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A COMPARATIVE STUDY OF ENERGY LOSS IN OGEE-CRESTED AND ROUND-CRESTED WEIRS THROUGH LABORATORY TESTING

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Abstract

Crest geometry is a critical determinant of energy transformation in open-channel flow; however, direct laboratory comparisons between ogee-crested and round-crested weirs remain limited. This study aimed to analyze and compare energy loss across both weir types under equivalent experimental conditions. A quantitative laboratory-experimental design was employed using an open-channel flume at the Hydraulics Laboratory, Department of Civil Engineering, Universitas Negeri Padang. Each weir model was tested in three trials, with channel-bed elevation, flow depth, and flow velocity measured at the upstream, crest, and downstream sections. Total energy loss was calculated using Bernoulli's equation, while frictional loss was estimated using the Darcy–Weisbach equation. The ogee-crested weir produced a mean total energy loss of 14.63 cm, whereas the round-crested weir produced 13.74 cm, yielding a difference of 0.89 cm. Frictional losses were 0.86 cm for the ogee-crested weir and 1.18 cm for the round-crested weir. Reynolds numbers of 33,408 and 40,880, respectively, indicated turbulent flow in both models. These findings demonstrate that total energy loss was governed not only by frictional resistance but also by turbulence and crest geometry. Under the tested conditions, the round-crested weir retained flow energy more effectively than the ogee-crested weir. This study contributes empirical evidence on the hydraulic performance of different crest geometries and provides practical insight for selecting weir configurations in open-channel flow applications.

Keywords: Crest Geometry; Energy Loss; Laboratory Experiment; Ogee-Crested Weir; Round-Crested Weir

INTRODUCTION

Open-channel flow constitutes a fundamental area of hydraulic engineering because of its extensive application in irrigation networks, urban drainage systems, natural rivers, flood-control facilities, and various water-regulating structures. Unlike pressurized flow in closed conduits, open-channel flow has a free surface exposed to atmospheric pressure, making its behavior strongly dependent on gravity, channel geometry, boundary resistance, and flow depth. The interaction among these factors produces variations in velocity, pressure, turbulence, and energy along the channel. A comprehensive understanding of these hydraulic characteristics is therefore essential for improving water-conveyance efficiency and ensuring the safe operation of hydraulic structures (Ben Meftah, 2022; Chanson, 2018) .

One of the principal issues in open-channel hydraulics is the nonuniform distribution of flow velocity. Vertically, velocity is generally lower near the channel bed because of boundary shear stress and increases toward the water surface. Horizontally, the velocity in the central section of a channel is commonly higher than that near the sidewalls because of lateral friction. These variations influence discharge measurement, specific-energy estimation, sediment movement, and hydrodynamic forces acting on hydraulic structures. In non-prismatic channels, velocity distribution becomes increasingly complex because geometric transitions induce acceleration, deceleration, turbulence, and energy redistribution within the flow (Carollo et al., 2018; Nezu & Sanjou, 2016).

The hydraulic performance of water-control structures is also an important concern in Indonesia, where irrigation channels, weirs, spillways, and drainage systems play a major role in water-resource management. Inefficient hydraulic design may generate excessive energy losses, unstable flow conditions, and local erosion downstream of a structure. Indonesian studies have examined energy behavior in different hydraulic systems, including specific-energy variations in stepped weirs and head losses in pipes with different materials. These findings demonstrate the continued importance of experimental investigation for supporting the design and evaluation of hydraulic infrastructure under local conditions (Azkina et al., 2025; Maneek et al., 2023).

A weir is a hydraulic structure commonly installed in an open channel to regulate upstream water levels, measure or control discharge, and modify downstream flow conditions. The presence of a weir changes the channel from a prismatic section into a non-prismatic flow region. This geometric transition alters the flow depth, velocity, pressure distribution, water-surface profile, and total energy. Flow transitions over hydraulic structures may also generate separation, recirculation, and turbulence, particularly when the geometric change is abrupt. Consequently, crest geometry becomes an important factor in determining whether water passes over the structure smoothly or experiences substantial hydraulic disturbance (Bombardelli et al., 2018; Zhu & Chanson, 2017).

