A Review on the Design and Analysis of the Hydraulic Performance of Labyrinth Weirs

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ABSTRACT

Weirs are one of the most important hydraulic structures for flow control, water discharge measurement, and regulating of upstream water elevation in canals, irrigation networks, and rivers. The researchers studied the performance, efficiency, relationships, and design diagrams of economically and hydraulically optimal and achieved more favorable results than linear weirs by changing the geometric and hydraulic parameters of these weirs. In the present study, the hydraulic performance and the optimal design relationships and curves of the labyrinth weirs were investigated. The results indicated that the hydraulic performance depends on the geometrical and hydraulic parameters and the geometric shape of the flat crest had the lowest discharge efficiency and at low hydraulic load values, the shape of the sharp crest had the highest discharge efficiency. Discharge efficiency decreases as the number of cycles increases and the relative impact of the arching input base details in labyrinth weirs. The maximum value of discharge efficiency in the ratio of total head to weir height is obtained due to the absence of nappe interference and local submergence. The trapezoidal labyrinth weirs have the best hydraulic efficiency and are recommended for use due to their special hydraulic capability.

Keywords: Discharge Efficiency, Flow Measurement, Hydraulic Performance, Labyrinth Weirs, Optimized Design

1. Introduction

In recent years, due to the optimal performance of labyrinth weirs, it has become a suitable alternative to linear weirs. Increasing the total length of these weirs inside the canal or reservoirs with limited width is one of the characteristics of labyrinth weirs [1]. Tullis et al. (1995) tested the trapezoidal labyrinth weir with four cycles and five different crest shapes. The results showed that the capacity of trapezoidal labyrinth weir is a function of the total hydraulic load, effective crest length, and discharge coefficient. The discharge coefficient is a function of the weir height, the total hydraulic load, the weir walls thickness, the crest shape, and the angle of the weirs sidewalls. By examining the effect of these parameters on the performance of labyrinth weirs, they presented new diagrams [2]. Ghaderi et al. (2020) investigated the effect of channel-bed slope and non-prismatic converging channel on the discharge coefficient of labyrinth weirs using a numerical method (FLOW-3D software). Simultaneous use of the slope of the bed and the angle of converging of the discharge significantly increases. The discharge coefficients were 28.64 and 30.42% higher compared to the similar channel model without geometric changes[3]. Ghaderi et al. (2020) investigated experimentally and numerically the effect of geometric parameters of triangular-trapezoidal labyrinth weir on flow-energy dissipation coefficient and flow regime created in the downstream in two different positions of overflow in the reservoir. The modified weir depletes almost all of the energy flowing through the blade from the top of the labyrinth by creating rotational currents in that area so that more energy is wasted by increasing the head angle and height of the weir [4]. Considering the optimal performance of labyrinth weirs compared with linear weirs, the most important hydraulic and geometric parameters of labyrinth weirs were studied comprehensively and extensively. It also challenges the opinions and studies of researchers about the mentioned parameters and discusses the removal of ambiguities and the improvement of hydraulic performance and introduces the ideal conditions related to hydraulic and geometric parameters. In the second part of this research, the design curves and design relationships of labyrinth weirs were evaluated, and the design methods, design interval, parameters affecting the design, and accuracy compared to similar studies are investigated. Finally, in the summary section, tips for optimal hydraulic and economical design are recommended.
2. Methodology

Hydraulic labyrinth weirs

The flow-on of three-dimensional labyrinth weirs and is not easily explained mathematically, and the flow function is obtained as an experimentally study based on dimensional analysis. The labyrinth weir capacity is a function of the total head, the effective crest length, and the discharge coefficient. The discharge coefficient is a function of the total head, weir height, weir thickness, crest shape, tip shape, and side edge angle. To simplify the analysis, the effect of viscosity and surface tension has been ignored [2]. Tullis et al. (1995) proposed a developed equation for trapezoidal labyrinth weirs to design labyrinth weirs. The most significant effect of the discharge coefficient depends on the same effective parameters, relative to the linear weir. The nose of the trapezoidal labyrinth weir at the apex and the angle of the labyrinth are also influential parameters. The Discharge relation to the labyrinth weirs can be expressed as follows [2].

\[ Q = \frac{2}{3} C_d \alpha^2 \sqrt{g L_c H_T^{3/2}} \]  

(1)

Where: \( Q \) is the overflow rate, \( g \) is gravity acceleration, the \( C_d \) is the discharge coefficient, \( L_c \) is the effective weir length, and \( H_T \) is the total energy above the weir.

