

Wave Labyrinth Weir: A New Shape Spillway to Minimize the Effect of the Vertex Angle

Arody Tanga¹, Muh. Galib Ishak¹, Yassir Arafat^{1*}

¹ Department of Civil Engineering,

Tadulako University, Bumi Tadulako Tondo, Palu, 94117, INDONESIA

*Corresponding Author: iazzyr@gmail.com

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Abstract

Increasing the discharge capacity of spillway structures is essential for efficient water management and flood control. This can be achieved in various ways, one of which is by lengthening the spillway crest. Labyrinth weirs, which provide a longer crest length compared to linear weirs within the same channel width, are commonly designed in trapezoidal, triangular, or rectangular forms. However, the convergence of the weir walls at sharp vertex angles tends to reduce discharge capacity. To address this limitation, a new wave labyrinth weir design—free of sharp corners—was proposed in this study to minimize the adverse effects of vertex angles. The shape of the wave labyrinth weir was derived from the cosine wave equation. The influence of the vertex angle was evaluated based on the discharge coefficient (C_d) at various upstream heads. The experimental investigation was conducted under free-flow conditions in a rectangular flume measuring 4.80 meters in length, 50 centimeters in width, and 40 centimeters in depth. Two physical models were fabricated using acrylic: a basic triangular labyrinth weir and the proposed wave labyrinth weir. Both models shared the same crest length ($L = 87$ cm) and height ($P = 10$ cm). Flow measurements were obtained through point gauge readings and the Thomson weir method. The results showed that the maximum discharge coefficient ($C_{d \text{ max}}$) for the wave labyrinth weir reached 0.88, compared to 0.82 for the triangular labyrinth weir. This confirms that the wave labyrinth weir effectively reduces the negative impact of vertex angles on discharge performance. In addition, the wave configuration contributed to smoother nappe flow and reduced turbulence, suggesting greater flow stability compared to the conventional design.

1. Introduction

Increasing spillway discharge capacity without raising upstream water levels or widening channels remains a major challenge in hydraulic engineering, primarily due to environmental, economic, and structural constraints that limit large-scale modifications to existing waterways. Consequently, weirs are essential hydraulic structures used to control water levels and facilitate various functions in rivers, reservoirs, and canals, including irrigation, hydropower generation, and navigation [1]. Specifically, in irrigation systems, weirs are commonly utilized to create a hydraulic head on the surface of a river, thereby enabling the controlled distribution of water through irrigation channels. Typically, weirs are linear in shape and positioned at a right angle to the river's flow. However, constructing weirs in flat or low-gradient areas poses considerable challenges. In these conditions, it is often necessary to maintain a low upstream water level to minimize backwater effects and reduce the required length

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of embankments. To address these challenges, the conventional discharge equation for weir flow offers several potential solutions. Desired outcomes can be achieved by increasing the length of the spillway crest, enhancing the discharge coefficient, or employing a combination of both strategies. Notably, these adjustments can be made without the need to widen the spillway channel or raise the upstream water level.

Furthermore, to further optimize flow regulation, labyrinth weirs have been developed. These innovative structures extend the effective crest length, thus increasing discharge capacity within a fixed channel width, which is particularly advantageous in areas with spatial constraints. The concept of the labyrinth weir was first introduced by Gentilini [2] in 1941. However, comprehensive design guidelines were not established until later by Hay & Taylor [3], building upon foundational work by Taylor [4]. Subsequently, Tullis *et al.* [5] developed a standardized discharge equation specifically for labyrinth weirs, which provides clearer insights into the factors influencing their performance. Their study demonstrates that the discharge coefficient is significantly affected by several critical parameters, including the type of labyrinth, total upstream head, wall height and thickness, sidewall angle, and crest shape. Each of these factors plays a vital role in determining the efficiency and performance of the weir in regulating flow and water levels.

The type of labyrinth, for instance, dictates the path the water must take over the crest, which in turn influences the energy dissipation and flow distribution. Similarly, the total upstream head, or the height of water upstream of the weir, is a key factor in determining the potential for flow over the weir and directly impacts the discharge capacity. In addition, wall height and thickness are also crucial elements, as they define the structural integrity and flow resistance of the weir. Thicker walls can increase stability but may introduce additional flow resistance, while the height of the wall determines the maximum water level that can be safely accommodated. The angle of the sidewalls is another important factor, as it affects the flow direction and velocity as water passes over the crest, influencing the overall efficiency of the weir in terms of flow control and energy dissipation.

Crest shape is equally significant, with different profiles offering distinct advantages depending on the specific design requirements of the weir. Common crest shapes for labyrinth weirs include sharp-crested, flat-top, quarter-round, half-round, and ogee profiles. Notably, each of these shapes has particular benefits: sharp-crested weirs tend to provide high flow rates but may require more precise control, flat-top crests offer a more stable flow with less turbulence, quarter-round and half-round crests can reduce the risk of erosion and maintain flow stability, while ogee profiles are often used to optimize flow capacity and minimize flow separation. The selection of the appropriate crest shape is therefore a crucial decision, as it must align with both the hydraulic conditions and the functional goals of the weir design [6].