A round-crested weir has a curved crest that allows the flow to follow the structure more gradually than it does over a sharp-edged profile. Its rounded surface may reduce abrupt changes in the flow direction and limit the tendency for flow separation around the crest. Previous experimental studies have shown that crest radius and upstream head affect discharge coefficients, velocity distributions, streamline curvature, and local pressure conditions. These hydraulic responses indicate that the performance of a round-crested weir depends not only on discharge but also on the interaction between crest geometry and the energy state of the approaching flow (Azimi et al., 2020; Felder & Chanson, 2016; Gong et al., 2019).

An ogee-crested weir also has a curved profile, but its geometry is generally designed to approximate the lower surface of a free-flowing nappe at a selected design head. This profile is widely applied to dam spillways because it can convey large discharges with relatively high hydraulic efficiency when the operating conditions are close to the design state. However, variations in upstream head and downstream slope may modify pressure conditions, flow attachment, and velocity patterns along the crest. Such changes can influence both discharge performance and the amount of energy dissipated as water passes over the structure (Albank & Khassaf, 2024; Salmasi & Abraham, 2022; Stilmant et al., 2022).

Energy loss is an essential parameter for evaluating the hydraulic performance of a weir. It represents the reduction in total energy caused by turbulence, friction, streamline curvature, flow contraction and expansion, and changes in velocity and depth. The magnitude of energy loss is affected by the geometry of the structure as well as by the upstream and downstream flow conditions. Previous investigations into piano key weirs, stepped spillways, and sharp-crested weirs have demonstrated that changes in crest shape and downstream configuration can produce substantial differences in energy dissipation efficiency (Alghazali & Musa, 2024; Pandey et al., 2024; Sohrabzadeh Anzani et al., 2024).

Although previous studies have contributed substantially to the understanding of hydraulic behavior over weirs, most have concentrated on discharge coefficients, pressure distributions, velocity patterns, or numerical simulations involving only one crest type. Research on ogee-crested structures has frequently emphasized flow prediction and velocity distribution through computational fluid dynamics or physical modelling, whereas research on rounded weirs has commonly examined local flow patterns and vortex formation around the crest (Karim & Mohammed, 2020; Kizilaslan et al., 2023).

Direct experimental comparisons of total energy loss between ogee-crested and round-crested weirs under equivalent channel geometry, discharge, and measurement conditions remain limited.

The novelty of this study lies in its direct laboratory comparison of energy loss across ogee-crested and round-crested weirs using the same experimental channel, measurement procedure, and flow conditions. Rather than focusing solely on discharge coefficients or local velocity distributions, the investigation evaluates total energy changes based on channel-bed elevation, flow depth, and flow velocity measured before and after each weir. Accordingly, this study aims to analyze and compare the magnitude of energy loss generated by ogee-crested and round-crested weirs through laboratory testing. The findings are expected to clarify the influence of crest geometry on energy transformation and provide an empirical reference for the selection, planning, and evaluation of hydraulic structures in open channels.

METHODS

This study employed a quantitative laboratory-experimental method to analyze and compare energy loss in open-channel flow passing over ogee-crested and round-crested weirs. The quantitative approach was selected because the hydraulic variables were measured numerically and analyzed objectively to determine differences between the two weir geometries. According to Creswell (2014), quantitative research is appropriate for examining differences among variables through systematic measurement and numerical analysis. The experiment was conducted from April to June 2026 at the Hydraulics Laboratory, Department of Civil Engineering, Universitas Negeri Padang. The research objects consisted of one ogee-crested weir model and one round-crested weir model, which were installed alternately in the same open-channel flume. Each weir model was tested in three repeated trials under the same channel, discharge, and operating conditions. This controlled comparative design was applied to ensure that differences in energy loss were primarily caused by crest geometry rather than variations in the experimental setting. In contrast to previous studies that examined a single weir profile or relied mainly on numerical simulation, this study directly compared the two crest geometries using the same laboratory apparatus and measurement procedures (Azimi et al., 2020; Karim & Mohammed, 2020; Salmasi & Abraham, 2022).

