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EFFECT OF PLAN SHAPE ON HYDRAULIC CHARACTERISTICS OF LABYRINTH WEIRS

Arody Tanga[1*], Muh. Galib Ishak[2] and Yassir Arafat[3]
[1,2,3]Civil Engineering Doctoral Study Program, Tadulako University
Jl. Soekarno-Hatta Km. 9 Palu, Sulawesi Tengah.
[*]Email: tangaarody@gmail.com

Abstract
Labyrinth weirs have a longer crest length compared to linear weirs to increase the discharge capacity for a given water head. Generally, the plan shape of labyrinth weirs is triangular, trapezoidal, and rectangular. In this regard, several studies have been published regarding determining the hydraulic characteristics of labyrinth weirs. However, the effect of changing the plan shape if other parameters such as the same length and height have not been addressed in the current literature. To fill this gap, this study aims to compare the hydraulic characteristics of flow over triangular, trapezoidal, and rectangular labyrinth weirs with the same length of the crest i.e. 230 cm length. Experiments study were conducted in a flume with a length of 16 m and a width of 95 cm. Three experimental models in this study were used. The results of this study indicated that changing the plan shape from trapezoidal to triangular increased the discharge coefficient (C_d) by about 38,0% on average. Furthermore, changing rectangular to triangular increased the C_d by about 64,5% on average. Thus, it can be concluded that the triangular model was the most efficient hydraulically compared to the others while the rectangular model was the least efficient.

Keywords: Hydraulic characteristic, Labyrinth weir, Plan shape

Abstrak
Bendung gergaji memiliki panjang puncak pelimpah yang lebih panjang dibandingkan dengan bendung lurus sehingga kapasitas debit aliran dapat meningkat untuk ketinggian air tertentu. Secara umum, bila dilihat dari atas, bendung gergaji berbentuk segitiga, trapesium, dan persegi panjang. Sehubungan hal ini, beberapa hasil penelitian terkait karakteristik hidrolik aliran melalui bendung gergaji, telah dipublikasi. Namun, penelitian terkait pengaruh perubahan bentuk pelimpah dengan parameter panjang dan tinggi yang sama, sampai saat ini belum ada dalam penelusuran literatur yang telah dilakukan. Untuk itu, penelitian yang dilakukan laboratorium ini bertujuan untuk membandingkan karakteristik hidrolik aliran pada bendung gergaji berbentuk segitiga, trapesium, dan persegi panjang, dengan panjang puncak pelimpah yang sama yaitu 230 cm. Penelitian menggunakan flume dengan panjang 16 m dan lebar 95 cm. Ada tiga model uji yang digunakan dalam penelitian ini. Hasil penelitian ini menunjukkan bahwa perubahan bentuk dari trapesium menjadi segitiga akan meningkatkan nilai koefisien debit (C_d), rata-rata 38,0%. Selanjutnya, mengubah bentuk dari persegi panjang menjadi segitiga akan meningkatkan nilai C_d, rata-rata 64,5%. Dengan demikian, dapat disimpulkan bahwa model segitiga adalah model paling efisien secara hidrolis dibandingkan dengan yang lain, sedangkan model persegi panjang adalah model yang paling tidak efisien.

Kata Kunci: *Karakteristik Hidrolik, Bendung Gergaji, Tampak atas*

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1. Introduction

Weirs are hydraulic structures that are constructed to regulate the water level, controlling the flow, and many others in canals, rivers, and reservoirs. As one of the structures in an irrigation system, weirs are erected to create a hydraulic head of the water river surface, and then the water is distributed by irrigation channels. Most of these weirs are linear weirs that are located perpendicular to the direction of the river flow. However, the challenge is when the weir being built is in a plain area, where in this area it is attempted to keep the water level upstream of the weir as low as possible so that the length of the embankment due to backwater is as short as possible. Theoretically following the standard discharge formula for flow over the weir, this can be achieved by extending the length of the spillway crest, increasing the discharge coefficient, or a combination of these approaches, without increasing the existing spillway channel width and/or water heads over the crest (Brater & King, 1996). Furthermore, the labyrinth weirs have been developed to increase both the weir length and the discharge capacity for a given width. The labyrinth weir was first introduced in 1941 by Gentilini, but as a pioneer study to produce design guidelines for the labyrinth weir was presented by Hay and Taylor based on the research by Taylor (Hay & Taylor, 1970). Tullis et al. developed a standard discharge capacity equation for flow over a labyrinth weir. They found the coefficient of the discharge depends on the type of the labyrinth weir, total head downstream of the weir, weir wall height, wall thickness, sidewall angle, and crest shape (Tullis et al., 1995). Commonly, the crest shape used for the labyrinth weir is sharp-crested, flat-top, quarter-round, half-round, and ogee (Falvey, 2003).