Figure 1. Scheme of trapezoidal labyrinth weir including geometric parameters [2]

According to Figure 1, the parameters affecting the discharge coefficient include total weir energy (\( H_T \)), the effective length of the weir (\( L_c \)), weir height (\( P \)), weir width (\( W \)), the angle between weir wall (\( \alpha \)), weir wall thickness (\( t_w \)), and the depth of flow (\( y \)). Therefore, based on dimensional analysis, the discharge coefficient was obtained as a function of dimensionless parameters. Dimensional analysis has been performed and various researches such as Tullis et al. (1995) and Hay and Taylor (1970) showed that the non dimension parameter of the ratio of total head to the height of \( H_T / P \) weir was considered as the most important parameter in flow coefficient relationships [2,5].

3. Results and Discussion

Nappe interference

Indelkofer and Rouve (1975) first introduced the phenomenon of nappe interference and investigated the effect of the mixing length of the flowing nappe by studying the vertices of triangular weirs and dividing the flow interference region of the triangular weir into two parts: 1- Close interference of the vertex due to the collision of flow lines from each wall 2- When the flow lines are parallel to the sidewalls, these researchers also presented an experimental relationship for the length of the turbulent region (Figure 2) [6].

Falvey (2003), by defining the relations of the nappe interference length for trapezoidal weirs with a variable wall angle, proved that the flow nappe interference length in triangular weirs is fundamentally different from other labyrinth weirs [7].

Crookston and Tullis (2012) found that parametric methods for limiting the size of the nappe interference region on a weir as a function of weir geometry (sidewall angle and crest shape) and flow conditions (water head and aeration of nappe flow) are on the weir. The term of the nappe interference on the weir causes a decrease in the efficiency of the labyrinth weir discharge by the collision or interaction of the nappe flow near the upstream apex. As the HT increases, the mixing nappe interference over the weir occurs when a
quasi-oblique hydraulic jump occurs. The discharge capacity is close to the upstream of the output cycle and causes the current to flow close to the upstream apex (flow interaction) relative to the free flow mode of the crest, which creates a local submergence condition [8].

**Local submergence**

Local submergence according to Figure (3) occurs when the discharge capacity of the input cycles is greater than the discharge capacity of the output cycles. Local submergence in the weir will be appropriate when a control point downstream does not increase the depth of flow. Local submergence reduces the efficiency of the labyrinth weir discharge, thus modify the downstream and channel cycle geometry, and local submergence for non-arc labyrinth weir occurs at very low $H_t/P$ values [8]. The decrease in the discharge coefficient with increasing $H_t/P$; $H_t/P>0.1$ is due to the development of local submergence in labyrinth weirs [1]. The local submergence region occurs near the upstream apexes, and the local submergence region increases with increasing $H_t$ [8].

![Figure 3. Local submergence region and defined parameters for labyrinth weirs](image)

By increasing the local submergence of other hydraulic phenomena related to the nappe interference of labyrinth weir, including wave stopping, the volume of air in the downstream cycles occurs [8].

**4. Conclusions**

In this research, the parameters affecting the hydraulic performance and the analysis of the curves and the relationships of the design of the labyrinth weirs have been studied in detail. Now, the results are briefly presented as follows.

1. One of the important features of the design method with the ratio of the total discharge of the labyrinth weir to the linear $Q/Q_N$ is the design with the lowest head on the weir and eliminating the effects of surface tension in the model results.

2. The $H/W$ ratio should not be less than 0.35 for the sidewall and the $H/P$ ratio should be greater than 0.3.

3. The $H/P$ parameters and the angle of apex weir can be used as effective parameters to define the discharge coefficient relationship due to their very high accuracy, and other geometric parameters must also be controlled for optimal weir performance.

4. For the included $l/w$ values, the $Q/Q_n$ ratio decreases with increasing $h/w$. Also, the built-in length ($l/w$) increases when the extended crest length ($L_e$) increases, so will the discharge.

**5. References**