Data were collected through direct observation and measurement at three sections: upstream of the weir, above the crest, and downstream of the weir. The measured parameters included channel-bed elevation (z), flow depth (h), and mean flow velocity (v). The instruments consisted of an open-channel flume, a water pump, a current meter, a vernier caliper, and a camera. The current meter was used to measure flow velocity, while the vernier caliper was used to verify the dimensions of each weir model. Before data collection, water was circulated until a stable flow condition was achieved, and all measurement points were kept consistent throughout the trials. The reliability of the measurements was maintained by conducting three repetitions for each weir type and applying identical procedures in every test. The total energy at each observation section was calculated using Bernoulli's equation: $E = z + h + (v^2 / 2g)$, where E is the total energy head, z is the channel-bed elevation, h is the flow depth, v is the mean flow velocity, and g is gravitational acceleration, taken as 9.81 m/s^2. Energy loss was determined using the equation $hL = E1 - E2$, where hL is the energy loss, E1 is the total energy at the upstream section, and E2 is the total energy at the downstream section. The three energy-loss values obtained for each weir were averaged and compared descriptively to identify the influence of crest geometry and determine which weir type was more effective in maintaining flow energy. This analytical procedure follows the principles of open-channel energy analysis described by Chanson (2018), Chow (2018), and White (2016).

RESULTS

The experimental results were obtained from laboratory testing of ogee-crested and round-crested weirs in an open-channel flume. Measurements were conducted at three observation points: upstream of the weir (Point 1), above the weir crest (Point 2), and downstream of the weir (Point 3). The measured parameters included channel-bed elevation, flow depth, and flow velocity. These parameters were used to calculate the total energy head and energy loss for each weir type.

The total energy at each observation point was determined using the energy equation derived from Bernoulli's principle:

$$H = z + y + V^2 / (2g) \quad (1)$$

where:

H = total energy head (m)

z = channel-bed elevation (m)

y = flow depth (m)

V = mean flow velocity (m/s)

g = gravitational acceleration, equal to 9.81 m/s²

The energy loss between two observation points was calculated using the following equation:

$$hL = H1 - H2 \quad (2)$$

The total energy loss between the upstream and downstream sections was calculated as follows:

$$hL,total = H1 - H3 \quad (3)$$

where:

hL = energy loss between two observation points (m)

hL,total = total energy loss between the upstream and downstream sections (m)

H1 = total energy at the upstream section (m)

H2 = total energy above the crest (m)

H3 = total energy at the downstream section (m)

1. Energy Loss over the Ogee-Crested Weir

The energy loss over the ogee-crested weir was determined by calculating the total energy at Points 1, 2, and 3. The calculation for Trial 1 is presented as an example.

At Point 1, the measured hydraulic parameters were:

$z1 = 0.600$ m

$y1 = 0.0829$ m

$V1 = 0.07$ m/s

The total energy at Point 1 was calculated as follows:

$$H1 = z1 + y1 + V1^2 / (2g)$$

$$H1 = 0.600 + 0.0829 + 0.07^2 / (2 \times 9.81)$$

$$H1 = 0.600 + 0.0829 + 0.00025$$

$$H1 = 0.68315 \text{ m}$$

At Point 2, the measured hydraulic parameters were:

$z2 = 0.525$ m

$y2 = 0.0120$ m

$V2 = 0.30$ m/s

The total energy at Point 2 was calculated as follows:

$H2 = z2 + y2 + V2^2 / (2g)$

$H2 = 0.525 + 0.0120 + 0.30^2 / (2 \times 9.81)$

$H2 = 0.525 + 0.0120 + 0.00459$

$H2 = 0.54159$ m

Therefore, the energy loss between Points 1 and 2 was:

$hL1-2 = H1 - H2$

$hL1-2 = 0.68315 - 0.54159$

$hL1-2 = 0.14156$ m

$hL1-2 = 14.16$ cm

At Point 3, the measured hydraulic parameters were:

$z3 = 0.510$ m

$y3 = 0.0140$ m

$V3 = 0.50$ m/s

The total energy at Point 3 was calculated as follows:

$$H3 = z3 + y3 + V3^2 / (2g)$$

$$H3 = 0.510 + 0.0140 + 0.50^2 / (2 \times 9.81)$$

$$H3 = 0.510 + 0.0140 + 0.01274$$

$$H3 = 0.53674 \text{ m}$$

The energy loss between Points 2 and 3 was:

$$hL2-3 = H2 - H3$$

$$hL2-3 = 0.54159 - 0.53674$$

$$hL2-3 = 0.00485 \text{ m}$$

$$hL2-3 = 0.48 \text{ cm}$$

The total energy loss between Points 1 and 3 was:

$$hL1-3 = H1 - H3$$

$$hL1-3 = 0.68315 - 0.53674$$

$$hL1-3 = 0.14641 \text{ m}$$

$$hL1-3 = 14.64 \text{ cm}$$

The same calculation procedure was applied to Trials 2 and 3. The total energy values obtained at each observation point are presented in Table 1.

Table 1. Total Energy Head over the Ogee-Crested Weir

Trial	H1 (m)	H2 (m)	H3 (m)
1	0.68315	0.54159	0.53674
2	0.68339	0.54178	0.53710
3	0.68235	0.54149	0.53564

Source: Experimental data, 2026.

Table 1 shows that the total energy head decreased continuously from the upstream section to the downstream section in all three trials. The upstream energy ranged from 0.68235 to 0.68339 m, while the downstream energy ranged from 0.53564 to 0.53710 m. This decrease indicates that part of the flow energy was dissipated as the water passed over the ogee crest.

The energy losses calculated from the total energy values are presented in Table 2.

Table 2. Energy Loss over the Ogee-Crested Weir

Trial	hL1−2 (cm)	hL2−3 (cm)	hL1−3 (cm)
1	14.16	0.48	14.64
2	14.22	0.47	14.69
3	14.09	0.48	14.57
Mean	14.16	0.48	14.63

Source: Experimental data, 2026.

As shown in Table 2, the total energy losses recorded in Trials 1, 2, and 3 were 14.64, 14.69, and 14.57 cm, respectively. The mean total energy loss was 14.63 cm. The difference between the highest and lowest values was only 0.12 cm. The standard deviation was approximately 0.06 cm, with a coefficient of variation of approximately 0.41%. These values indicate a high level of consistency among the three experimental trials.

Most of the energy loss occurred between the upstream section and the crest. The mean energy loss between Points 1 and 2 was 14.16 cm, representing approximately 96.8% of the total energy loss. In comparison, the mean energy loss between the crest and the downstream section was only 0.48 cm. This result indicates that the most substantial energy transformation occurred as the approaching flow rose and accelerated over the ogee crest.

2. Frictional Energy Loss over the Ogee-Crested Weir

In addition to the total energy loss calculated using Bernoulli's equation, frictional energy loss was estimated using the Darcy–Weisbach equation:

$$hf = f \times [L / (4R)] \times [V^2 / (2g)] \quad (4)$$

where:

hf = frictional energy loss (m)

f = Darcy friction factor

L = channel length (m)

R = hydraulic radius (m)

V = mean flow velocity (m/s)

g = gravitational acceleration, equal to 9.81 m/s²

For the ogee-crested weir, the parameters used were:

f = 0.0331

L = 7.00 m

$R = 0.0288$ m
$V = 0.29$ m/s
$g = 9.81$ m/s²

The frictional energy loss was calculated as follows:

$$hf = 0.0331 \times [7.00 / (4 \times 0.0288)] \times [0.29^2 / (2 \times 9.81)]$$

$$hf = 0.0331 \times 60.76 \times 0.00429$$

$$hf = 0.00863 \text{ m}$$

$$hf = 0.86 \text{ cm}$$

The Darcy–Weisbach calculation produced a frictional energy loss of 0.86 cm. This value represents the distributed loss associated with channel resistance and is smaller than the total energy loss calculated using Bernoulli's equation. The difference indicates that the total energy loss was not caused solely by channel friction but also by local hydraulic effects, including changes in flow depth, acceleration, turbulence, streamline curvature, and the geometry of the ogee crest.

3. Energy Loss over the Round-Crested Weir

The total energy and energy loss over the round-crested weir were calculated using the same procedure. Trial 1 is presented as an example.

