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ITB Golden Ratio Spillway Crest: An Innovative Spillway Geometry For Design Simplicity And Optimal Hydraulic Performance

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Abstract

A spillway is a vital structure in dams or weirs, designed to safely discharge excess water when reservoir levels exceed operational limits. Its performance depends greatly on crest geometry. In Indonesia, the Ogee and cylindrical spillways are the most commonly used. The Ogee spillway is recognized for its superior hydraulic efficiency and ability to maintain low-pressure profiles; however, it requires complex geometry and high construction precision. Conversely, the cylindrical spillway is easier to construct but lacks consistent design standards, particularly for defining the crest radius, which may complicate in design and construction. To address the need for a practical yet theoretically sound alternative, the ITB Golden Ratio Spillway was introduced. This design applies the mathematical golden ratio ($\phi \approx 1.618$) to the crest geometry, aiming to achieve hydraulic performance comparable to traditional Ogee crest spillways while simplifying design and construction. The result is a spillway geometrical structure that combines visual simplicity with engineering functionality. The performance of the ITB Golden Ratio Spillway—Types A and B—was evaluated using numerical simulations with Flow-3D, and the results were validated through hydraulic physical model tests. The Golden Ratio Spillway delivers comparable flow capacity to ogee and cylindrical spillway. This makes the ITB Golden Ratio Spillway a compelling and innovative alternative, offering simplicity in field application and optimal hydraulic performance.

Keywords: *Golden Ratio, spillway, spillway capacity, spillway design curve.*

Abstrak

Pelimpah merupakan struktur penting pada bendungan atau bendung, yang dirancang untuk melepaskan kelebihan air dengan aman ketika permukaan waduk melebihi batas operasional. Kinerjanya sangat bergantung pada geometri puncak pelimpah. Di Indonesia, pelimpah Ogee dan pelimpah bulat adalah yang paling umum digunakan. Pelimpah Ogee dikenal karena efisiensi hidroliknya yang baik dan kemampuannya untuk mempertahankan profil tekanan rendah. Namun, pelimpah ini membutuhkan geometri yang kompleks dan presisi yang tinggi terutama pada saat konstruksi. Sebaliknya, pelimpah silindris lebih mudah dibangun tetapi kurang memiliki standar desain yang konsisten, terutama untuk menentukan radius puncak pelimpah, yang dapat mempersulit desain dan konstruksi. Untuk mengatasi kebutuhan akan alternatif yang praktis namun secara teoritis tepat, Pelimpah Golden Ratio ITB diperkenalkan. Desain ini menerapkan konsep golden ratio dengan rasio matematis

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($\phi \approx 1{,}618$) pada geometri puncak pelimpah, bertujuan untuk mencapai kinerja hidrolik yang sebanding dengan pelimpah puncak Ogee yang sudah ada tetapi dapat menyederhanakan dari proses desain dan konstruksi. Hasilnya adalah struktur geometris pelimpah yang menggabungkan kesederhanaan visual dengan fungsionalitas teknik. Kinerja Pelimpah ITB Golden Ratio tipe A dan B dievaluasi menggunakan simulasi numerik dengan Flow-3D, dan hasilnya divalidasi melalui uji model fisik. Pelimpah ITB Golden Ratio memberikan kapasitas aliran yang sebanding dengan mercu ogee dan mercu bulat. Hal ini menjadikan Pelimpah Golden Ratio ITB sebagai alternatif yang menarik dan inovatif, menawarkan kesederhanaan dalam desain dan kinerja hidraulik yang optimal.

Kata-kata Kunci: *Mercu pelimpah, ITB Golden Ratio, mercu pelimpah baru, kinerja hidraulik pelimpah.*

1. Introduction

Spillways are essential hydraulic structures integrated into dams, reservoirs, or weirs. Their primary function is to safely convey excess water when the water level in the reservoir exceeds the operational limit or reaches the normal threshold due to high inflow discharge, as mentioned by USBR (1987). In a spillway system, the spillway crest is the topmost part where water initiates to overflow or discharge through the structure. It serves as a critical element that governs flow initiation and significantly influences the hydraulic efficiency and overall flow characteristics.

1.1. Types of spillway crest

The design of the spillway crest plays a crucial role in determining the hydraulic performance of a spillway. Engineers have continually developed various crest shapes to optimize water flow, reduce negative pressure, and maximize discharge capacity—each tailored to the specific requirements and scale of the project. The following are some of the most commonly used types of spillway crest profiles:

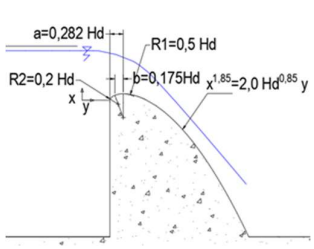
1. Sharp-crested weir: This is the simplest overflow form and has served as a foundation for hydraulic studies since the 19th century, particularly in Europe and America. While accurate for discharge measurement, it is less efficient for handling large flows and tends to induce negative pressure downstream. As a result, it is rarely applied in large dam structures.