Based on plan form geometry, labyrinth weirs are classified into three fundamental configurations: rectangular, triangular, and trapezoidal. In terms of hydraulic performance, previous studies have primarily focused on the influence of geometric parameters on the hydraulic characteristics of labyrinth weirs [7] – [12]. An experimental study by Tanga *et al.* [13] concluded that the triangular labyrinth weir is more hydraulically efficient than the other types. This conclusion was further supported by a subsequent study by Tanga *et al.* [14], which demonstrated that labyrinth weirs with shorter upstream and downstream wall lengths exhibited higher hydraulic efficiency. However, the disadvantage of the triangular type lies in the effect of the vertex angle, which leads to a reduction in discharge capacity [4]. In this context, Indlekofer & Rouvé [15] conducted a theoretical study on sharp-crested triangular labyrinth weirs and introduced the concept of nappe interference as a consequence of the vertex angle. Nappe interference refers to the disruption of flow caused through the convergence of nappes emanating from opposing weir walls proximate to the upstream apex. They found that such interference reduces the effective crest length available for discharge.

The portion of the crest influenced by this phenomenon is commonly referred to as the disturbance length. This term encapsulates the specific area where flow disruptions occur, leading to a variety of hydraulic effects that can significantly influence discharge efficiency in weir systems. Furthermore, in a broader context, Crookston & Tullis [1] conducted a comprehensive investigation into the complex phenomenon of nappe interference. Their research focused on identifying various flow characteristics that adversely affect the hydraulic performance of labyrinth weirs, including the detrimental impacts of localized submergence. Their findings revealed that both nappe interference and local submergence are not isolated phenomena but are instead significantly influenced by a range of operational parameters. These parameters include nappe aeration conditions, which describe the extent to which the flow is exposed to air and how this exposure affects its stability and performance; apex length, which describes the configuration of the weir apex in relation to the flow; sidewall angle, which can alter the flow direction and velocity; and total upstream head, a critical factor that affects the overall flow rate and pressure conditions upstream of the weir, all of which are particularly important.

The conclusions drawn by Crookston & Tullis [1] were subsequently validated and expanded upon by Kumar *et al.* [16]. Their experimental studies focused on sharp-crested triangular labyrinth weirs operating under free-flow conditions within a rectangular channel setting. Through a series of controlled experiments, they demonstrated that nappe interference has a pronounced effect on the discharge coefficient of the weirs. Specifically, their results indicated that as the headwater ratio increased, the adverse effects of nappe interference became more pronounced, leading to a significant reduction in discharge efficiency. Taken together, this body of

work underscores the intricate interplay of hydraulic factors that influence the performance of labyrinth weirs and highlights the necessity for further investigation into optimizing their design and operation to mitigate these inefficiencies.

On the other hand, recent studies have focused on modifying the corner geometry of labyrinth weirs to improve their hydraulic performance. Yousif *et al.* [17] experimentally demonstrated that the corner shape of rectangular labyrinth weirs significantly influences their discharge capacity. Their findings showed that replacing the flat apex of a rectangular labyrinth weir with a semi-circular apex increased the discharge capacity by approximately 19%, despite a reduction of about 14% in the original effective crest length. Similarly, Villarroel *et al.* [18] investigated the effect of modifying the apex geometry from a trapezoidal to a circular shape. Their results indicated that labyrinth weirs with circular apices exhibit higher discharge coefficients compared to those with trapezoidal apices.

In summary, an exhaustive examination of the scholarly literature indicates that the influence of vertex angles on discharge performance can be substantially mitigated through alterations to the corner geometries of labyrinth weirs. Nevertheless, there has been limited research on labyrinth weir types that eliminate corner angles entirely. In this context, Zadeh *et al.* [19] experimentally investigated a sinusoidal weir configuration. However, because the sinusoidal profile is based on a circular arc, the total spillway length depends on the arc radius of each cycle.

To address this limitation, the present study explores a wave labyrinth weir as an alternative design that eliminates both corner angles and arc-based geometry. This new configuration is intended to minimize the negative effects of vertex angles while maximizing discharge capacity. Accordingly, the principal aim of this investigation is to propose an innovative design for the wave labyrinth weir, intended to enhance performance by attenuating the impact of vertex angles. Although previous studies have attempted to improve performance by modifying the apex shape (e.g., to semi-circular or trapezoidal forms), none have completely eliminated sharp corners. Therefore, this study presents a cornerless design derived from a cosine wave profile, introducing a fundamentally new approach to improving labyrinth weir efficiency. This distinguishes the wave labyrinth design from sinusoidal or arc-based models, which still rely on geometric curvature constraints.

Ultimately, this research not only aims to advance the theoretical understanding of labyrinth weir functionality but also seeks to provide a practical framework for enhancing their operational performance in real-world applications. Through experimental validation and analysis, this study endeavors to demonstrate the efficacy of the wave labyrinth design in increasing discharge efficiency while mitigating the negative implications of corner angles.