At Point 1, the measured hydraulic parameters were:

$z1 = 0.600$ m
$y1 = 0.0778$ m
$V1 = 0.05$ m/s

The total energy at Point 1 was:

$$H1 = z1 + y1 + V1^2 / (2g)$$

$$H1 = 0.600 + 0.0778 + 0.05^2 / (2 \times 9.81)$$

$$H1 = 0.600 + 0.0778 + 0.00013$$

$$H1 = 0.67793 \text{ m}$$

At Point 2, the measured hydraulic parameters were:

$z2 = 0.525$ m

$y2 = 0.0180$ m

$V2 = 0.30$ m/s

The total energy at Point 2 was:

$H2 = z2 + y2 + V2^2 / (2g)$

$H2 = 0.525 + 0.0180 + 0.30^2 / (2 \times 9.81)$

$H2 = 0.525 + 0.0180 + 0.00459$

$H2 = 0.54759$ m

The energy loss between Points 1 and 2 was:

$hL1-2 = H1 - H2$

$hL1-2 = 0.67793 - 0.54759$

$hL1-2 = 0.13034$ m

$hL1-2 = 13.03$ cm

At Point 3, the measured hydraulic parameters were:

$z3 = 0.510$ m

$y3 = 0.0150$ m

$V3 = 0.70$ m/s

The total energy at Point 3 was:

$H3 = z3 + y3 + V3^2 / (2g)$

$H3 = 0.510 + 0.0150 + 0.70^2 / (2 \times 9.81)$

$H3 = 0.510 + 0.0150 + 0.02497$

$H3 = 0.54997$ m

However, the original experimental table reported H3 as 0.53997 m. Using the stated values of $z3 = 0.510$ m, $y3 = 0.0150$ m, and $V3 = 0.70$ m/s produces 0.54997 m rather than 0.53997 m. Therefore, the flow depth, velocity, or reported total energy at Point 3 should be rechecked against the laboratory record before the manuscript is finalized.

Following the value reported in the original experimental table, the total energy loss for Trial 1 was calculated as:

$hL1-3 = H1 - H3$

$hL1-3 = 0.67793 - 0.53997$

$hL1-3 = 0.13796$ m

$hL1-3 = 13.80$ cm

The total energy values recorded for the three round-crested weir trials are presented in Table 3.

Table 3. Total Energy Head over the Round-Crested Weir

Trial	H1 (m)	H2 (m)	H3 (m)
1	0.67793	0.54759	0.53997
2	0.67813	0.54818	0.54787
3	0.68222	0.54140	0.53822

Source: Experimental data, 2026.

Table 3 demonstrates a reduction in total energy from the upstream section to the downstream section for each round-crested weir trial. However, the reduction varied more widely than that observed for the ogee-crested weir, particularly in Trial 2, where the downstream energy remained relatively high.

The energy-loss values calculated for the round-crested weir are presented in Table 4.

Table 4. Energy Loss over the Round-Crested Weir

Trial	hL1−2 (cm)	hL2−3 (cm)	hL1−3 (cm)
1	13.03	0.76	13.80
2	13.00	0.03	13.03
3	14.08	0.32	14.40
Mean	13.37	0.37	13.74

Source: Experimental data, 2026.

The total energy losses for the round-crested weir were 13.80, 13.03, and 14.40 cm for Trials 1, 2, and 3, respectively. The resulting mean total energy loss was 13.74 cm. The range between the highest and lowest values was 1.37 cm. The standard deviation was approximately 0.69 cm, with a coefficient of variation of approximately 5.00%. Although the measurements remained within a relatively narrow range, the round-crested weir produced greater variability among the trials than the ogee-crested weir.

The mean energy loss between Points 1 and 2 was 13.37 cm, representing approximately 97.3% of the mean total energy loss. The energy loss between Points 2 and 3 averaged only 0.37 cm. This result indicates that, similar to the ogee-crested weir, most energy dissipation occurred as the water approached and passed over the crest rather than in the downstream section.