Based on the plan shape, there are three basic types of labyrinth weirs: triangular, trapezoidal, and rectangular shape. In this regard, the study of the hydraulic characteristics by changing the geometry parameters of the labyrinth weirs an interesting matter. Hussain et al. (2022) experimentally investigated the triangular labyrinth weir and concluded that a small vertex angle leads to an increase in flow capacity or performance for the weir. Villarroel et al. (2021) studied the influence of crest geometric on the discharge coefficient efficiency of the labyrinth. The results showed that a weir with a circular apex has a higher discharge coefficient than a weir with a trapezoidal apex, increasing on average by 4.7%. Yousif et al. (2021) investigated characteristics of flow over rectangular labyrinth weirs with round corners. The results showed that the round-cornered rectangular labyrinth weirs improve hydraulic efficiency. Zadeh et al. (2021) investigated flow over sinusoidal and semicircular labyrinth weirs in the laboratory. The results showed that semicircular and sinusoidal labyrinth weirs can pass larger discharges concerning a linear weir (∼30%). Several recent experimental studies have been published, however, the effect of changing the plan shape if other parameters such as the same length and height have not been addressed in the current literature.

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Thus, the main objective of this study is to compare the hydraulic characteristics of flow over triangular, trapezoidal, and rectangular labyrinth weirs with the same length and height.

2. Material and Methods

The experiments study were performed in a masonry-wall flume of 16 m length, 95 cm width, and 70 cm height that comprised a ground water tank, electric pump, pipes, head tank, sliding gate, and V-notch at the Hydraulic Laboratory of the Civil Engineering Tadulako University (Figure 1).

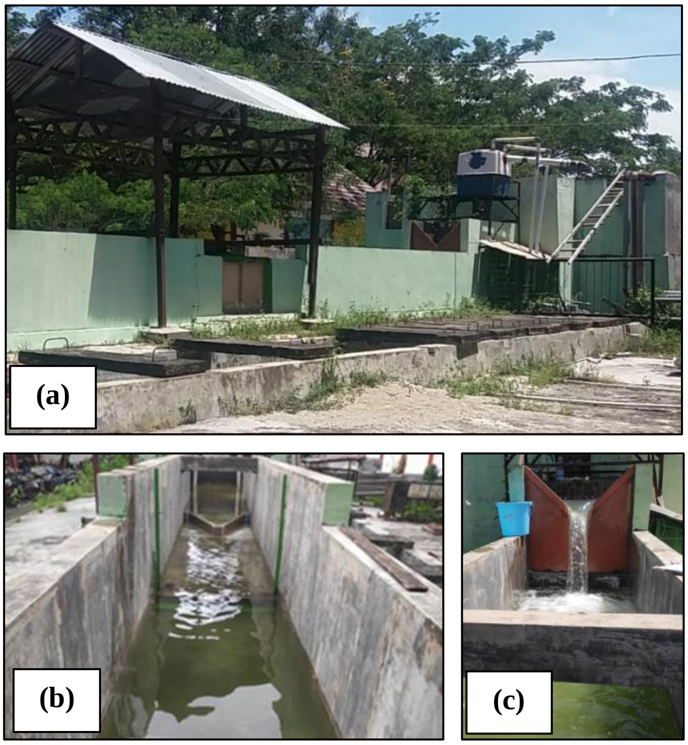

Figure 1. Photograph of the Laboratory Facility
(a) Outside View of the Flume Test Facility. (b) Flume. (c) V-notch

Before starting experimental work on the model test, the V-notch is calibrated by using the volumetric method. The maximum flow rate of the electric pump is 20 l/s and water entered into the flume is controlled through a sliding gate. The discharge over the labyrinth weir can be expressed as (Tullis et al., 1995):

$$Q = \frac{2}{3} C_d \, L \sqrt{2g} \; {H_T}^{1,5} \tag{1}$$

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where Q is the discharge over a labyrinth weir; C_d is the discharge coefficient of the labyrinth weir; L is the effective length of the crest weir; g is the gravitational acceleration constant (≈9,81 m/s^2) and H_T is the total head on the crest of the weir, see Figure 2. The C_d depends on the flow characteristics and geometry parameters of the weir, and H_T is defined as:

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

where h is the vertical distance from the weir crest to the water surface upstream of the weir, and V is the velocity for the flow upstream of the weir.