2. Cylindrical crest: Developed as an improvement from a sharp crest, this crest has curved radii designed to reduce flow contraction and potential negative pressure. This form began to be widely used since the late 19th century, was more stable, efficient, and was the subject of much research in Europe and North America. Its simplicity in construction and adaptability to different flow conditions made it a practical solution for early dam and weir designs across various regions.

3. Ogee Crest (Ogee/WES Crest): This crest profile is specifically designed to follow the natural trajectory of free-flowing water over the threshold, making it highly efficient and most commonly used on large dams around the world. This design was then extensively standardized by the U.S. Army Corps of Engineers (USACE, 1977) at the Waterways Experiment Station (WES) in Vicksburg, Mississippi. The goal is to maximize the capacity of the spillway discharge and significantly reduce the risk of cavitation damaging the structure. The shape of the Ogee is often considered the gold standard in spillway crest design due to its optimal hydraulic performance.

In Indonesia, the two most commonly used types of spillway crests in spillway structures are the Ogee type and the cylindrical type (PU Dirjen SDA, 2013).

Figure 1. shows an ogee spillway, often used in dams. It has a relatively high geometric design complexity due to the numerous formulas involved, requiring precision, especially during construction. The main components include:



Upstream:
R1=0.5 hd
R2=0.2 hd
a=0.282 hd
b=0.175 hd
c= a-b
Downstream:
$X^{1.85}=2.0hd^{0.85}y$

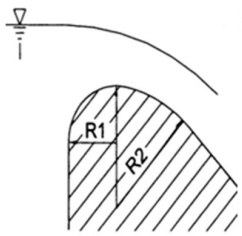
Figure 1. Geometry of ogee crest (PU Dirjen SDA, 2013)

Meanwhile, **Figure 2.** shows the cylindrical crest type Spillway geometry which is simpler in design and construction than the Ogee. However, according to KP-02 PU of the Director General of Natural Resources (2013), there is no definite reference for the ratio of the upstream (R_1) and downstream (R_2) radius in the two-arched cylindrical crest Spillway crest. R_1 ranges from 0.3–0.7 hd (stone masonry) and 0,1–0,7 hd (concrete masonry), while R_2 is undefined, with a downstream gradient of 1:1.

The Spillway discharge capacity is greatly influenced by its geometry. The selection of the right design is crucial for the efficiency and safety of the dam. Spillway geometry has a direct impact on runoff capacity, where the optimal shape includes a specific cylindrical arc that improves the efficiency of flood discharge and energy dissipation, while paying attention to downstream conditions. Therefore, further research is needed on the Spillway of the golden ratio concept to evaluate the hydraulic

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performance of this new geometry.



Upstream: R1=0.3 to 0.7 hd (stone masonry) and 0.1 to 0.7 hd (concrete masonry)
Downstream: R2= no ratio provision yet
Gradien 1:1

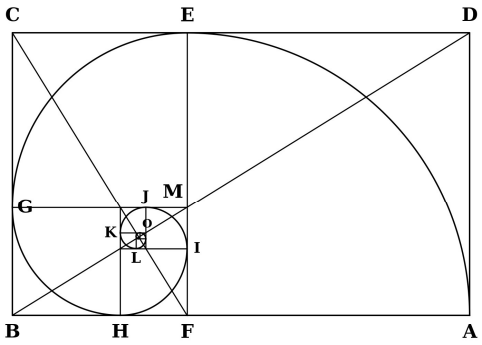
Figure 2. Geometry of the cylindrical crest (PU Dirjen SDA 2013)

1.2. The evolution of spillway design: ITB Golden Ratio Spillway Innovations

Spillway designs have evolved over time to improve efficiency and safety. Spherical Spillway crest began to be used in the late 19th century, followed by Ogee-type Spillways, also known as WES Spillways. This Ogee design was developed in the early 20th century at the Waterways Experiment Station, United States (USACE, 1977).

Since then, the Ogee crest has remained the principal standard for spillway design owing to its high discharge efficiency. Subsequent research has produced two main families of post-Ogee innovation. The first comprises analytical and empirical refinements of the Ogee profile itself, including the continuous crest formulation of Hager (1987), the continuous profile of Montes (1992), and the more recent VC-Ogee relationship of Van Vuuren and Coetzee (2016), which extends the Ogee to three-dimensional approach-flow conditions. The second comprises non-linear, plan-view innovations such as the labyrinth weir and the Piano Key Weir (PKW) introduced by Lempérière and Ouamane (2003), which increase the discharge per unit channel width by folding the crest in plan to extend its effective length. However, no fundamentally new two-dimensional crest profile defined by a single, closed-form geometric ratio has previously been proposed as an alternative to the empirically-derived Ogee profile. The ITB Golden Ratio Spillway addresses this gap by deriving the entire upstream-crest-downstream geometry from the constant $\varphi \approx 1.618$.

