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Article

An experimental investigation into improving the efficiency of rectangular labyrinth weirs

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Abstract: For both existing and new dams, labyrinth weirs are a preferred choice for increasing spillway capacity due to their ability to handle significantly higher water discharges per unit length compared to linear weirs. Through physical models, this study tested ten configurations of rectangular labyrinth weirs to optimize their discharge capacity. The research identified alveoli width and entrance shape as critical factors for performance and efficiency, respectively. Wider alveoli and rounded/triangular entrances demonstrated significant improvements. Additionally, the ratio of length to width was identified as an important factor.

Keywords: control structures; experimental test; rectangular labyrinth

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1. Introduction

Labyrinth weirs are a flood control design that can handle more water flow than straight weirs, even though they take up less space (Figure 1). Its curved plan-view shape permits an extended crest length within the current spillway width. By utilizing a non-linear plan view, labyrinth weirs achieve a longer crest length within the same spillway width. As demonstrated by Tullis et al. [1], this innovative design can greatly enhance discharge capacity, achieving multiple times the capacity of a linear weir. By choosing labyrinth weirs, projects can achieve significant cost savings compared to traditional approaches like rehabilitating or building entirely new dams (Lemperière and Ouamane [2]). In contrast, with a lower specific discharge capacity (approximately 2.15 h^1.5 for Creager), a linear weir may impact project costs due to the need for adjustments to compensate for efficiency. Hence, the labyrinth weir is ideal for implementation in dam projects or in both natural and artificial channels where there is a requirement to efficiently augment spillway discharge and/or storage capacity at a reasonable cost. The Keno Canal project in the USA was the first to be equipped with this type of weir, implemented by Murphy [3]. It's noteworthy that a linear weir would need to be three times longer than the labyrinth weir to handle the same amount of water flow. However, the initial investigation into labyrinth weir performance was conducted by Gentilini in [4]. While

Gentilini [4] initiated the study by examining a triangular shape, Hay and Taylor [5] made significant contributions to our understanding of how labyrinth weirs impact discharge capacity. Recently, numerous investigations on different labyrinth weir shapes have been conducted to understand and improve their efficiency, including Tanga et al [6], Mojtaba et al. [7], Bshkoj et al [8], Farehe et al. [9], Parisa et al [10], Ahmad et al. [11], Ghare [12], Anees et al. [13], Erick et al. [14], Mohammad et al [15], Akbar et al. [16], Nina et al. [17], Ali et al [18], Caterina et al [19], Rustiati et al [20], Erdinc et al [21] and Azarpeyvand et al [22] .

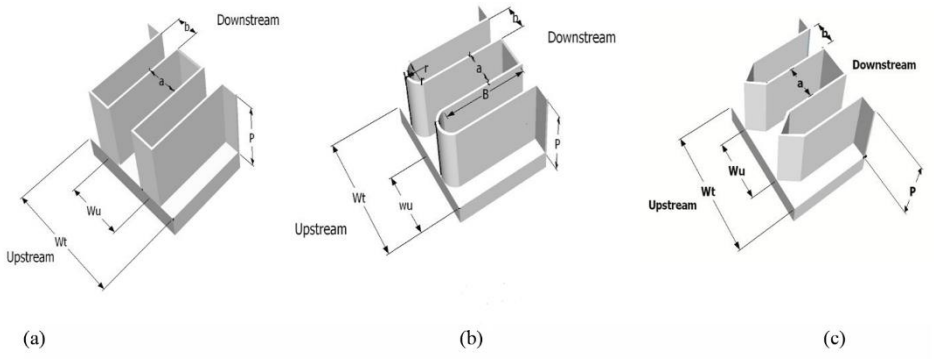


Figure 1. Entrance shapes variations

1.1. **Flow efficiency in rectangular labyrinth weir**

Despite their simple geometry, rectangular labyrinth weirs offer a compelling combination of high performance and low construction costs. However, research on their performance has been limited.

Ouamane and Ben Said [23] as well as Ben Said and Ouamane [24, 25] explored different physical models of rectangular labyrinth weirs, which were crafted with entrances featuring rounded configurations. Their findings revealed that the rectangular labyrinth weir outperforms the trapezoidal weir, especially when dealing with moderate discharge rates. Observations indicated that the rectangular labyrinth configuration provides greater discharge capacity than the trapezoidal shape when the L/W ratio equals 4 and 5 [24, 25]. It has been found that this type of labyrinth weir can reduce costs due to its more compact dimensions.