2. Methodology

2.1 Wave Labyrinth Weir Design Equation

Since a labyrinth weir has a zig-zag plan shape, the wall of the wave labyrinth weir was designed using a curved shape based on the mathematical expression of a cosine wave, as defined in Eq. (1) and illustrated in Fig. 1.

$$y(x) = \pm A \cos kx \quad (1)$$

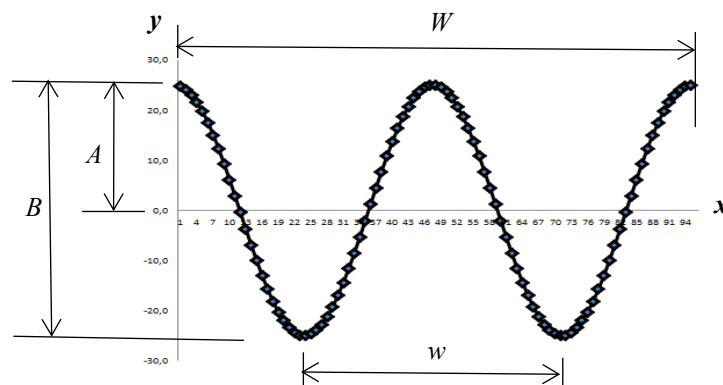


Fig. 1 Cosine wave curve for two number of weir cycles

In this equation, (x,y) represents the coordinates along the x- and y-axes; A is the wave amplitude; k is the wave number; W is the total width of the labyrinth; N is the number of wave cycles; w is the width of a single labyrinth cycle; and B is the total labyrinth length. The amplitude (A), cycle width (w), and wave number (k) are determined using Eqs. (2)-(4):

$$A = B/2 \quad (2)$$

$$w = W/N \quad (3)$$

$$k = 2\pi/w \quad (4)$$

2.2 Hydraulic Equation for Wave Labyrinth Weir

The governing equation used to describe the discharge (Q) over a wave labyrinth weir follows the formulation proposed by Tullis *et al.* [4]. Fig. 2 presents the primary hydraulic parameters of the labyrinth weir.

$$Q = \frac{2}{3} C_d L \sqrt{2g} H_T^{1.5} \quad (5)$$

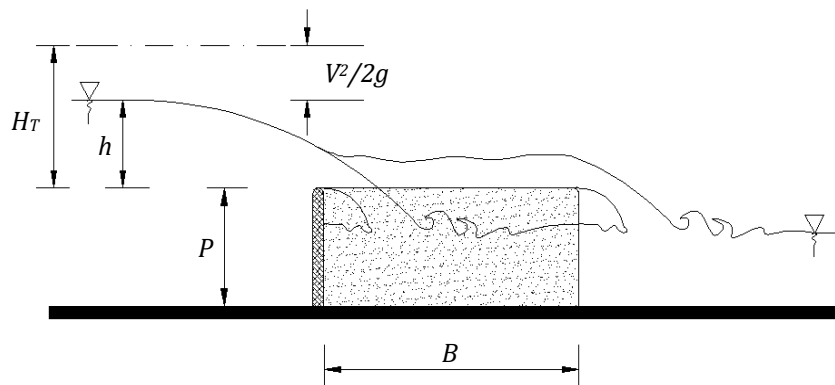


Fig. 2 Flow over labyrinth weir [13]

where Q is the flow rate over the labyrinth weir; C_d is the dimensionless discharge coefficient, which depends on the geometric parameters of the labyrinth weir; L is the effective length of the weir crest; g is the acceleration due to gravity; and H_T is the total upstream head, as defined in Eq. (6).

$$H_T = h + V^2/2g \quad (6)$$

Here, h represents the head over the weir, measured from the crest to the upstream water surface, while V denotes the mean velocity of the approaching flow.

2.3 Effects of the Vertex Angle on the Hydraulic Efficiency

The vertex angle refers to the internal angle formed at the apex of the repeating crest geometry, measured between two adjacent sidewalls of the weir. The vertex angle directly affects how the apex geometry influences the distribution and velocity of flow over the weir.

A key impact of this parameter is its potential to cause nappe interference in labyrinth spillways. This occurs when nappes flowing over adjacent weir sections collide, thereby reducing hydraulic efficiency. Indlekofer & Rouvé [15] introduced the concept of the *nappe effective disturbance length* (L_d) to describe the portion of the crest affected by such interference, as illustrated in Fig. 3.