This design adopts the concept of the golden ratio ($\varphi \approx 1.618$), a fixed mathematical ratio that is widely found naturally. Golden-ratio-based geometry offers visual balance and structural efficiency, making it an important principle in architecture and art, which blends beauty and function (Akhtaruzzaman & Shafie, 2012). For further understanding, **Figure 3.** shows the Golden Spiral AEGHIJKLO depicted in the Golden Rectangle ABCD.

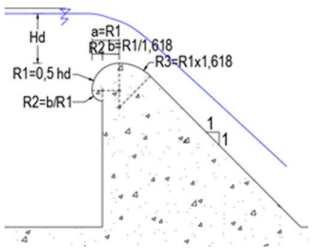


$$\frac{BD}{FC} = \frac{AF}{FB} = \frac{GC}{BG} = \frac{HB}{FH} = 1.618\ldots$$

Figure 3. Golden Rectangle ABCD and golden spiral AEGHIJKLO

$$\frac{BD}{FC} = \frac{AF}{FB} = \frac{GC}{BG} = \frac{HB}{FH} = 1.618\ldots \quad (1)$$

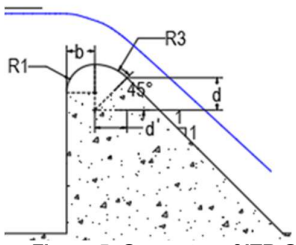
Figure 4. shows the Geometry of ITB Golden Ratio Type A. It is a combination of Ogee and gold ratio. Upstream uses R_1=0.5 hd (Ogee standard), with a = R_1, b = R_1 / 1.618, and R_2 = b / 1.618. Downstream uses $R_3 = R_1 \times 1.618$ and a gradient of 1:1 (round type). This design creates smooth flow transitions as well as harmonious shapes (Annas, 2025).



Upstream:
R1=0.5 hd (refer to Ogee)
a = R1
b= R1/1.618
R2 = b/1.618
Downstream :
R3=R1x1.618
1:1 gradient (refers to the Cylindrical type)

Figure 4. Geometry of ITB Golden Ratio type A (Annas Syaeful, 2025)

Figure 5. shows the Geometry of the ITB Golden Ratio Type B, a simplified version of Type A. Upstream uses R_1 = 0.5 hd and b = R_1. Downstream uses $R_3 = R_1 \times 1.618$ and a gradient of 1:1 (round type). This approach makes Type B easier to apply in construction, while maintaining aesthetics and the principle of golden ratio (Annas, 2025).



Upstream:
R1=0.5 hd (refer to Ogee)
b= R1
Downstream :
R3=R1x1.618
1:1 gradient (refers to the Cylindrical type)

Figure 5. Geometry of ITB Golden Ratio type B (Annas Syaeful, 2025)

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Fundamentally, the geometry of the ITB Golden Ratio Type B is similar to that of a two-radius spherical crest. However, its uniqueness lies in the provision of a definite reference upstream-downstream radius ratio based on the golden ratio. This is very significant because until now, the PU Director General of Water Resources (2013) has not set a definite ratio for R_1 and R_2 on a rounded crest with two arches, so that the ITB Golden Ratio Type B Spillway offers a concrete solution.

2. Methodology

This study evaluated the hydraulic performance of the ITB Golden Ratio Spillway Types A and B using a combination of numerical modeling and physical hydraulic model tests. The research flow starts from literature study, data collection, geometry model preparation, numerical simulation, physical experiment validation, to analysis of results, as presented in **Figure 6.**.

Tabel 1. Positioning of the ITB Golden Ratio Spillway among major innovations in spillway crest design

Spillway design	Innovation category	Reference
Sharp-crested weir	Baseline (19th c.)	USACE (1977)
Cylindrical (two-arc)	2D arc-based	KP-02 (PU, 2013)
Ogee (WES)	2D nappe-shaped (1925)	USACE (1977); USBR (1987)
Hager continuous Ogee	2D refinement (1987)	Hager (1987)
Labyrinth weir	3D plan-view	Schleiss (2011)
Piano Key Weir (PKW)	3D plan-view (2003)	Lempérière & Ouamane (2003)
VC-Ogee	2D refinement (2016)	Van Vuuren & Coetzee (2016)
ITB Golden Ratio (Type A & B)	2D crest profile (2025)	Annas (2025); Natakusumah et al. (2025a)
Spillway design	**Defining principle**	**Construction complexity**
Sharp-crested weir	Vertical edge, single thickness	Simple
Cylindrical (two-arc)	Two arcs without standardized R_1/R_2 ratio	Simple
Ogee (WES)	Empirical fit to free-jet trajectory	Complex (compound curvature)
Hager continuous Ogee	Analytical continuous Ogee profile	Complex
Labyrinth weir	Folded planform extends crest length	Moderate
Piano Key Weir (PKW)	Folded keys with sloped floors	Complex (cantilevers)
VC-Ogee	Ogee corrected for 3D approach flow	Complex
ITB Golden Ratio (Type A & B)	Single ratio $\varphi \approx 1.618$ defines all radii	Simple

2.1. Geometry plan

This study includes three types of Spillways: Ogee, Cylindrical, and ITB Golden Ratio (Types A and B). The Ogee spillway is designed based on the USBR profile standard (1987) while the Cylindrical spillway refers to the KP-02 PU of the Director General of Natural Resources with a variation in the curved radius. Specifically for the Golden Ratio Spillway, the geometry is designed based on the principle of golden ratio (φ=1.618) as explained by Annas (2025). The geometry calculation uses data on Spillway height (P), water surface height (Hd), and width (L) to determine the radius and gradient of the downstream plane. All geometry models are created in *.stl format using Google SketchUp.