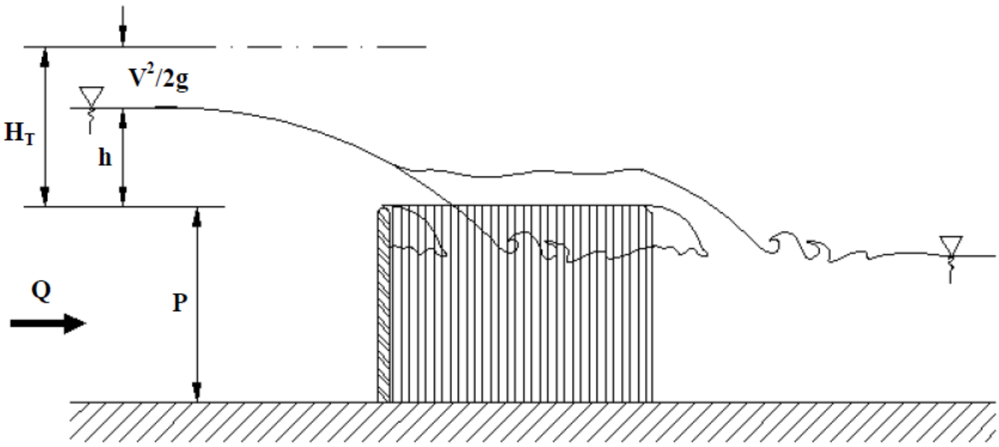

Figure 2. Flow Parameters Labyrinth Weir

This experimental study is based on 3 plan shape models: 1 model for triangular, 1 model for trapezoidal, and 1 model for rectangular shapes. All the laboratory-scale physical labyrinth weir models were made of fiber cement board with a thickness equal to 2 cm. The number cycles (N) of models were made for N = 2. All the model crest length was taken the same i.e. L = 230 cm, and the same weir height i.e. P = 15 cm. Half-round shapes are provided for all the crest shape models. Table 1 and Figures 3 present the details of the models studied in this research.

Table 1. Characteristics of the Weir Models.

Model Type	**Cycle Number** ***N***	**Plan Shape**	**Crest Shape**	**Crest Length** ***L*** ***(mm)***	**Weir Height** ***P*** ***(mm)***
M1	2	Triangular	half-round	2300	150
M2	2	Trapezoidal	half-round	2300	150
M3	2	Rectangular	half-round	2300	150

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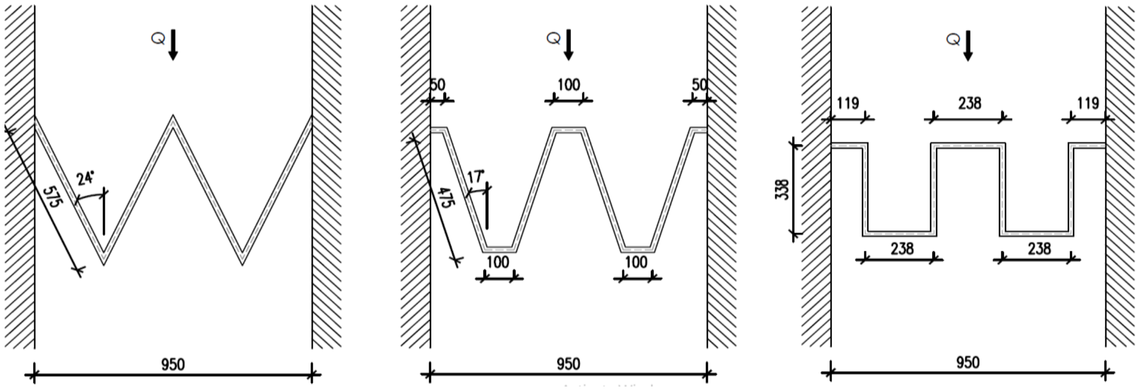

(M1) **(M2)** **(M3)**

Figure 3. Plan Shapes of the Weir Models

(M1) Triangular Weir. (M2) Trapezoidal Weir. (M3) Rectangular Weir.