4. Frictional Energy Loss over the Round-Crested Weir

The Darcy–Weisbach parameters used for the round-crested weir were:

$f = 0.0315$

$L = 7.00$ m

$R = 0.0292$ m

$V = 0.35$ m/s

$g = 9.81$ m/s²

The frictional energy loss was calculated as follows:

$hf = 0.0315 \times [7.00 / (4 \times 0.0292)] \times [0.35^2 / (2 \times 9.81)]$

$hf = 0.0315 \times 59.93 \times 0.00624$

$hf = 0.01178$ m

$hf = 1.18$ cm

The calculated frictional energy loss for the round-crested weir was 1.18 cm. This value was 0.32 cm higher than the frictional energy loss calculated for the ogee-crested weir. Nevertheless, the total energy loss based on Bernoulli's equation was lower for the round-crested weir. This difference indicates that the Darcy–Weisbach calculation represents only distributed frictional resistance, whereas the Bernoulli-based calculation includes the combined effects of friction, turbulence, geometric transitions, velocity changes, and other local losses.

5. Comparison of Energy Loss between the Two Weir Types

A summary of the energy-loss results for the ogee-crested and round-crested weirs is presented in Table 5.

Table 5. Comparison of Energy Loss between Ogee-Crested and Round-Crested Weirs

Weir type	Mean hL1−2 (cm)	Mean hL2−3 (cm)	Mean total energy loss (cm)	Frictional loss (cm)
Ogee-crested weir	14.16	0.48	14.63	0.86
Round-crested weir	13.37	0.37	13.74	1.18
Difference	0.79	0.11	0.89	−0.32

Source: Experimental data, 2026.

Table 5 shows that the ogee-crested weir produced a mean total energy loss of 14.63 cm, whereas the round-crested weir produced a mean total energy loss of 13.74 cm. The difference between the two mean values was 0.89 cm. Descriptively, the total energy loss over the ogee-crested weir was approximately 6.48% greater than that over the round-crested weir.

The results demonstrate that crest geometry influenced the transformation and dissipation of energy in the open-channel flow. Under the laboratory conditions applied in this study, the round-crested weir retained a greater proportion of the upstream energy because it generated a lower mean total energy loss. Its curved surface may have provided a more gradual flow transition and reduced the local disturbance experienced by the water as it passed over the crest.

In contrast, the ogee-crested weir produced a slightly greater total energy reduction. Although an ogee profile is generally designed to follow the lower nappe shape at a particular design head, its hydraulic performance depends on whether the experimental head corresponds to that design condition. A difference between the actual operating head and the design head may alter flow attachment, pressure distribution, and turbulence along the crest.

The results also indicate that energy loss was concentrated primarily between the upstream section and the crest for both weir types. The downstream sections contributed only a small proportion of the total loss. Therefore, the geometry of the crest and the associated acceleration of the approaching flow were the dominant factors affecting energy transformation in the tested models.

Overall, the experimental findings show that the round-crested weir generated a lower mean total energy loss than the ogee-crested weir. Therefore, under the specific dimensions, discharge, and laboratory conditions used in this study, the round-crested weir was more effective in maintaining total flow energy. However, this conclusion is descriptive and applies only to the tested models and operating conditions. Additional tests with different discharges, upstream heads, crest dimensions, and flow regimes are required before the results can be generalized to full-scale hydraulic structures.

DISCUSSION

The results demonstrate that crest geometry influenced the magnitude of energy loss in open-channel flow. The ogee-crested weir produced a mean total energy loss of 14.63 cm, whereas the round-crested weir produced a mean value of 13.74 cm. The difference of 0.89 cm indicates that the ogee-crested weir generated approximately 6.48% greater total energy loss than the round-crested weir under the tested conditions. Thus, the experimental objective of identifying differences in energy loss between the two crest profiles was achieved. The findings indicate that the round-crested weir was more effective in maintaining the total energy of the flow, although this conclusion is limited to the dimensions, discharges, and hydraulic conditions applied in the laboratory experiment.

The difference between upstream and downstream energy can be explained using the energy principle derived from Bernoulli's equation. Total energy in open-channel flow consists of elevation head, pressure head represented by flow depth, and velocity head. Under actual flow conditions, part of this energy is dissipated through boundary friction, turbulence, streamline curvature, flow separation, contraction, expansion, and mixing. Consequently, the downstream total energy is lower than the upstream total energy. This interpretation is consistent with the fundamental theory of open-channel hydraulics, which states that transitions in channel geometry alter the distribution and transformation of flow energy (Ben Meftah, 2022; Chanson, 2018, 2019; Chow, 2018; White, 2016).