2.2. Numerical modelling

The search for the discharge coefficient (Cd and C/Cd) for the ITB Golden Ratio is the main focus of this research, which is fully achieved through numerical testing. This approach is different from conventional methods that rely on physical hydraulic testing in the laboratory, which is much more time-consuming and costly. The discharge curves of both types of ITB Golden Ratio Spillway show remarkable compatibility with physical data, supporting the potential

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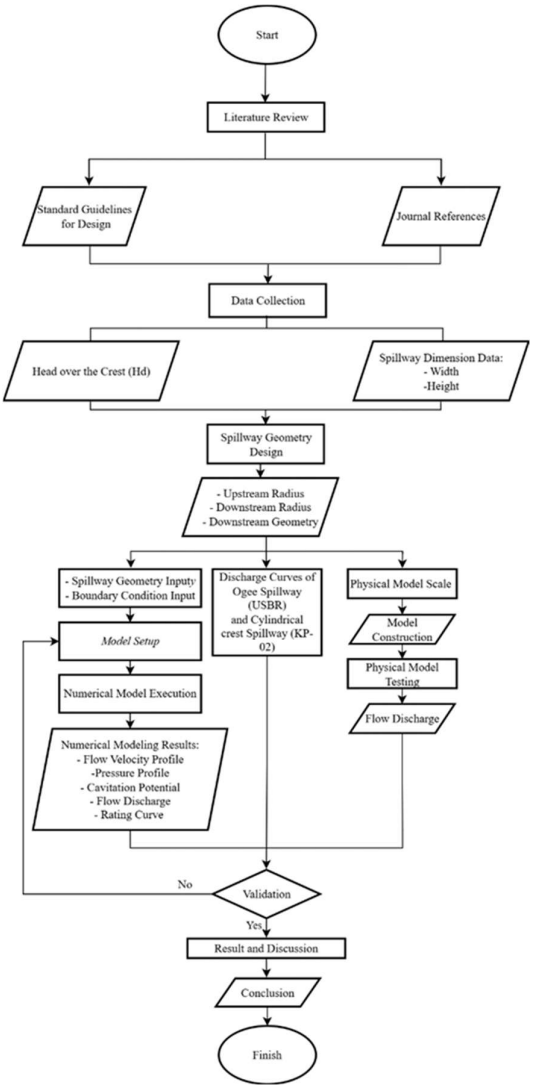


Figure 6. Research flow chart

numerical flume to replace the physical flume in the early stages of design.

Numerical modeling was performed using Flow-3D software. The Spillway model is inserted as a 3D mesh, then conditioned with the relevant boundary and fluid parameters. Simulated discharges are varied for each type of Spillway, resulting in a data of water level and discharge (rating curve). The analysis covers a variety of crucial hydraulic parameters such as pressure distribution, flow separation, and cavitation potential based on σ index.

As illustrative examples, **Figure 7.** and **Figure 8.** show the velocity and pressure profiles on the Type A and Type B ITB Golden Ratio Spillways, respectively, with P/Hd = 3 and a vertical upstream face, providing a visual overview of how these parameters are analyzed in numerical simulations.