3. Results and Discussion

All experiments were carried out for steady and free overflow conditions under flow rates of 0,6-13,4 l/s. Table 2 presents some details about the experimental runs carried out in this study.

Table 2. Characteristics of the Weir Models.

Model Type	N	Plan Shape	Q (m^3/s)	h (m)	H_T/P	C_d
M1	2	Triangular	0.0006–0.0134	0.0050–0.0200	0.03–0.14	0.25–0.77
M2	2	Trapezoidal	0.0006–0.0134	0.0078–0.0243	0.05–0.17	0.13–0.51
M3	2	Rectangular	0.0006–0.0134	0.0150–0.0315	0.10–0.21	0.05–0.35

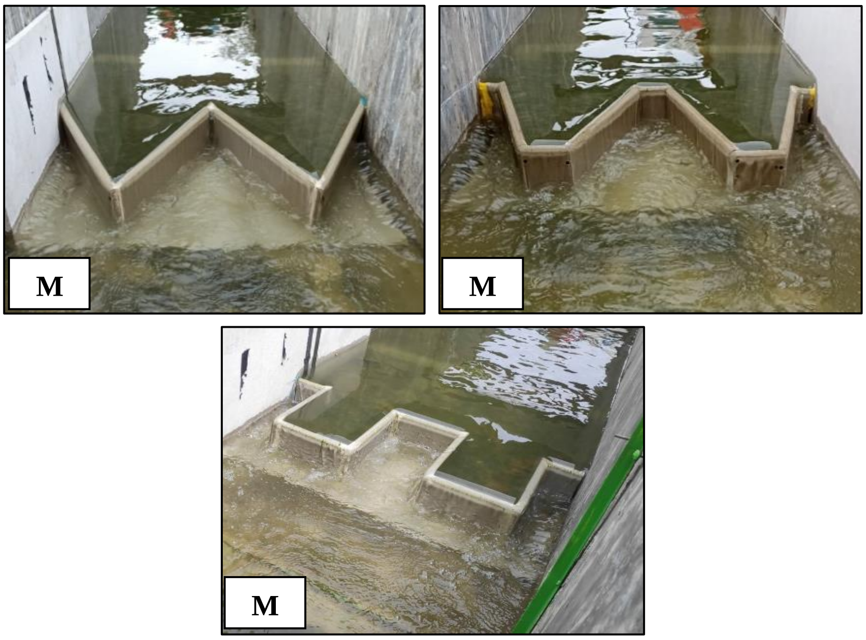

Figure 4. Photograph Flow Condition of the Weir Models
(M1) Triangular Weir. (M2) Trapezoidal Weir. (M3) Rectangular Weir

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3.1. Effect of Plan Shape on the Flow Depth Over the Weir

The results of the experiments show that the plan shape has significant effects on flow depth over the weir (*h*) for the same length of crest weir, see Fig. 5.