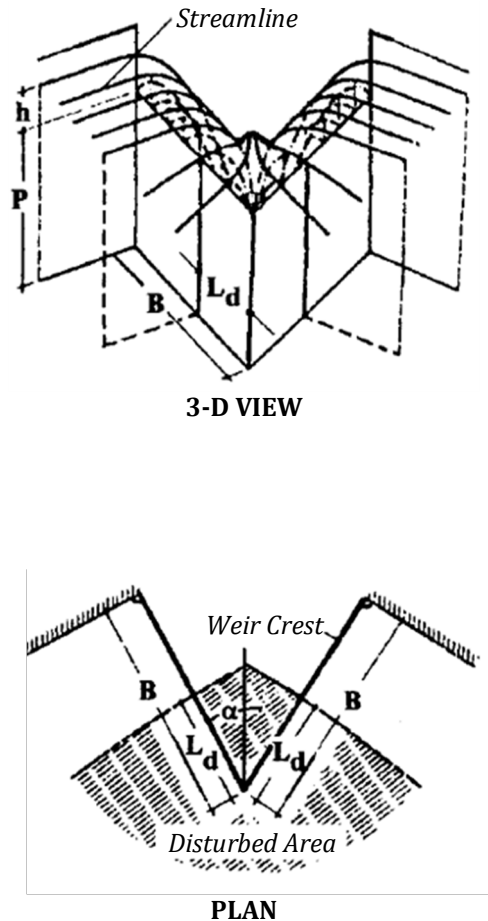


Fig. 3 Nappe interference from Indlekofer, H. & Rouve, G. [15]

2.4 Experimental Works and Limitations

The experiments on labyrinth weirs were conducted in the Hydraulics Laboratory of the Department of Civil Engineering, Tadulako University, Indonesia. This laboratory provided the necessary facilities to perform hydraulic experiments under controlled conditions to ensure reliable and reproducible results. The tests were conducted in a fixed rectangular flume with dimensions of 4.80 m in length, 0.50 m in width, and 0.40 m in depth, which were adequate to simulate realistic flow conditions of prototype structures.

The experimental setup was comprehensive, incorporating several key components to ensure the successful execution of the tests. It included an inlet tank to supply water to the flume, an outlet tank for managing the discharge, and a centrifugal pump that was utilized to maintain a consistent flow rate throughout the experiments. A sluice gate was integrated into the system to provide precise control over the flow entering the flume, thereby allowing for targeted adjustments to analyze the performance of the labyrinth weirs under varying hydraulic conditions. Additionally, a V-notch weir was employed for discharge measurement, serving as a standard method to calculate flow rates with a high degree of accuracy.

To enhance the quality of the data collected, a perforated sheet steel wall was strategically installed within the flume. This design feature was implemented to minimize turbulence and surface waves, which can introduce significant errors in flow measurements and affect the performance assessments of the weir models. By mitigating these disturbances, the integrity of the experimental results was preserved, leading to more accurate conclusions regarding the hydraulic behavior of the weirs.

Regarding the physical models, two weir models were fabricated from 1 cm thick acrylic sheets to ensure durability and visibility during testing. Each model consisted of one cycle ($N = 1$), with a half-round (HR) crest shape, a crest height (P) of 10 cm, and a crest length (L) of 87 cm. Specifically, the wave labyrinth weir model was designed according to the cosine wave equation (Eq. 1), aimed at improving hydraulic performance through optimized flow characteristics.

Finally, the geometric parameters of both models are summarized in Table 1, while Fig. 4 illustrates their plan views. These detailed representations aid in understanding the experimental configuration and serve as a reference for future studies on labyrinth weir optimization.

Table 1 Geometric characteristics of the labyrinth weir model tests

Model	Weir Type	Effective Length L (cm)	Height P (cm)	Number of Cycles N	Crest Shape
M1	Wave Labyrinth Weir	87	10	1	HR
M2	Triangular Labyrinth Weir	87	10	1	HR