The main goal of this study is to offer practical insights for designing rectangular labyrinth weirs for use in channels and rivers. The models tested included three flat rectangular labyrinth weirs with alveoli width ratios (a/b) of 0.67, 1, and 1.5, along with additional models featuring rounded entrances for width ratios of 0.67, 1, 1.5, 1.3, and 1.6. Furthermore, additional tests were conducted on three models: two rounded rectangular labyrinth weirs with crest length ratios of L/W 4 and 6, and one featuring an L/W ratio of 6 with an angular entrance. These tests aimed to enhance understanding of labyrinth behavior by varying the L/W ratio from 4 to 6.

1.2. **Capacity of discharge in labyrinth weirs**

The following equation was used to quantify the capacity of labyrinth weirs:

$$\boldsymbol{Q = C_w\sqrt{2g}WH^{\frac{3}{2}}} \quad (1)$$

Where:
Q: discharge over weir (m3 /s)
Cw: discharge coefficient
g: gravity acceleration (m/s2)
W: weir width (m)
H: total upstream head (m)

2. Methodology

Experiments on the rectangular labyrinth weir's physical model were conducted at Biskra University's Hydraulic Planning and Environment Laboratory. These experiments occurred within a straight rectangular channel, measuring 12 meters in length, 1 meter in width, and 1 meter in depth (Figure 2). The experimental setup included two pumps capable of delivering up to 180 liters per second into an upstream stilling basin. This basin featured a perforated wall to maintain uniform approach flow conditions. One sidewall of the channel was glass for flow observation. Electromagnetic and ultrasonic flowmeters measured discharge, while ultrasonic level sensors gauged flow depth. Water circulated from a storage tank through the flume via a stilling basin. After flowing over the weir crest for 5 minutes, data was recorded. The models used were constructed from metal sheet with a height of 15 cm. Free flow conditions were maintained, testing approximately fifteen discharges ranging from 30l/s to 150l/s per model, repeated thrice for accuracy, totaling 366 runs.

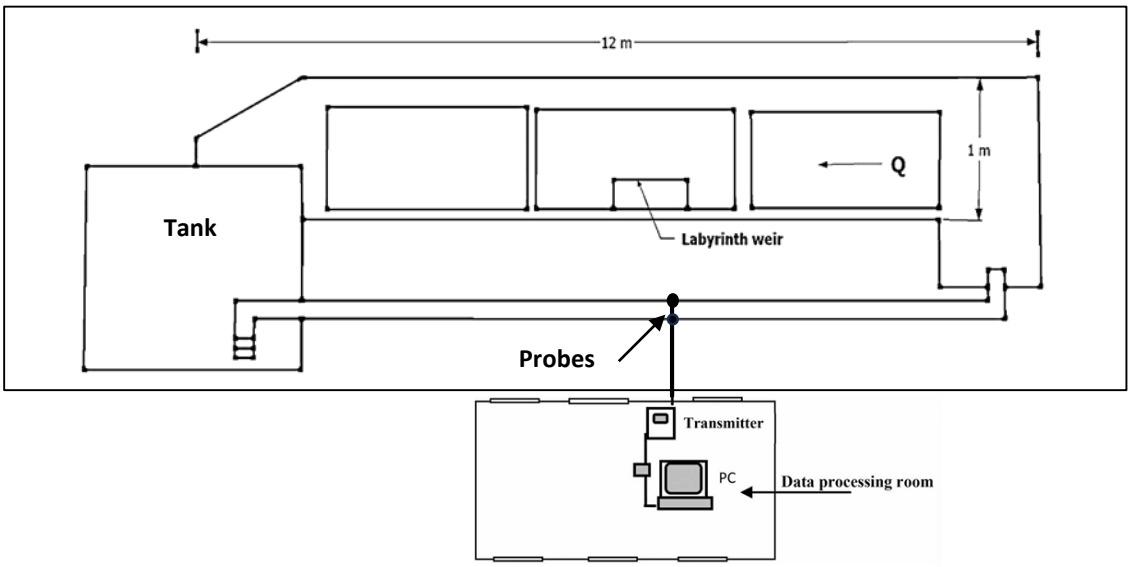


Figure 2. Experimental flume layout

3. Results and discussions

3.1. Alveoli width a/b

Three physical models with L/W ratio of 4 and flat entrance were used to investigate the effect of varying inlet-to-outlet alveoli width ratios (a/b = 0.67, 1, 1.5) on their performance (figure 3). Alveoli width ratios of 1 and 1.5 exhibit relatively similar efficiencies. At moderate head ratios, utilizing a/b = 1.5 yields a potential increase of up to 2% in comparison to a ratio of 1. The model with an a/b ratio of 0.67 exhibited the lowest weir capacity compared to the models with a/b ratios of 1 and 1.5. Efficiency loss reaches 10% for lower to moderate head ratios (Ht/P = 0.2 to 0.7). It is evident that as the values of a/b increase, the capacity of the inlet alveoli also rises, leading to enhanced efficiency of the labyrinth weir.