The experimental results further show that most energy loss occurred between the upstream section and the crest. The mean energy loss between Points 1 and 2 was 14.16 cm for the ogee-crested weir and 13.37 cm for the round-crested weir. Meanwhile, the mean loss between the crest and downstream section was only 0.48 and 0.37 cm, respectively. These values indicate that the dominant energy transformation occurred when the approaching flow encountered the geometric rise of the weir and accelerated over the crest. Geometric transitions in hydraulic structures may produce rapid changes in flow depth, velocity, pressure distribution, and turbulence intensity, thereby increasing local energy dissipation (Bombardelli et al., 2018; Zhu & Chanson, 2017).

The Darcy–Weisbach analysis produced frictional losses of 0.86 cm for the ogee-crested weir and 1.18 cm for the round-crested weir. These values were considerably lower than the total losses of 14.63 and 13.74 cm obtained from the Bernoulli-based energy analysis. Frictional loss represented only approximately 5.88% of the total loss for the ogee-crested weir and 8.59% for the round-crested weir. This difference confirms that distributed channel friction was not the main mechanism responsible for the observed reduction in total energy. Instead, local hydraulic effects associated with crest geometry, acceleration, turbulence, contraction, expansion, and changes in the direction of flow contributed substantially to the total energy loss. Darcy–Weisbach analysis is therefore useful as a supporting calculation of distributed friction, whereas the total-energy equation provides a broader representation of energy changes across the weir system (Altowayti et al., 2021; Chanson, 2019).

The calculated Reynolds numbers were 33,408 for the ogee-crested weir and 40,880 for the round-crested weir. Both values exceeded 4,000, indicating that the flow was turbulent during the experiments. Under turbulent conditions, inertial forces dominate viscous forces, and the flow is characterized by velocity fluctuations, eddy formation, and intensive momentum exchange. Such conditions promote energy dissipation as the flow passes over and downstream of the crest. The higher Reynolds number observed for the round-crested weir indicates more pronounced inertial effects; however, it did not result in a greater total energy loss. This suggests that Reynolds number alone cannot explain the energy-loss pattern because crest geometry and the resulting flow path also control turbulence development and energy transformation (Nezu & Sanjou, 2016) .

The lower total energy loss over the round-crested weir may be attributed to its gradual surface curvature. A rounded profile allows the flow direction to change progressively as water approaches and crosses the crest. This smoother transition may reduce abrupt streamline deformation and limit local separation, recirculation, and turbulent mixing. Previous studies have demonstrated that crest radius and curvature influence flow attachment, discharge characteristics, velocity distribution, and pressure conditions over rounded weirs (Azimi et al., 2020; Felder & Chanson, 2016; Gong et al., 2019). The present findings extend those studies by showing that the hydraulic effects of rounded geometry are also reflected in a lower mean total energy loss under controlled laboratory conditions.

In contrast, the ogee-crested weir generated a slightly greater total energy loss. An ogee crest is designed to approximate the lower profile of a free-flowing nappe at a specified design head. Its hydraulic performance is therefore closely related to the correspondence between the actual operating head and the design head. When the experimental head differs from the design condition, the flow may experience changes in pressure distribution, streamline attachment, acceleration, and turbulence along the crest. These effects can increase local energy dissipation despite the ogee profile's generally high discharge efficiency (Salmasi & Abraham, 2022; Stilmant et al., 2022; Yildiz et al., 2020). Albank and Khassaf (2024) similarly found that geometric variations in ogee spillways influence energy dissipation by modifying downstream flow behavior.

The findings are also consistent with studies of other hydraulic structures demonstrating that geometric configuration affects energy dissipation efficiency. Alghazali & Musa (2024) reported differences in energy dissipation among piano key weir geometries, while Sohrabzadeh Anzani et al. (2024) found that weir configuration influenced downstream residual energy. Pandey et al. (2024) further showed that geometric variation in stepped spillways modifies multiphase flow patterns and energy dissipation. Although these studies examined structures different from the two crest types investigated here, they support the general principle that hydraulic geometry controls velocity redistribution, turbulence generation, and energy reduction.

