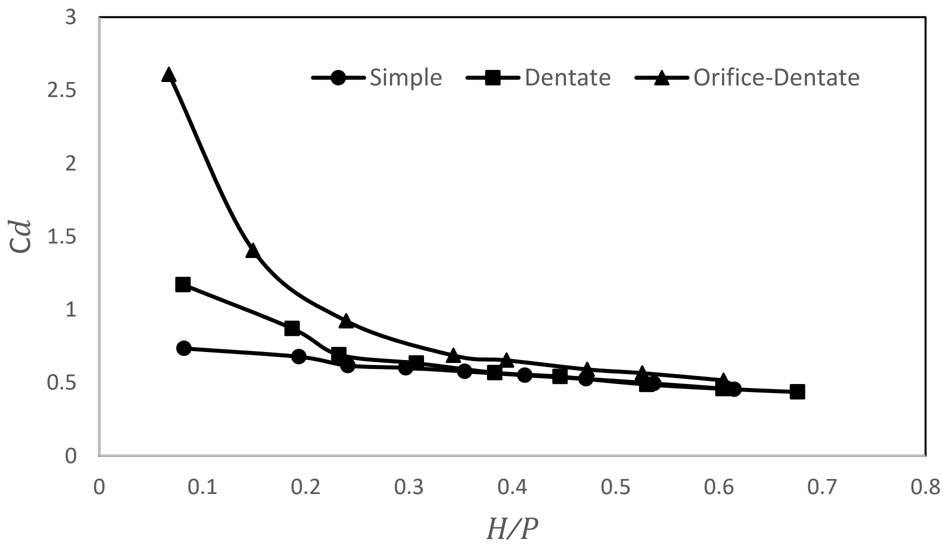

Figure 5. The values of C_d versus H/P for all models for L/W = 3.

Furthermore, for H/P=0.6, it reached 10.6% and 8.5%. By increasing the ratio of H/P=0.2 to H/P=0.6, the difference between the discharge coefficient of orifice-dentate and simple weirs decreased by 53.5, indicating the dent and orifice in high heads lose their efficiency discharge coefficient would be close to the simple labyrinth weir.

According to Fig. 6, for L/W=4 and H/P=0.2, the discharge coefficient of simple, dentate, and orifice–dentate labyrinth weir were respectively 0.55, 0.60, and 0.80. The discharge coefficient for these weirs and for H/P=0.6 were 0.35, 0.36, and 0.40, respectively. Therefore, for H/P=0.2, the discharge coefficient of dentate labyrinth weir was 9% more than simple labyrinth weir and the discharge coefficient of orifice-dentate labyrinth weir was 42% more than simple labyrinth weir and 33% more than dentate labyrinth weir. Furthermore, for H/P=0.6, the discharge coefficient of dentate labyrinth weir was 2.8% more than the simple labyrinth weir and the discharge coefficient of orifice dentate labyrinth weir was, respectively 13.9% and 11.1% more than the simple and dentate labyrinth weirs. In this magnification ratio (L/W), there was also an increase in the discharge coefficient of dentate and orifice–dentate compared to the simple labyrinth weir. About 28% decrease in discharge coefficient of simple and orifice dentate labyrinth weirs from H/P=0.2 to H/P=0.6 showed decreasing the efficiency of dents and orifice in high heads. The discharge coefficients of the three types of labyrinth weirs had low differences than to each other in high heads. The reason for this is the increase of flow interference in high heads.

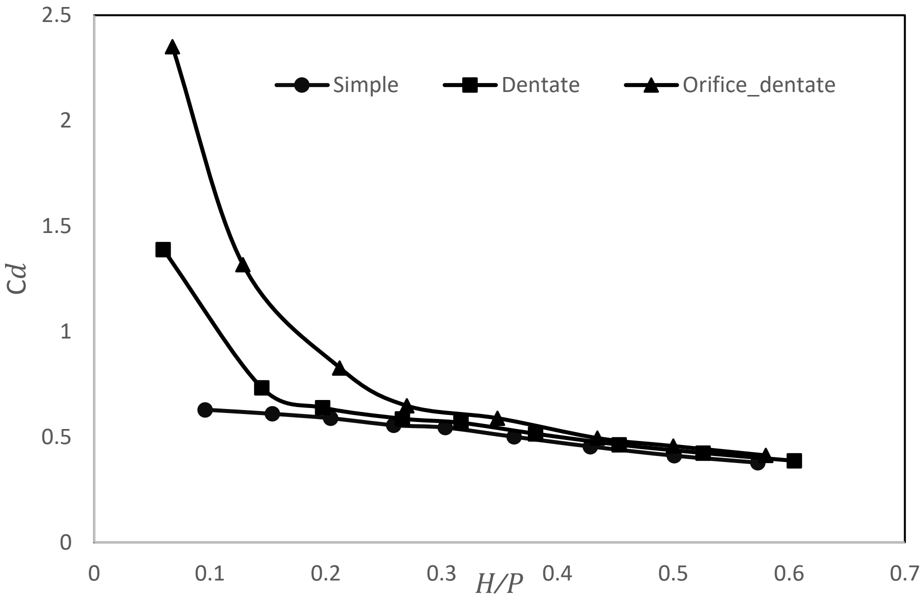

Figure 6. C_d versus H/P for L/W = 4.

Also, the comparison of figures 4, 5 and 6 showed that the increase of L/W in labyrinth weir caused reduction of the discharge coefficient because with increasing L/W, flow transverse curvature in upstream and flow interference in downstream of the weir were increased.

4. Conclusion

In this investigation, the effect of creating dent and orifice on the discharge coefficient of labyrinth weir in two cycles were experimentally investigated. In all magnification ratios, dentate labyrinth weir has more discharge coefficient than simple and orifice-dentate labyrinth weir. Similarly, the discharge coefficient of orifice-dentate labyrinth weir is more than dentate labyrinth weir. Ahmadi et al. [1] has done experiments on dentate and orifice labyrinth weirs in one-cycle. They concluded orifice weir has more discharge capacity than simple and dentate labyrinth weirs that similar results were obtained in this study. But discharge coefficients in Ahmadi et al. study were more than the present study. It seems that increasing the cycle number will create more flow interference and it can reduce the discharge coefficient. Similar to the results of the present study, Bahreh Bar et al. [2] concluded orifice labyrinth weirs has higher discharge coefficient than to simple labyrinth weir especially in low H/P ratios.

The results showed that the increase of the magnification ratio and flow discharge in labyrinth weir caused more flow interference in downstream of the weir and more flow transverse curvature in upstream while both factors will cause reduction of the discharge coefficient. In a similar study, Tullis and Crookston [12] concluded by increasing the flow discharge and the magnification ratio, the flow interference will increase and the discharge coefficient of labyrinth weir gets closer to the linear weirs. This means that all labyrinth weir types, will lose a lot of their main advantage (water surface head reduction) at high discharges.

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