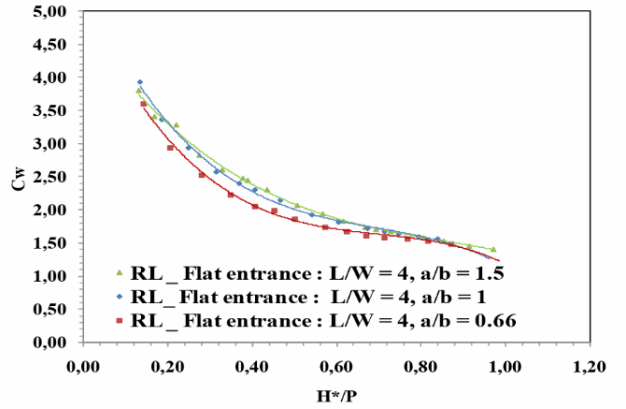


Figure 3. Alveoli width effect

3.1.1. Entrance shape effect

In this phase of the study, both flat and rounded entrances were investigated to evaluate their impact. The comparison involved eight models of rectangular labyrinth weirs, all with an L/W ratio of 4. However, the range of a/b ratios varied between 0.67 and 1.5 for weirs with flat entrances and between 0.67 and 1.63 for those with rounded entrances. For an a/b ratio of 0.67 and moderate head ratios ranging from 0.3 to 0.8, a model with a rounded entrance demonstrated an increase in discharge efficiency of up to 6% compared to a model with a flat entrance, as illustrated in figure 4. However, for low and high relative heads, both labyrinth weirs exhibit similar efficiencies. At a/b = 1, the rounded shape offers a slight improvement over the flat entrance, resulting in an approximate 5% gain in discharge efficiency (see Figure 5).

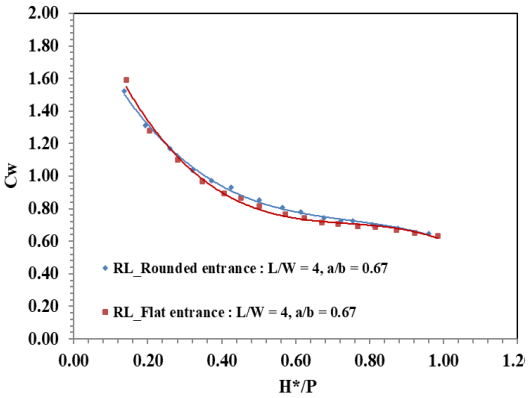


Figure 4. Effect entrance for a/b = 0.67

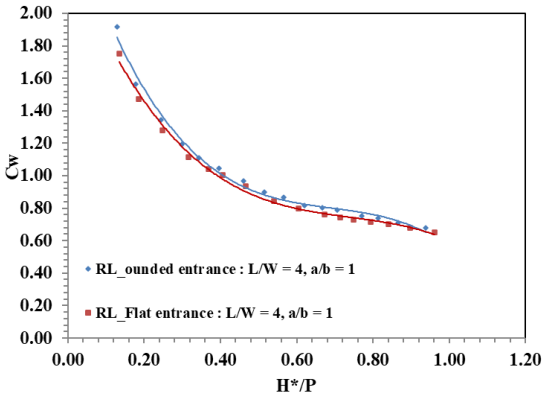


Figure 5. Effect entrance for a/b = 1

For a/b > 1, employing rounded entrances enhances the efficiency of all tested models. The gain in discharge capacity can reach up to 12% (figure 6).