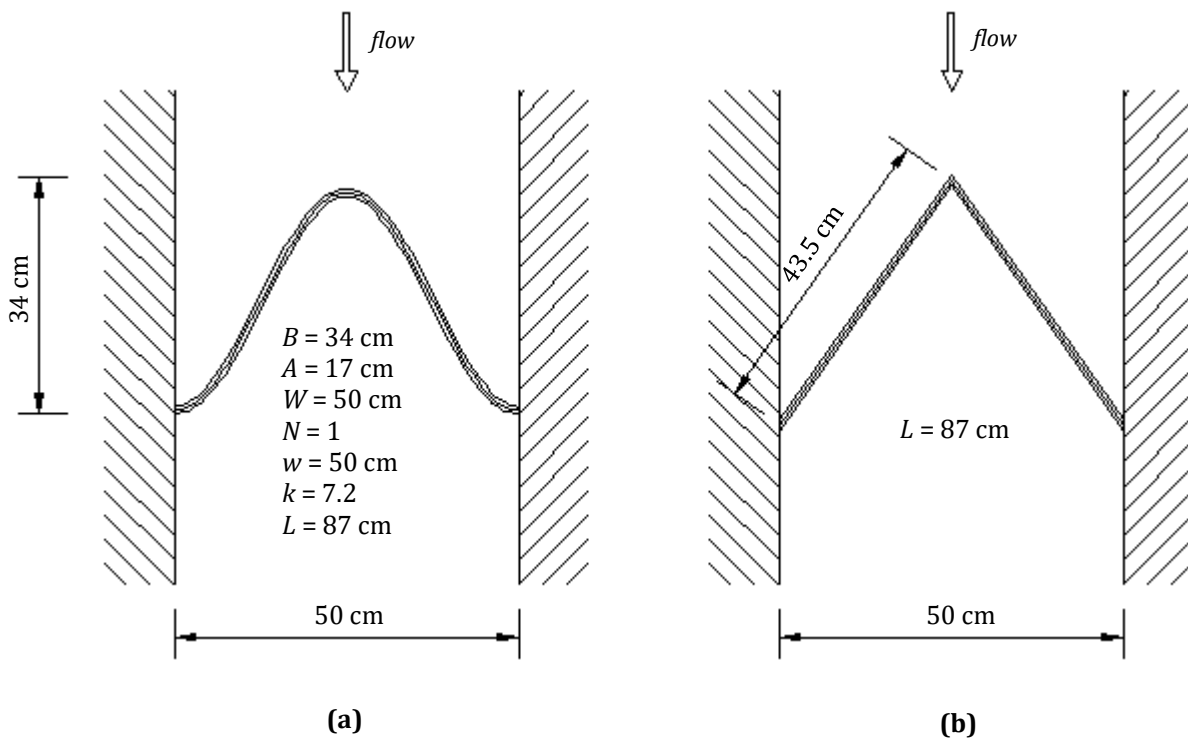


Fig. 4 Plan views of the weir model test (a) M1: Wave labyrinth; (b) M2: Triangular labyrinth

Due to flume size limitations, the upstream heads were kept relatively low ($h = 0.009 - 0.027$ m). Although this range approaches the lower threshold where surface tension and viscous effects may occur, comparable head conditions have been validated in previous laboratory studies. Tullis *et al.* [20] demonstrated that labyrinth weirs tested under heads of $0.007 - 0.016$ m produced stable nappe behavior and consistent discharge characteristics, confirming the hydraulic reliability of low-head experiments when flow steadiness is maintained. In this study, steady and uniform flow conditions were ensured for both weir geometries, making the results suitable for comparative hydraulic evaluation, even though slight scale effects may influence absolute discharge coefficients.

3. Result and Discussion

In this investigation, a series of experiments were meticulously conducted under steady-state conditions, specifically tailored to emulate free overflow scenarios typical of hydraulic structures. The steady-state regime is vital in hydraulic research as it ensures that flow parameters remain constant throughout the duration of each experiment, thereby facilitating accurate measurements of discharge performance. Fig. 5 provides visual

documentation of the two distinct models that were tested, illustrating the variations in design and geometry that were subjected to analysis.

The experimental setup was designed to ensure that flow rates were precisely controlled and monitored, allowing for a comprehensive assessment of the hydraulic behavior of each model under the specified conditions. Following the data collection, the discharge coefficients for the flow rates over each model were systematically calculated using Equation (5), which serves as a foundational formula in hydraulic engineering for determining flow efficiency through weir structures. This calculation is essential, as it provides insight into the performance characteristics of each weir model by quantifying the relationship between the flow rate and the head over the weir crest.

To facilitate a clear understanding of the results, the ranges of the collected data, alongside their corresponding discharge coefficients, are succinctly summarized in Table 2. This table serves as a critical resource for interpreting the performance outcomes of the tested models, enabling comparisons between them. It encapsulates the flow rate measurements, the calculated discharge coefficients, and the conditions under which the experiments were conducted, thus providing a comprehensive overview of the hydraulic performance. The careful delineation of data in Table 2 not only supports the validation of the experimental findings but also contributes to the broader discourse on the optimization of labyrinth weirs, as it enables other researchers to reference and build upon the methodologies and results presented in this study. By systematically documenting the experimental conditions and outcomes, this research aims to advance the understanding of weir hydraulics and promote the application of improved designs in hydraulic engineering practice.

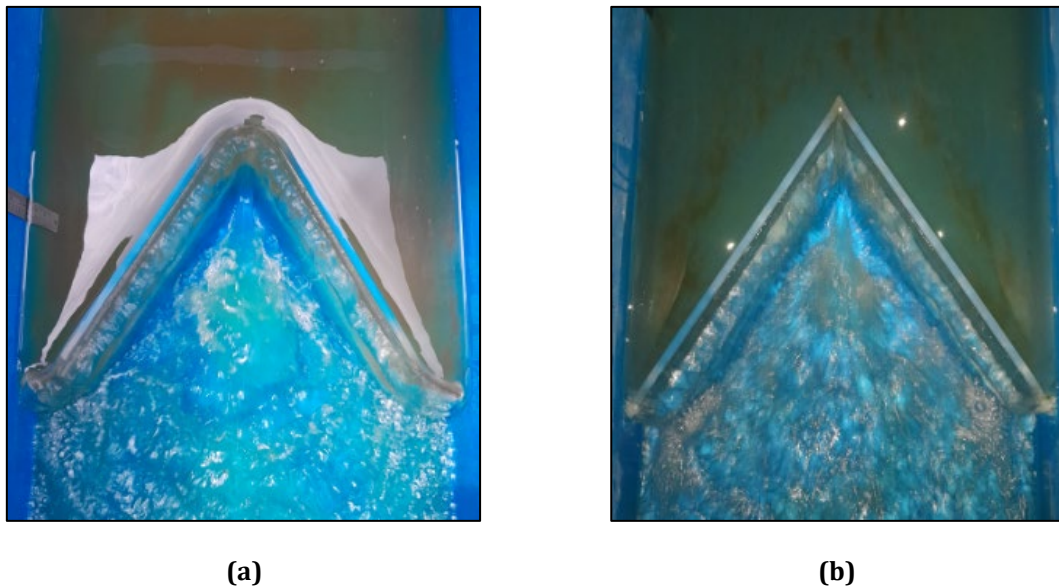


Fig. 5 Photograph of the weir model tests (a) M1: Wave labyrinth; (b) M2: Triangular labyrinth