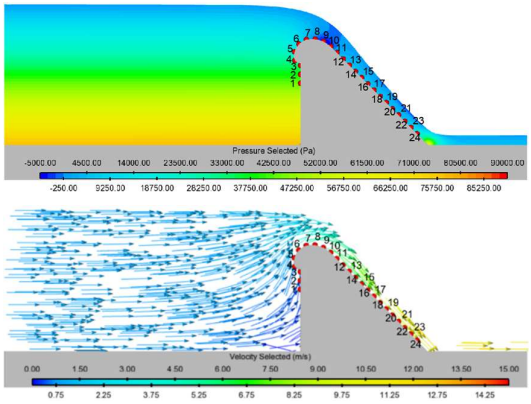


Figure 7. Velocity flow pressure profile on Spillway Golden Ratio type A

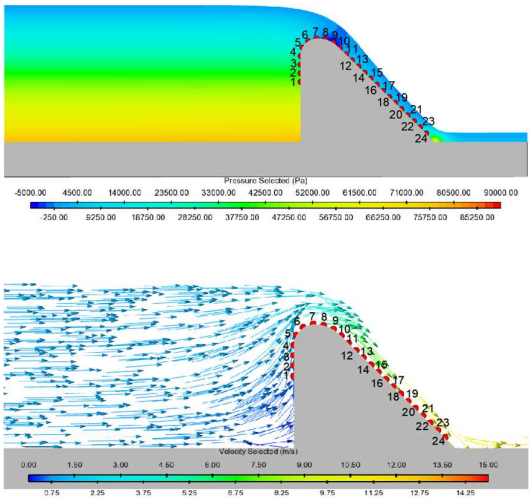


Figure 8. Velocity flow pressure profile on Spillway Golden Ratio type B

2.2.1. Design Discharge Coefficient (Cd) of ITB Golden Ratio Type A

Figure 9. shows the first design curve used in the analysis of the ITB Golden Ratio Type A Spillway, representing the relationship between the initial discharge coefficient (Cd) and the P/Hd variation. This curve is compared with the Ogee Spillway Crest curve provided by USBR (1987). From this figure, it can be seen that the curve for the ITB Golden Ratio Type A lies slightly above the Ogee curve from USBR.

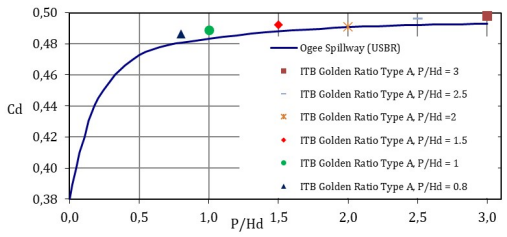


Figure 9. Design Discharge Coefficient (Cd) of ITB Golden Ratio type A

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Figure 10. shows the second design curve used in the analysis of the ITB Golden Ratio Type A Spillway. It represents the relationship between the correction coefficient C_1 (i.e., C/Cd) and the H/Hd ratio, where H is the actual water level and Hd is the design water level. This curve is essential for calculating the actual discharge correction factor relative to the design discharge coefficient (Cd). The curve is compared with the Ogee Spillway Crest curve provided by USBR (1987). From the figure, it can be observed that the curve for the ITB Golden Ratio Type A closely follows the USBR curve but lies slightly below it towards the end.

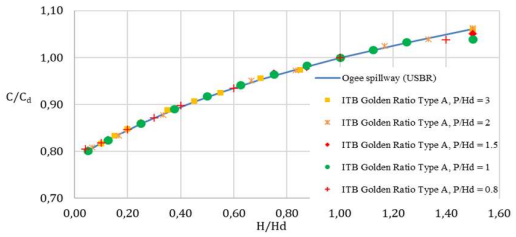


Figure 10. Correction Coefficient C/Cd of ITB Golden Ratio type A

2.2.2. Design Discharge Coefficient (Cd) of ITB Golden Ratio Type B

Figure 11. shows the first design curve used in the analysis of the ITB Golden Ratio Type B Spillway, representing the relationship between the initial discharge coefficient (Cd) and the P/Hd variation. This curve is compared with the Ogee Spillway Crest curve provided by USBR (1987). From the figure, it can be seen that the curve for the ITB Golden Ratio Type B closely matches the Ogee curve from USBR.

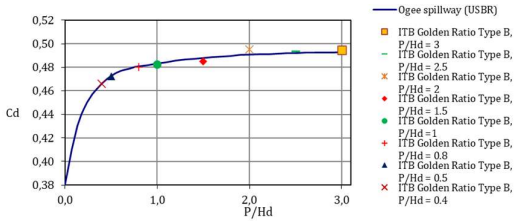


Figure 11. Discharge Coefficient (Cd) of ITB Golden Ratio type B

Figure 12. shows the second design curve used in the analysis of the ITB Golden Ratio Type B Spillway. It represents the relationship between the correction coefficient C_1 (i.e., C/Cd) and the H/Hd ratio, where H is the actual water level and Hd is the design water level. This curve is essential for calculating the actual discharge correction factor relative to the design discharge coefficient (Cd). The curve is compared with the Ogee Spillway Crest curve provided by USBR (1987). From the figure, it can be observed that the curve for the ITB Golden Ratio Type B closely follows the USBR curve but lies slightly below it toward the end.

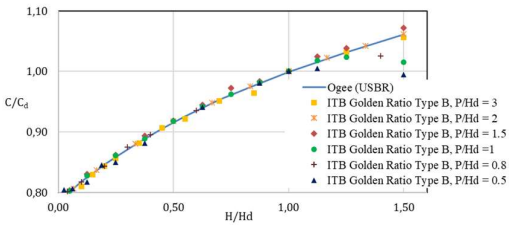


Figure 12. Correction Coefficient C/Cd of ITB Golden Ratio type B

2.3. Physical tests in the laboratory

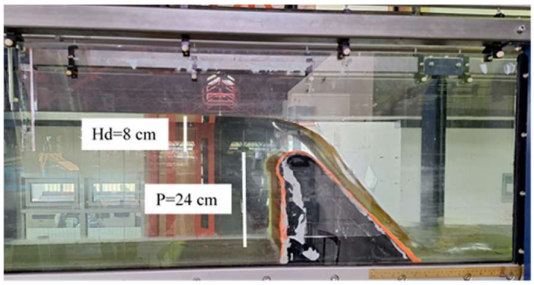
To establish the discharge curves for the ITB Golden Ratio Type A and B spillways, the discharge coefficient curves (Cd) from **Figure 9.** and **Figure 11.**, along with the correction coefficients (C/Cd) from **Figure 10.** and **Figure 12.**, serve as the calculation basis. Although the Type A and Type B models were tested at different physical scales (1:25 and 1:40, respectively). The two scales were used to examine possible scale effects under Froude similarity; since both models agree closely with the numerical results, scale effects are considered negligible.