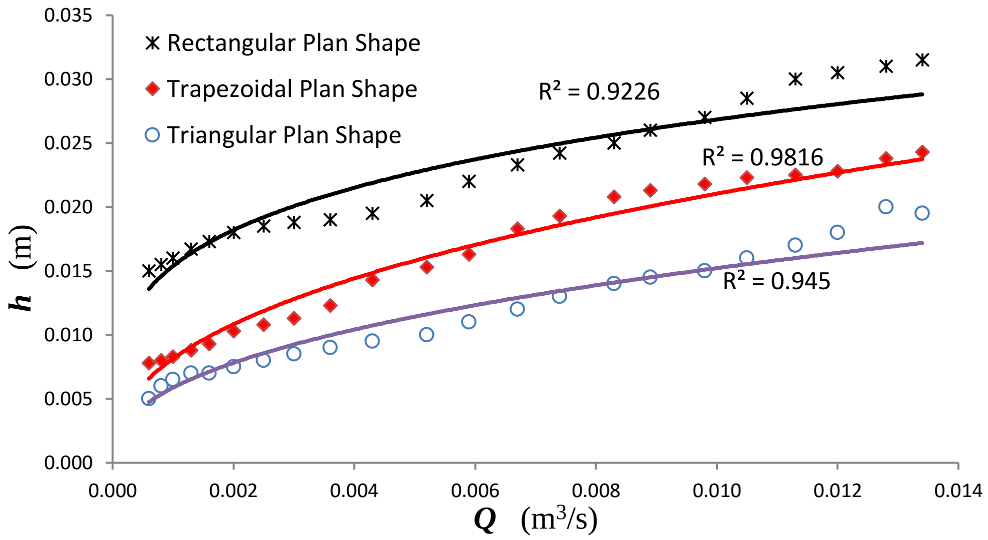

Figure 5. Comparison of Flow Depth Over the Weir (*h*) for All Physical Models

As the discharge over the weirs increased, the flow depth increased for all weirs; however, for a similar discharge, the flow depth of the triangular plan shape weir was the lowest of other weirs, and the rectangular plan shape weir was the highest.

Based on Figure 5, the percentage of efficiency hydraulic in the flow depth due to the plan shapes of all the models can be shown in Table 3.

Table 3. The Percentage Changes in the Flow Depth Due to the Plan Shapes

Parameter	Percentage change in flow depth (%)		
	M2/M1	**M3/M1**	**M3/M2**
Flow depth (*h*)	19,0–56,0	55,0–200,0	20,2-93,8
	38,8*	107,4*	50,0*

* Average values

Table 3 shows that comparing the M2 model to the M1 model, the range of increase in the flow depth was 19,0-56,0% or 38,8% on average. Comparing the M3 model to the M1 model, the range of increase in the flow depth was 55,0-200,0% or 107,4% on average. And then comparing the M3 model to the M2 model, increased by 50,0% on average; the range of increase in the flow depth was 20,2-93,8%.

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3.2. Effect of Plan Shape on the Discharge Coefficient

The effect of plan shape on the C_d is shown as a function of the ratio H_T/P, as shown in Fig. 6. Eq. (1) was used to get C_d and eq. (2) for H_T.

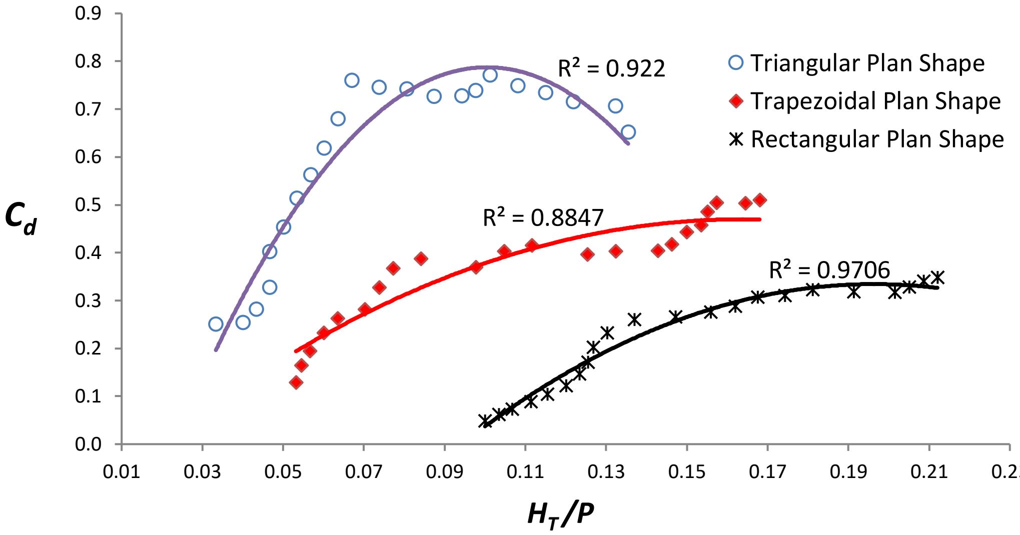

Figure 6. Comparison of Discharge Coefficient (C_d) for All Physical Models

As the total head over the weirs increased, the discharge coefficient increased for all weirs; however, for a similar total head, the discharge coefficient of the triangular plan shape weir was the highest of other weirs, and the rectangular plan shape weir was the lowest.

Based on Figure 6, the percentage of efficiency hydraulic in the discharge coefficient due to the plan shapes of all the models can be shown in Table 4.