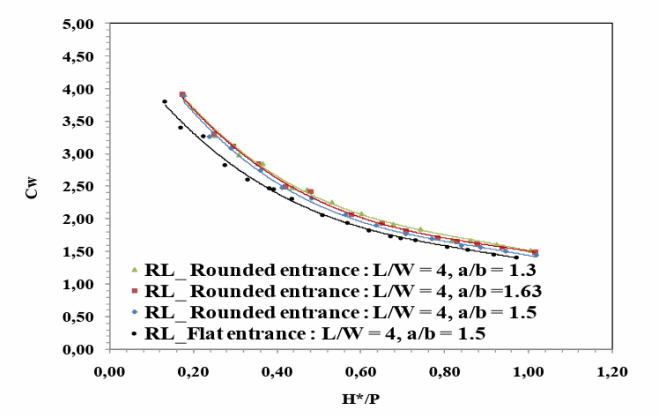


Figure 4. Effect entrance for various ratio a/b.

3.1.2 Effect of developed length

Ideally, for labyrinth weirs with low relative head (Ht/P), the discharge flow (Q) increases proportionally with the weir's crest length (L). However, under high head conditions, the flow can influence the effectiveness of the crest length, thereby diminishing its capacity. Thus, it is essential to assess how this process can impact efficiency from both hydraulic and economic perspectives. To achieve this, the rounded rectangular labyrinth weir with a crest length ratio of L/W = 4 was compared to two rectangular labyrinths under channel conditions. These two models have the same crest length ratio of 6, but they feature different entry forms. The initial model features a rounded entrance, whereas the alternative is equipped with an angular entrance.The experimental results confirm that the crest length is a dominant parameter governing the hydraulic efficiency of rectangular labyrinths. Increasing the crest length ratio from 4 to 6 significantly enhances its capacity, particularly for low heads (figure 7). Furthermore, the analysis of these results reveals that the labyrinth model designed with an angular entrance is a more efficient variant in terms of hydraulic efficiency compared to the labyrinth weir with a rounded entrance, for both L/W ratios of 4 and 6.

For an H/P ratio of 0.3, the results indicate that adopting a triangular shape for the entrance increases the discharge capacity by up to 3% compared to the rounded rectangular labyrinth weir with the same L/W ratio. It also enhances discharge efficiency by up to 14% compared to a rounded labyrinth with an L/W ratio of 4. However, for the rounded entrance and when the L/W ratio is 6, there is an increase in discharge efficiency of up to 8% compared to the model with an L/W ratio of 4 for an H/P ratio of 0.3.

For an H/P ratio of 0.7, the angular labyrinth weir remains the most efficient variant. However, the labyrinth with an L/W ratio of 4 becomes more efficient relative to the labyrinth with an L/W ratio of 6. The discharge efficiency variance between the angular labyrinth weir and the two rounded labyrinth weirs is 2% for L/W = 4 and 3% for L/W = 6. Interestingly, the rounded rectangular weir with L/W = 4 showed a 2% improvement in efficiency compared to the rounded labyrinth weir with L/W = 6.

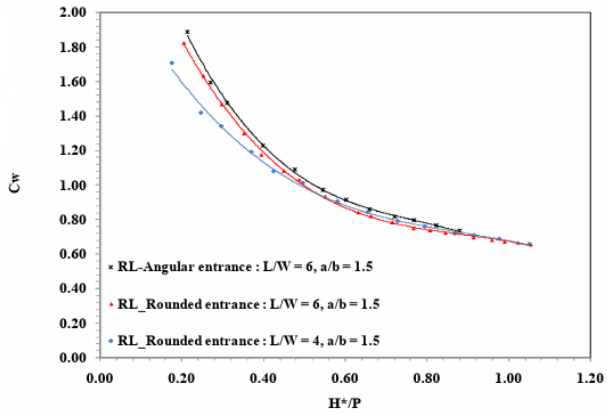


Figure 5. Effect of the developed length.

4. Conclusions

This study explores how varying the inlet-outlet width ratio, entrance shape, and crest length ratio (L/W) affects the discharge efficiency of rectangular labyrinth weirs using channel experiments. The principal conclusions drawn from this study are as follows:

- A weir with an a/b ratio of 1.5 demonstrated a 10% increase in efficiency compared to a model with a/b of 0.67, and a 2% improvement over a model with an a/b of 1.
- The weir entrance significantly impacts discharge efficiency, particularly for a rectangular labyrinth with an a/b ratio greater than 1.
- The angular rectangular labyrinth weir consistently proves to be the most efficient variant across all tested relative heads. However, the capacity of the rounded rectangular labyrinth with an L/W = 6 decreases compared to the labyrinth with an L/W = 4. The latter becomes more efficient, particularly for high heads.

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