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**The effects of dentate crest and a row of consecutive orifices along and below the crest
edge on labyrinth weir efficiency**

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Abstract:

A labyrinth weir is one of the most effective ways of increasing weir efficiency that it can pass more discharge compared with a linear overflow structure. In this study, two proposed models of labyrinth weir, one with a dentate crest and another with a row of orifices along and below the crest edge were compared with a simple labyrinth weir, measuring their effects on the discharge coefficient. Experiments on nine labyrinth weir models were conducted in the hydraulic laboratory flume. These experiments indicated that creation both of dentate crest edge and row of consecutive orifices lead to an increased discharge coefficient of between 11 to 25.3 percent and 31.6 to 52.9 percent, respectively, relative to simple labyrinth weir. By increasing upstream head water, discharge coefficient for labyrinth weir model with dentate crest and the model with a row of consecutive orifices are closer together and eventually will be the same.

Key words: triangular labyrinth weir, orifice, dentate edge, discharge coefficient.

1. Introduction:

Labyrinth weirs are used to regulate water table and control flow in channels, rivers and flood passing through reservoirs of dams. It can be designed in plans with triangular, trapezoidal, rectangular or curved geometry with alternating cycles in the width of flow. The major criterion in design of this type of weir is the increased capacity of flow transmission over the weir with a fixed height of the weir crest for a determined upstream water depth. This advantage of labyrinth weirs in channels and rivers makes less freeboard and also saves on costs. Given these advantages of labyrinth weirs, their main application is in rivers and channels that have low fixed width. Lux and Hinchliff (1985) provided charts for discharge coefficient of triangular and trapezoidal labyrinth weirs and knew the discharge coefficient as a function of two ratios, H_0/P and L/W that H_0 is total upstream head, P is upstream height of the weir wall, L is crest length and W is cycle width. Tullis et al (2007) examined the effect of downstream submergence of labyrinth weirs and presented dimensionless relationships. Lopes et al. (2008) and Emiroglu et al. (2010) investigated labyrinth spillways in the context of energy dissipation and discharge capacity. Crookston and Tullis (2012) experimentally studied the interference characteristics of nappe and local submergence in labyrinth weirs with two and four triangular cycles and different apex angles. These investigations showed that at low discharges, the labyrinth weir discharge coefficient is greater than for a linear spillway, and the intensity of interference gradually increases with increased flow discharge. This leads to a reduction in the flow discharge coefficient and its value tends converge to the flow discharge coefficient in broad-edged weirs. Crookston et al. (2012) investigated the hydraulic performance of the labyrinth weirs operating under high headwater ratios with physical and numerical modeling. Their results showed that the mathematical model can accurately predict the labyrinth weir head-discharge relationship obtained from the physical model. Emiroglu et al. (2014) investigated the hydraulic characteristics of

trapezoidal labyrinth side weirs. The results showed that a side weir with one cycle has slightly greater discharge coefficient. Also, the empirically obtained equations for discharge coefficient agree considerably with the experimental data. Balar et al. (2015) proposed a mathematical model for double and triple cycle labyrinth weirs and compared it with an experimental model. Their results showed that there is a good accordance between mathematical and experimental models. In this study, to increase discharge coefficient of triangular labyrinth weir, the effects of dentate crest and a row of consecutive orifices below the crest edge were investigated.

2. Materials and methods

2.1. Labyrinth weir discharge equation:

The flow passing over a labyrinth weir is three-dimensional; hence, it is very difficult to describe mathematically. So, the discharge function is obtained from a combination of dimensional analysis and experimental results. In order to simplify the analysis, the scale of models and speeds were considered large enough to be prevented from the effects of viscosity and surface tension. In this study flow nappe breakers have not been used. Considering other effective variables, Q , as the discharge per cycle of labyrinth weir, is defined by the following function:

$$Q = F(L, A, W, P, D, T, R, H_o, H_d, g) \quad (1)$$

The hydraulic and geometric parameters in the above function are shown in Figure 1, including, total upstream head (H_o), downstream water depth (H_d), cycle crest length (L), cycle width (W), half apex length (A), upstream height of the weir wall (P), downstream height of the weir wall (D), wall thickness (T), and radius of the weir crest curvature (R).

Using dimensional analysis, the discharge function can be written as follows (Lux and Hinchliff 1985):

$$Q = CWH_0\sqrt{gH_0} \quad (2)$$

Equation (2) is the general form of the weirs equation, in which g is the gravity acceleration and dimensionless coefficient C is the discharge coefficient. In labyrinth weirs, C is a function of H_0/P (headwater ratio) and L/W (Longitudinal magnification).

2.2. Laboratory Flume:

In this study, hydraulic models were tested within a glass flume to a length of eight meters and a height 70 cm, a width 50 cm. The flume was fed by a pump with a maximum discharge rate of 25 liters per second. The discharge sensor which used is a digital flow meter calibrated by manufacturer in the factory and has high accuracy and discharge measurement accuracy by this device was about ± 0.01 liter per second. Water table level was measured by a rail point gauge that could be moved along the flume.