Table 4. The Percentage Changes in the Discharge Coefficient Due to the Plan Shapes

Parameter	Percentage change in Discharge Coefficient (%)		
	M2/M1	M3/M1	M3/M2
Discharge Coefficient (C_d)	22,7–48,7	47,6–80,8	23,9-62,9
	38,0*	64,5*	42,4*

* Average values

Table 4 shows that comparing the M2 model to the M1 model, the range of decrease in the discharge coefficient was 22,7-48,7% or 38,0% on average. Comparing the M3 model to the M1 model, the range of decrease in the discharge coefficient was 47,6-80,8% or 64,5% on average. And then comparing the M3 model to the M2 model, decreased by 42,4% on average; the range of decrease in the discharge coefficient was 23,9-62,9%.

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4. Conclusions

An experimental study of the effects of the plan shape on the characteristics hydraulic of labyrinth weirs has been done under free-flow conditions in a rectangular channel. This experimental study is based on 3 plan shape models: 1 model for triangular, 1 model for trapezoidal, and 1 model for rectangular shapes. The results show that:

- The plan shape was one of the important factors that affect the hydraulic characteristics of the labyrinth weir both flow depth over the weir (h) and discharge coefficient (C_d) of the weir.
- The triangular plan shape model was the most efficient compared to the others while the rectangular plan shape model was the least efficient.
- Changing the plan shape labyrinth weir from trapezoidal to triangular decreased flow depth over the weir (h) by about 38,8% on average. Furthermore, changing the plan shape labyrinth weir from rectangular to triangular decreased flow depth over the weir (h) by about 107,4% on average.
- Changing the plan shape labyrinth weir from trapezoidal to triangular increased the discharge coefficient (C_d) by about 38,0% on average. Changing the plan shape labyrinth weir from rectangular to triangular increased the discharge coefficient (C_d) by about 64,5% on average. Furthermore, changing the plan shape labyrinth weir from rectangular to trapezoidal increased the discharge coefficient (C_d) by about 42,4% on average.

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References

Brater, E. F., & King, H. W. (1996). *Handbook of hydraulics* (J. E. Lindell & C. E. Wei (eds.); 7th ed.). McGraw-Hill.

Falvey, H. T. (2003). *Hydraulic design of labyrinth weirs* (American Society of Civil Engineers (ed.)). ASCE Press.

Hay, N., & Taylor, G. (1970). Performance and design of labyrinth weirs. *Journal of the Hydraulics Division*, *96*(11), 2337–2357.

Hussain, R. A., Hassan, S. A., & Jamel, A. A. J. (2022). Experimental study on flow over triangular labyrinth weirs. *International Journal of Design and Nature and Ecodynamics*, *17*(2), 249–255. https://doi.org/10.18280/ijdne.170211

Kheilapour, M., Mozaffari, J., Asadolah, S., & Movahed, M. (2022). *Experimental study of discharge coefficient of combination labyrinth weirs*. *7*(4), 1–9. https://doi.org/10.22055/jhs.2022.38073.1184

Said, M. Ben, & Ouamane, A. (2021). Performance of rectangular labyrinth weir – an experimental and numerical study. *Water Supply*, *00*(0), 1–17. https://doi.org/10.2166/ws.2022.005

Diterima 11 Februarii 2023, Direvisi 19 Maret 2023, Diterima untuk publikasi 20 April 2023

Tullis, J. P., Amanian, N., & Waldron, D. (1995). Design of labyrinth spillways. *Journal of Hydraulic Engineering*, *121*(3), 247–255. https://www.usbr.gov/tsc/techreferences/hydraulics_lab/pubs/PAP/PAP-0782.pdf

Villarroel, E. M., Velázquez, J. F., Bustamante, W. O., Delgado, C. D., & Tapia, H. S. (2021). Influence of crest geometric on discharge coefficient efficiency of labyrinth weirs. *Flow Measurement and Instrumentation*, *81*(August). https://doi.org/10.1016/j.flowmeasinst.2021.102031

Yousif, O. S. Q., Abdulrahman, K. Z., Qadir, W., Ali, A. S., & Karakouzian, M. (2021). Characteristics of flow over rectangular labyrinth weirs with round corners. *Hydrology*, *8*(4), 158. https://doi.org/10.3390/hydrology8040158

Zadeh, M. S., Varaki, M. E., & Biabani, R. (2021). Experimental study on flow over sinusoidal and semicircular labyrinth weirs. *ISH Journal of Hydraulic Engineering*, *27*(S1), 304–313. https://doi.org/10.1080/09715010.2019.1644679

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