Table 2 Ranges of data collected from the labyrinth weir model tests

Model	Weir Type	Discharge Q (m ³ /s)	Head Over the Weir h (m)	Discharge Coefficient C_d	Number of Runs
M1	Wave Labyrinth Weir	0.0013-0.0102	0.0090-0.0270	0.59-0.88	17
M2	Triangular Labyrinth Weir	0.0010-0.0096	0.0095-0.0274	0.43-0.82	19

Overall, the wave labyrinth weir (M1) exhibits greater discharge coefficients compared to the triangular labyrinth weir (M2), underscoring its enhanced hydraulic efficiency. This superior performance primarily results from the smoother flow transition and minimized nappe interference provided by M1's curved geometry. From a

practical perspective, these findings suggest that wave labyrinth weirs offer significant advantages for improving spillway capacity and minimizing energy loss, while also avoiding major alterations to existing channel widths or upstream water levels, which are crucial factors in contemporary water management and embankment design.

3.1 Effect of the Vertex Angle for Flow Over the Weir

Fig. 6 presents the observed flow patterns over the two labyrinth weir models under high-discharge conditions, providing valuable insights into how weir geometry influences flow distribution and nappe behavior. The comparative analysis reveals that the vertex angle of each labyrinth weir plays a pivotal role in shaping flow characteristics, with significant implications for discharge efficiency and energy dissipation.

In the case of the M1 model, the flow distribution is notably uniform and stable across the crest (see Fig. 6(a), surface jump lines of M1). This alignment is indicative of a well-designed structure that promotes favorable hydraulic conditions. The formation of surface jump lines, which are observed to develop symmetrically and progressively downstream of the crest, signifies a smooth and controlled flow transition. The absence of sharp corners allows for smoother redirection of the flow, minimizing nappe interference and turbulence near the vertex. As a result, the flow remains attached and streamlined, leading to enhanced energy dissipation and an increased effective discharge length. The effective crest length approaches the actual weir length, confirming optimal hydraulic performance under free-flow conditions.

Conversely, the M2 model (see Fig. 6(b)) exhibits sharper convergence of flow near the apex, resulting in significant nappe interference and turbulent separation. These effects reduce the effective discharge area and cause irregular surface jumps near the crest, indicating unstable energy dissipation. The percentage difference in discharge coefficient between M1 and M2 averages approximately 8–12% across similar head conditions, emphasizing the influence of smoother crest geometry on reducing turbulence intensity.

The contrasting behaviors of the two models underscore the critical impact of geometric parameters on hydraulic performance in labyrinth weirs. The findings not only highlight the importance of design considerations in optimizing flow dynamics but also contribute to the broader understanding of weir efficiency-related phenomena. By elucidating how variations in vertex angles affect flow stability, turbulence, and energy dissipation, this study provides essential insights for engineers and researchers engaged in the design of hydraulic structures. These results serve as a basis for future investigations aimed at refining weir configurations to enhance their performance in practical applications, ultimately leading to more efficient water management strategies in hydraulic engineering. Practically, this observation underscores the importance of optimizing the vertex angle in labyrinth weir design. By minimizing flow separation and turbulence, the hydraulic efficiency of the structure can be significantly improved [1].