2.4. ITB Golden Ratio Crest Profile type A

Figure 13. shows the physical model of the ITB Golden Ratio Type A Spillway. This model, built at a 1:25 scale, features a vertical upstream face. The spillway height (P) is set at 6 meters, and the design water level (Hd) is 2 meters. Discharge measurements for this test were conducted in a laboratory flume channel with dimensions of 12.5 meters × 30 cm × 45 cm. Laboratory test results using the physical model of the Golden Ratio Type A at a P/Hd ratio of 3 have been recorded.

2.5. ITB Golden Ratio Crest Profile type B

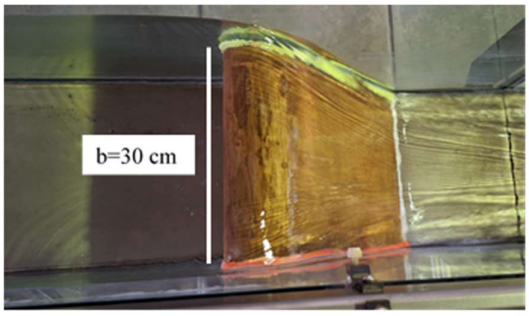
Figure 14. shows the physical model of the ITB Golden Ratio Type B Spillway, built at a 1:40 scale relative to the prototype. The model features a vertical upstream face, with a spillway height (P) of 6 meters and a design water level (Hd) of 2 meters.



(a)

Figure 13. ITB Golden Ratio Spillway Type A Model witha 1:25 Scale, Up picture (a): side view, bottom picture (b): top view

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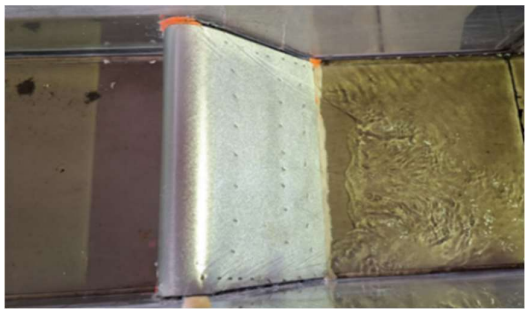
(b)

Figure 14. ITB Golden Ratio Spillway Type A Model with a 1:25 Scale, Up picture (a): side view, bottom picture (b): top view (continued)

Discharge measurements were conducted in a laboratory flume channel with dimensions of 12.5 meters × 30 cm × 45 cm. The results of the laboratory tests for the Type B model, conducted at a P/Hd ratio of 3 and a scale of 1:40, have been recorded.



(a)



(b)

Figure 15. ITB Golden Ratio Spillway Type B Model with a 1:40 scale, up picture (a): side view, bottom picture(b): top view.

3. Study Results and Discussion

The main analysis in this section focuses on the performance of the ITB Golden Ratio Type A and Type B Spillways. We specifically compared the data obtained from the physical model in the laboratory with the results of numerical simulations using Flow-3D. To this end, we conducted a series of discharge tests at various water levels using both physical models.

3.1. Analysis of the results of the spillway of ITB Golden Ratio type A

Physical model **Figure 13.** shows the 1:25 scale of the prototype ITB Golden Ratio Type A vertical upstream, with an Spillway height (P) of 6 m and a design water level (Hd) of 2 m.

Discharge measurements were carried out on this model in the laboratory, with some variation in the height of the water table above the landmark. The results, which correspond to the discharge analysis on numerical modeling and calculations, can be seen in **Table 2.** and visualized on **Figure 15**.

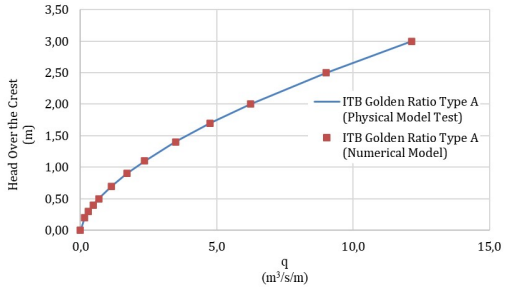


Figure 16. Comparison of ITB Golden Ratio Type A Spillway Discharge Curve (P/Hd=3, vertical upstream) from Physical Model Test and Numerical Model.