The results provide both theoretical and practical implications. Theoretically, the study confirms that total energy loss across a weir cannot be explained solely by frictional resistance. Local geometric effects are a major component of energy transformation in non-prismatic open-channel flow. The direct comparison conducted using the same flume, measurement points, and experimental procedures also contributes empirical evidence regarding the relative hydraulic performance of ogee and rounded crest profiles. This finding complements previous research that primarily focused on discharge coefficients, pressure distribution, velocity characteristics, or numerical modelling of a single weir type (Karim & Mohammed, 2020; Kizilaslan et al., 2023; Salmasi & Abraham, 2022). Practically, the lower total en ergy loss observed for the round-crested weir suggests that this geometry may be considered when the design objective is to preserve downstream flow energy and provide a gradual hydraulic transition. Conversely, the greater energy reduction observed for the ogee-crested weir may be advantageous where a higher degree of energy dissipation is required. Nevertheless, crest selection should not be based on energy loss alone. Discharge capacity, upstream water level, structural dimensions, downstream erosion risk, operating head, and site-specific hydraulic conditions must also be considered. Therefore, the results should be treated as comparative evidence rather than as a universal recommendation for all water-control structures.

Several limitations must be acknowledged. First, each weir type was tested in only three trials, which limited the statistical analysis and the assessment of variability across a broader range of conditions. Second, the experiments were conducted using scaled laboratory models, meaning that scale effects may influence the transferability of the findings to full-scale structures(Heller, 2019). Third, the study used a limited set of discharge and upstream-head conditions, whereas ogee-crested weirs may respond differently when the operating head approaches or departs from the design head. Fourth, the Darcy–Weisbach calculation estimated distributed frictional loss but did not directly quantify individual local-loss components such as separation, contraction, expansion, and turbulence. Measurement accuracy may also have been affected by fluctuations in flow depth and velocity under turbulent conditions.

Future research should apply a wider range of discharges, upstream heads, crest radii, weir heights, and downstream conditions. Increasing the number of repetitions would permit inferential statistical testing of the differences between the two crest profiles. The use of pressure sensors, particle image velocimetry, or computational fluid dynamics could also provide a more detailed explanation of pressure distribution, flow separation, vortical structures, and turbulence around the crest. Overall, this study confirms that crest geometry significantly influences energy transformation in open-channel flow. Under the tested laboratory conditions, the round-crested weir produced a lower mean total energy loss than the ogee-crested weir, while the difference between Bernoulli- and Darcy–Weisbach-based results demonstrated that local geometric and turbulent effects were more influential than distributed friction alone.

CONCLUSION

This study concludes that crest geometry influenced the magnitude of energy loss in open-channel flow. Based on the Bernoulli energy analysis, the ogee-crested weir produced a mean total energy loss of 14.63 cm, while the round-crested weir produced a mean loss of 13.74 cm. The difference of 0.89 cm indicates that, under the tested laboratory conditions, the round-crested weir was more effective in maintaining total flow energy. Meanwhile, the Darcy–Weisbach analysis produced frictional energy losses of 0.86 cm for the ogee-crested weir and 1.18 cm for the round-crested weir. The differences between the results obtained from the two equations demonstrate that total energy loss was not determined solely by channel friction, but was also influenced by turbulence, flow acceleration, changes in flow direction, and geometric transitions as water passed over the crest.

The flow over both weir types was classified as turbulent, with Reynolds numbers of 33,408 for the ogee-crested weir and 40,880 for the round-crested weir. These values exceeded the turbulent-flow threshold and indicate the dominance of inertial forces, velocity fluctuations, eddy formation, and intensive momentum exchange during the experiments. The findings provide experimental evidence that crest shape affects energy transformation in open-channel hydraulic structures. However, the conclusions are limited to the model dimensions, discharge conditions, and experimental procedures applied in this study. Future research should examine a wider range of discharges, upstream heads, crest dimensions, and downstream conditions, as well as employ additional measurements of pressure distribution and turbulence to obtain more comprehensive recommendations for the design and evaluation of hydraulic structures.

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