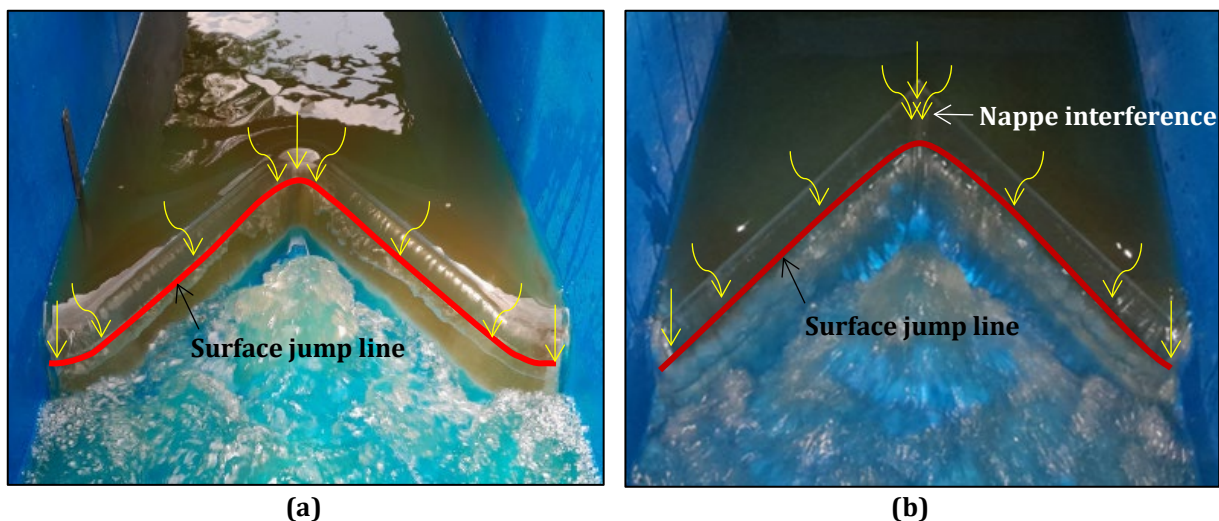


Fig. 6 Photograph of flow over the weir model tests (a) M1: Wave labyrinth; (b) M2: Triangular labyrinth

3.2 Effect of the Vertex Angle for Hydraulic Characteristic of the Weir

As shown in Fig. 7, the polynomial fit for M1 (grey curve) and M2 (black curve) illustrate the relationship between the discharge coefficient (C_d) and the total head-to-weir height ratio (HT/P) for the two labyrinth weir models tested. The figure clearly demonstrates that the weir geometry significantly influences the discharge coefficient. The trends are well represented by polynomial fitting, with coefficients of determination $R^2 = 0.9814$ for the M1

model and $R^2 = 0.9923$ for the M2 model, indicating strong correlations between the variables. Moreover, 5% error bars were incorporated to account for potential variations in the measured discharge coefficients arising from experimental uncertainties, including flow measurement accuracy and fluctuations in surface readings. The relatively small size of these error bars indicates a high degree of reliability and consistency in the experimental data, thereby reinforcing the credibility of the observed trends between the M1 and M2 models.

Across all values of H_T/P , the wave labyrinth weir (M1) consistently shows higher C_d values compared to the triangular labyrinth weir (M2) (see Fig. 7, M1 curve). This indicates that the wave configuration offers a more efficient flow path, likely due to smoother flow transitions and reduced flow separation along the crest. Both models show that C_d increases with H_T/P up to a certain point, reflecting improved flow efficiency as the head increases. However, after reaching a peak (around $H_T/P \approx 0.2$), C_d begins to slightly decline, possibly due to the onset of submergence effects or increased turbulence over the crest. A sensitivity analysis was conducted to examine how changes in the H_T/P ratio influence the discharge coefficient. The wave labyrinth weir maintained a relatively stable discharge coefficient (C_d) at higher H_T/P ratios than the triangular type, indicating reduced vulnerability to flow instability and turbulence.