3.2. Analysis of the results of the spillway of ITB Golden Ratio type B

Physical model on **Figure 14** shows the 1:40 scale of the prototype ITB Golden Ratio Type B vertical upstream, with an Spillway height (P) of 6 m and a design water level (Hd) of 2 m. Discharge measurements were carried out on this model in the laboratory, with some variation in the height of the water table above the landmark. The results, which correspond to the discharge analysis on numerical modeling and calculations, can be seen in **Table 3**. and visualized on **Figure 16**.

Table 2. Golden Ratio test results type A P/Hd=3 vertical upstream (q = unit discharge, b = 0.30 m flume width)

H Physical Model (cm)	Q Physical Model (l/s)	Q Physical Model (m³/sec)	H Prototype Scale 25 (m)	q Prototype Scale 1:25 (m³/s/m)	q Numerical (m³/s/m)	Relative Error (%)
0	0	0	0	0	0	0
0.8	0.39	0.00039	0.2	0.16	0.16	0.77
1.2	0.72	0.00072	0.3	0.30	0.30	0.79

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Table 2. Golden Ratio test results type A P/Hd=3 vertical upstream (q = unit discharge, b = 0.30 m flume width) (continued)

1.6	1.19	0.00119	0.4	0.50	0.47	4.51
2,0	1.65	0.00165	0.5	0.69	0.67	2.25
2.8	2.75	0.00275	0.7	1.15	1.15	2.14
3.6	4.20	0.00420	0.9	1.75	1.71	2.39
4.4	5.80	0.00580	1.1	2.42	2.35	2.55
5.6	8.57	0.00857	1.4	3.57	3.49	2.18
6.8	11.82	0.01182	1.7	4.93	4.76	3.28
8,0	15.50	0.01550	2.0	6.46	6.24	3.36
10,0	22.56	0.02256	2.5	9.40	9.01	4.18
12,0	30.50	0.03050	3.0	12.71	12.15	4.38

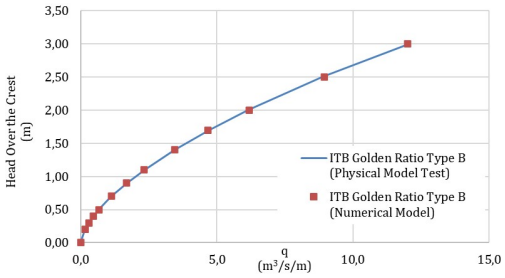


Figure 17. Comparison of spillway discharge curve ITB Golden Ratio type B (P/Hd=3, vertical upstream) from physical model test and numerical model

Table 3. Golden Ratio test results type B P/Hd=3 vertical upstream (q = unit discharge, b = 0.30 m flume width)

Physical Model		Prototype Scale 1:40			q Numerical	Relative Error
H	Q	Q	H	$q = Q \cdot 40^{1.5}/b$		
(cm)	(l/s)	(m³/s)	(m)	(m³/s/m)	(m³/s/m)	%
0.00	0.00	0.00000	0.00	0.00	0.00	0.00
0.50	0.19	0.00019	0.20	0.16	0.16	0.94%
0.75	0.33	0.00033	0.30	0.28	0.30	7.32%
1.00	0.56	0.00056	0.40	0.47	0.47	1.04%
1.25	0.72	0.00072	0.50	0.61	0.56	9.21%
1.75	1.37	0.00137	0.70	1.16	1.13	2.15%
2.25	1.95	0.00195	0.90	1.64	1.70	3.09%
2.75	2.65	0.00265	1.10	2.23	2.33	4.22%
3.50	3.96	0.00396	1.40	3.34	3.45	3.33%
4.25	5.38	0.00538	1.70	4.54	4.68	3.21%
5.00	7.16	0.00716	2.00	6.04	6.19	2.60%
6.25	10.30	0.01030	2.50	8.69	8.94	2.92%
7.50	14.60	0.01460	3.00	12.31	12.02	2.38%

4. Conclusions and Recommendations

Based on the numerical simulations using Flow-3D and the laboratory physical model tests of the ITB Golden Ratio Spillway Types A and B, the following conclusions can be drawn:

1. This study introduced and evaluated the ITB Golden Ratio Spillway—a novel crest geometry derived from the mathematical golden ratio ($\varphi \approx 1.618$)—as an alternative to conventional ogee and cylindrical spillway designs. Two configurations, Type A and Type B, were

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analyzed through numerical simulations using Flow-3D and validated by laboratory-scale physical model testing. **Figures 15** and **16** show that the relative difference between the numerical simulations and the physical model tests is at most 4.5% for Type A and 9.2% for Type B, i.e. below 10% for both types.

2. The results demonstrate that both types perform comparably to the traditional ogee spillway in terms of discharge capacity and pressure distribution, while offering advantages in construction simplicity, geometric clarity, and reduced cavitation risk. Notably, the strong agreement between numerical and physical results affirms the reliability of simulation-based design in early-stage spillway development.