2.3. Labyrinth weir experimental models:

In this study, nine triangular labyrinth weir models with longitudinal magnifications of $L/W = 2, 3, 4$ were made for three cases of labyrinth weir, with simple crest, with dentate crest and with a row of consecutive orifices along and below the crest edge (Figure 2). To examine the effect of dentate crest on labyrinth weir efficiency, dents with a length and width of 2 cm and at distance of 2 cm from each other were created on the triangular labyrinth weir crest. Also, in order to examine the impact of consecutive orifices along and below the crest edge of labyrinth weir on labyrinth weir efficiency, a row of square-shaped orifices to a width of 2 cm and at a distance of 4 cm (center to center) were created below the crest edge of triangular labyrinth weir models. The models were made of Perspex plates with a thickness of 3 mm, height of 15 cm, and cycle width of 20 cm. According to USBR research, when the headwater is equal to or less than 2 cm and the channel width is less than 15 cm, the effect of viscosity

and surface tension will be obvious (USBR 1980). In the present research, the headwater and the channel width for all models were greater than the recommended value.

3. Results and discussion :

Figures (3), (4) and (5) indicate discharge coefficient changes against headwater ratio changes (H_0/P) for $L/W=2, 3$ and 4 , respectively. Given figures, is obvious that in all cases, the discharge coefficient is significantly reduced along with the increased headwater ratio (H_0/P). It should be noted, with the increase in L/W , the range of discharge coefficient changes will increase. At the beginning of the curves that flow is in the aeration stage, the slope of the curve is steeper than the rest of stages; in other words, at this stage, with the increased total upstream head, the discharge coefficient decreases more quickly. Also, by examining all these curves, it can be seen that by increasing the longitudinal magnification ratio (L/W) the discharge coefficient (C) increases, as well. According to equation 2, increasing the crest length in a constant width and fixed discharge, results in decreasing H_0 and increasing C . As can be seen, in all ratios of L/W , with increasing H_0/P ratio, the discharge coefficient C decreases. This phenomenon probably is because of increasing downstream flow interference. The results obtained in this section confirm the results by Lux and Hinchilff (1985).

According to figures, the C coefficient in dentate crest labyrinth weir is more than the simple one, which indicates the effect of dentate on increasing the weir efficiency. Also, for all models, the discharge coefficient (and therefore, the efficiency) of labyrinth weirs with consecutive orifices below the crest is greater than simple models and also dentate crest models. For Q_{min} and $L/W=2$, the model with consecutive orifices increases the discharge coefficient by 31.6%, while the model with dentate crest increases by 11% than simple labyrinth weir. For Q_{min} and $L/W=3$, the model with consecutive orifices increases

the discharge coefficient by 45.2%, and the model with dentate crest by 13.5% than simple labyrinth weir. Finally, For $Q_{\min}$ and $L/W=4$, the model with consecutive orifices increases the discharge coefficient by 52.9% and the model with dentate crest by 25.3% than simple labyrinth weir. According to the results, in addition to the labyrinth weirs with consecutive orifices have a higher efficiency than to other models, the efficiency of all types of models increases with increasing L/W .

Another interesting observation from the charts is that in $L/W=3$ and $L/W=4$, when the ratio H_0/P exceeds 0.35; the C coefficient variations of models with orifices and models with dentate crest is identical. This means that by increasing of H_0/P than a certain amount, the effect of orifices on the increasing of discharge coefficient than other models has decreased.

4. Conclusion:

In this research the efficiency of two proposed triangular labyrinth weir models, one with dentate crest edge and other with a row of consecutive orifices along and below the crest edge, have been compared with a simple triangular labyrinth weir. By increasing the L/W ratio, the discharge coefficient C increases. Under identical weir dimensions (L , W , and P), discharge (Q), slope and roughness of the bed, the labyrinth weir efficiency with a dentate crest exceeds that of a simple labyrinth weir. In addition, the efficiency of a labyrinth weir with a row of consecutive orifices along and below the crest edge exceeds that of both a simple crest and dentate crest. The results for $Q_{\min}$ and $L/W=2$ ratio indicate that the model with a dentate crest and the model with a row of consecutive orifices increase the discharge coefficient by 11% and 31.6% and for $L/W=3$ ratio by 13.5% and 45.2%, also for $L/W=4$ ratio by 25.3% and 52.9% respectively, compared with simple models. In addition, for $L/W=3$ and $L/W=4$ ratios, when headwater ratio (H_0/P) increases, the efficiency of a labyrinth weir

model with a row consecutive orifices along and below the crest edge and the efficiency of labyrinth weir model with dentate crest converge such that at a headwater ratio (H_0/P) of more than 0.35 the performance of two models do not differ. Finally, while recognizing the need for additional testing, it can be concluded that the increased efficiency of the proposed models recommends them for practical applications.

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Fig. 1. Longitudinal section of passing flow through simple labyrinth weir

Fig. 2. Three triangular labyrinth weir models a) simple, b) with dentate crest and c) with a row of consecutive orifices below the crest edge

Fig. 3. Changes of C coefficient versus H_0/P for all models when $L/W=2$.

Fig. 4. Changes of C coefficient versus H_0/P for all models when $L/W=3$.

Fig. 5. Changes of C coefficient versus H_0/P for all models when $L/W=4$.

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Fig. 1. Longitudinal section of passing flow through simple labyrinth weir
50x51mm (300 x 300 DPI)

Fig. 2. Three triangular labyrinth weir models a) simple, b) with dentate crest and c) with a row of consecutive orifices below the crest edge

63x24mm (300 x 300 DPI)

Fig. 3. Changes of C coefficient versus H_0/P for all models when $L/W=2$.
79x46mm (300 x 300 DPI)

Fig. 4. Changes of C coefficient versus H_0/P for all models when $L/W=3$.

77x41mm (300 x 300 DPI)

Fig. 5. Changes of C coefficient versus H_0/P for all models when $L/W=4$.

157x85mm (300 x 300 DPI)