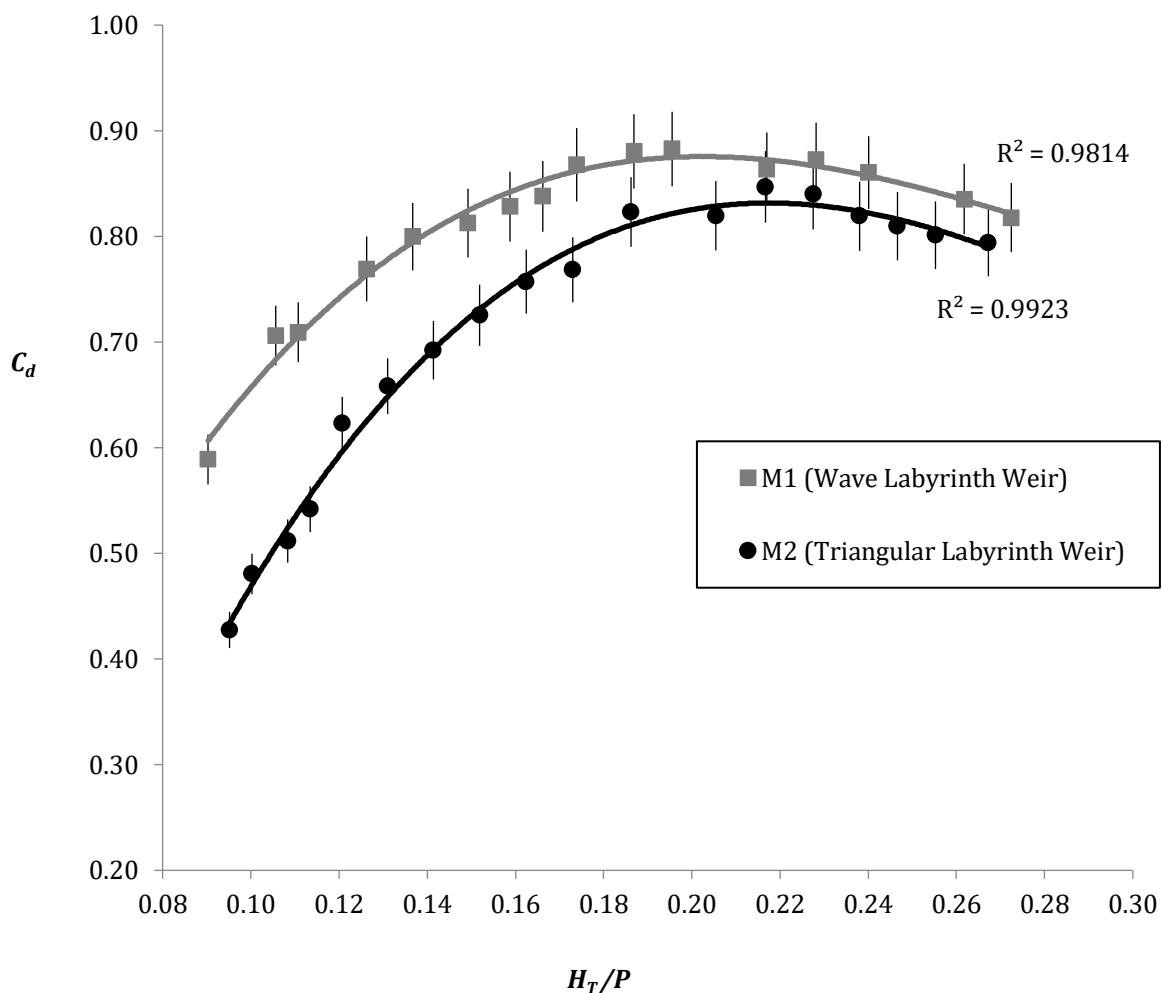


Fig. 7 Variation of C_d with the H_T/P ratios of all models tested

In comparative terms, M1 exhibits superior hydraulic performance, attaining a peak C_d of approximately 0.88, which reflects enhanced hydraulic efficiency. Additionally, M1 demonstrates smoother flow behavior across a range of upstream head conditions. Conversely, M2 achieves a slightly lower peak C_d of around 0.82, potentially attributable to its sharper crest geometry and more pronounced flow convergence and divergence.

From an engineering perspective, this finding implies that wave labyrinth weirs are capable of sustaining higher discharge rates under variable upstream conditions, making them well-suited for dynamic flow environments like urban stormwater systems or irrigation channels in low-gradient areas. The smoother nappe

flow and reduced turbulence also suggest lower maintenance and reduced risk of energy loss or structural fatigue in long-term operation [21], [22].

4. Conclusions

From the experimental assessment of two distinct labyrinth weir designs, the following inferences may be derived:

1. The vertex angle significantly influences flow behavior over labyrinth weirs. Smoother transitions and smaller angles, as observed in wave-shaped designs, help minimize nappe interference, enhance flow stability, and increase discharge capacity. In contrast, sharper vertex angles in triangular configurations tend to induce localized turbulence, leading to reduced hydraulic performance.
2. The wave labyrinth weir consistently exhibits higher C_d values compared to the triangular labyrinth weir across all H_T/P ranges. The maximum C_d observed for the wave labyrinth weir was approximately 0.88, whereas the triangular configuration reached a peak C_d of around 0.82. These results indicate superior hydraulic efficiency of the wave-shaped crest design.
3. The wave labyrinth weir increases the effective crest length and promotes more uniform flow distribution. In comparison, the triangular labyrinth weir shows lower flow efficiency due to less effective utilization of the crest surface.
4. The results of this study provide important insights for hydraulic engineers and designers in optimizing the performance of labyrinth weirs in practical applications. The superior hydraulic efficiency of the wave labyrinth weir highlights its potential to enhance spillway capacity, improve irrigation flow control, and support stormwater management systems, all without requiring major structural modifications.
5. This study was conducted using small-scale physical models under controlled steady-state conditions. Consequently, the influence of scale effects and transient flow phenomena present in full-scale hydraulic systems may not be entirely represented. Recognizing these constraints, future studies should aim to address such discrepancies to ensure broader applicability and accuracy of the experimental findings.
6. Future investigations should focus on systematically examining the impact of various vertex angles, assessing the behavior of wave labyrinth weirs under unsteady flow conditions, and evaluating scale effects to enhance the development of design standards for real-world hydraulic structures.

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Conflict of Interest

The authors hereby declare that there are no conflicts of interest associated with the publication of this paper. They affirm that the research, analysis, and conclusions presented in this work were conducted and formulated impartially, without any external influence or personal interest that could potentially affect the integrity or objectivity of the study. Furthermore, the authors confirm that there are no financial, professional, or personal relationships that could be perceived as influencing the results or interpretation of the findings. This statement ensures transparency and upholds the ethical standards of academic publishing.

Author Contribution

*The authors confirm contribution to the paper as follows: **study conception and design:** Arody Tanga; **data collection:** Arody Tanga; **analysis and interpretation of results:** Arody Tanga, Muh. Galib Ishak, Yassir Arafat; **draft manuscript preparation:** Arody Tanga, Yassir Arafat. All authors reviewed the results and approved the final version of the manuscript.*

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