3. By blending aesthetics, hydraulic efficiency, and practical constructability, the ITB Golden Ratio Spillway presents a promising design alternative—particularly for projects that require performance and elegance without the geometric complexity of standard ogee profiles. These innovations contribute not only to hydraulic design theory but also to more efficient infrastructure practices. The ITB golden ratio spillway is more efficient in terms of the time required at the design stage and also the construction geometry because it uses a simple formula compared to Ogee.

4. The ITB Golden Ratio Spillway can be applied to large, medium, or small dams, because its entire geometry is defined by the design head (Hd) and the constant φ and therefore scales directly with the size of the structure. However, its application to large dams should be introduced gradually and supported by further testing, since the present validation is based on laboratory models at scales of 1:25 and 1:40 and on a limited range of P/Hd and H/Hd, whereas large dams operate at higher heads where scale effects, crest pressures, cavitation risk and approach-flow conditions become more critical.

5. Future research may expand this concept into stepped or energy-dissipating variants, explore scale effects further, or validate performance under sediment-laden flows and varying approach conditions. Further work should also include measurements of the crest pressure distribution and cavitation index on larger-scale models, tests with sloping upstream faces and P/Hd ratios outside the present range, and field monitoring of prototype structures, particularly Type B weirs exposed to boulder transport, to confirm their hydraulic performance and durability under actual operating conditions.

Based on these findings and on practical considerations for field application, the following recommendations are proposed for the use of the ITB Golden Ratio Spillway:

1. The ITB Golden Ratio Type A crest is recommended for dam spillways. Because the reservoir traps most of the coarse sediment, little bed load or boulders pass over the crest, so the Type A profile, whose compound upstream radii give hydraulic performance closest to the Ogee crest, can be used without significant risk of impact or abrasion damage.

2. The ITB Golden Ratio Type B crest is recommended for weirs in rivers, where boulders and coarse bed load are frequently carried over the crest during floods. Its simpler geometry, with a single upstream radius and broader, smoother curvature, is less vulnerable to impact and abrasion damage and is easier to construct and repair in the field.

3. A further practical benefit of the distinction described in Recommendations 1 and 2 is that the crest shape itself indicates its design condition: a compound upstream curvature (Type A) identifies a spillway designed for sediment-free reservoir outflow, whereas a single upstream radius (Type B) identifies a crest designed to pass boulder-laden river flow. The intended function of the structure can therefore be recognised directly in the field, which is useful during inspection, operation and maintenance.

4. For river weirs, the crest and downstream face should be protected against abrasion, for example with high-strength concrete or an armouring layer, and the downstream energy dissipator should be designed to allow the passage of boulders. Regular inspection of the crest after major floods is also recommended, so that local damage can be repaired before it alters the discharge characteristics of the weir

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5. For preliminary design, the discharge coefficient (Cd) and correction coefficient (C/Cd) curves in Figures 9–12 may be used directly within the tested ranges for a vertical upstream face (P/Hd = 0.8–3.0 for Type A and 0.4–3.0 for Type B, with H/Hd up to about 1.5). Outside these ranges, or for high-hazard dams, the design should be confirmed by a site-specific physical or numerical model study, including a check of crest pressures and cavitation potential at heads above the design head.

5. Since the KP-02 design criteria do not yet specify the ratio between the upstream and downstream radii of two-radius cylindrical crests, the ITB Golden Ratio geometry is recommended for consideration as a reference profile in future revisions of the national design guidelines, so that designers have a definite and consistent basis for selecting the crest radii of both dam spillways and river weirs.

5. Credit Authorship Contribution Statement

Dantje Kardana Natakusumah: Conceptualization (lead), Methodology (lead), Writing – Original Draft (lead), Supervision (lead), Funding acquisition (lead); Syaeful Annas: Investigation (lead), Data curation (lead), Formal analysis (supporting), Writing – Original Draft (supporting); Joko Nugroho: Writing – Review & Editing (equal), Validation (supporting), Supervision (supporting); Eka Oktariyanto Nugroho: Investigation (supporting), Writing – Review & Editing (equal), Arno Adi Kuntoro: Writing – Review & Editing (equal), Resources (supporting); Fitra Adinata: Software (supporting), Visualization (supporting), Writing – Review & Editing (supporting).

6. Publication Note

This article is an extended English-language version of the article published in Indonesian in Jurnal Teknik Sipil, 32(3), 315–334 (Natakusumah et al., 2025a), and of the oral presentation at the 5th International Conference on Sustainable Infrastructure and Built Environment (SIBE 2025), organized by the Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung, on 4–5 November 2025 in Bandung, Indonesia (Natakusumah et al., 2025b). Following the recommendation of the SIBE 2025 Scientific Committee, it is published with the agreement of the Editor of Jurnal Teknik Sipil to make the results accessible to an international readership.

Compared with the Indonesian article, this version presents an expanded literature positioning (Table 1), revised conclusions, and new practical recommendations, namely the use of Type A for dam spillways and Type B for river weirs. The underlying numerical and experimental data are the same in both articles.

7. Acknowledgements

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