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Alternative weir design using circular crested type and vlughter type energy dissipators on the Yeh Empas longstorage in Tabanan Regency

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ABSTRACT

Climate change affects seasonal changes throughout the world, including in Indonesia a tropical country that experiences rainy and dry seasons with the possibility of facing drought or flood disasters. The long storage construction has an objective to overcome the problem of water availability during the dry and rainy seasons. The Yeh Empas long storage is one of the construction weirs with rubber as a barrier and a movable gate in the Yeh Empas River as a reservoir for raw water for Tabanan Regency. The utilization of movable gates and rubber weir bodies has disadvantages in terms of cost and construction time due to the ordering time. The objective of the current study is to design an alternative weir using circular crested type and Vlughter type energy dissipators without replacing the long storage function. The weir was designed by implementing a 100-year return period flood discharge of 163.29 m^3/dt. The design result depicts the dimensions of weir elements consisting of the crest radius, the crest height, the energy dissipator length, the upstream slope, the downstream slope, and the effective width is 1.00 m, 3.30 m, 5.70 m, 2:3, 1:1, and 26.31 m, respectively.

Keywords: alternatives; design; weir.

1 Introduction

Various types of dams have been increasingly constructed all over the world for irrigation, flood control, power generation, environmental protection, etc [1]. Climate change affects the availability of water. Indonesia is a tropical country that experiences dry seasons and rainy seasons with the possibility of facing drought or flood disasters.

Bali is one of Indonesia's provinces with abundant water resource potential. Based on data from Balai Wilayah Sungai Bali-Penida, the area of the river basin in Bali is recorded at 5,636.66 km^2, and the total length of the river is 2,706 m which flows throughout the administrative area.

One of the buildings that can be used to overcome the problem of drought due to dry seasons and flooding from high rainfall intensity is Longstorage. Long storage is a water retaining structure that functions to store water in relatively flat rivers, canals, and/or ditches by blocking the flow to raise water so that the volume of water storage increases.

Long storage is an alternative that can be applied to stem and drain water in a watershed. Yeh Empas River is the site of Longstorage which was built on Yeh Empas River in Tabanan Regency.

The construction of long storage buildings on the Yeh Empas River uses a moveable weir construction equipped with water gates and rubber as the body of the weir.

Construction of Yeh Empas Longstorage was started on 9th January 2021 and finished on 25th December 2021. In carrying out the construction of Yeh Empas' long storage in Tabanan Regency, the largest cost was spent on purchasing gate panel items and rubber [2]. These two items are not produced in Indonesia, so they must import from Colorado, United States for their procurement. The cost of experts also affects project financing [2].

The reason for choosing to use a fixed weir is that this type is conventional in Indonesia and is widely used in Indonesia. Maintenance of weirs is still not too costly, because many weirs with this construction are

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quite old but still standing strong today. Weir maintenance costs money and time because we have to use experts and equipment imported from abroad.

The Vlughter type energy dissipator was chosen because this type is suitable for rivers with a characteristic difference in energy levels of less than 4.50 meters, and in the river at the planning location, namely the Yeh Empas River, it has a height difference of 2.10 meters [3]. Then alternate planning using energy dissipators can be used.

Based on these problems above, the authors try to design an alternative weir plan using a fixed weir by using a round light with a Vlughter-type energy dissipator on the Yeh Empas long storage without changing the main function of the long storage itself.

[4]Construction development in river areas often encounters obstacles in the form of landslides around the river. Before construction in the river area, it is necessary to investigate the condition of the soil around the construction site. Core drilling is the most useful subsurface exploration method for investigating the location, extent, and constituent makeup of soil and rock state at a potential dam site. Nonetheless, core drilling becomes increasingly difficult through overburden layers thicker than 40-50 m, because [5]: (1) the existence of unpredictable super-large rock particles;(2) frequent borehole collapse; and (3) uncontrollable loss of drilling fluid.

Geophysical exploration methods, such as electrical and electromagnetic methods, seismic procedures, gravity techniques, magnetic methods, and so on, are now increasingly used in dam engineering [6]. These techniques are mostly used to locate the interface between overburden and bedrock and to detect weak layers [7]

A retaining wall is a structure that is constructed to retain the lateral earth pressure of soil [8]. The main function of the retaining wall is to stabilize the hill slide and control erosion.

Efforts to overcome the occurrence of landslides are by constructing a retaining wall. In this plan, a retaining wall with a gravity wall type is also planned to hold the soil around the weir.

2 Data and Methods

The location of the construction is in the Yeh Empas Watershed which has an area of 155,02 km^2, with the downstream location located in Kediri District [2]. Technically, the location of the project is in the administrative area of Br. Dinas Sudimara Kelod, Tabanan District, Tabanan Regency (Figure 1).

In this re-design process through some careful and detailed analysis. Grouping of data types and data sources is also done to avoid the similarity of the data to be analyzed. Most of the data will use secondary data obtained from the Balai Wilayah Sungai Bali-Penida (BWS Bali Penida) of Bali Province and Meteorology & Climatology Berue of Region III Denpasar. The flowchart of the weir design and the retaining wall can be seen in Figure 2.

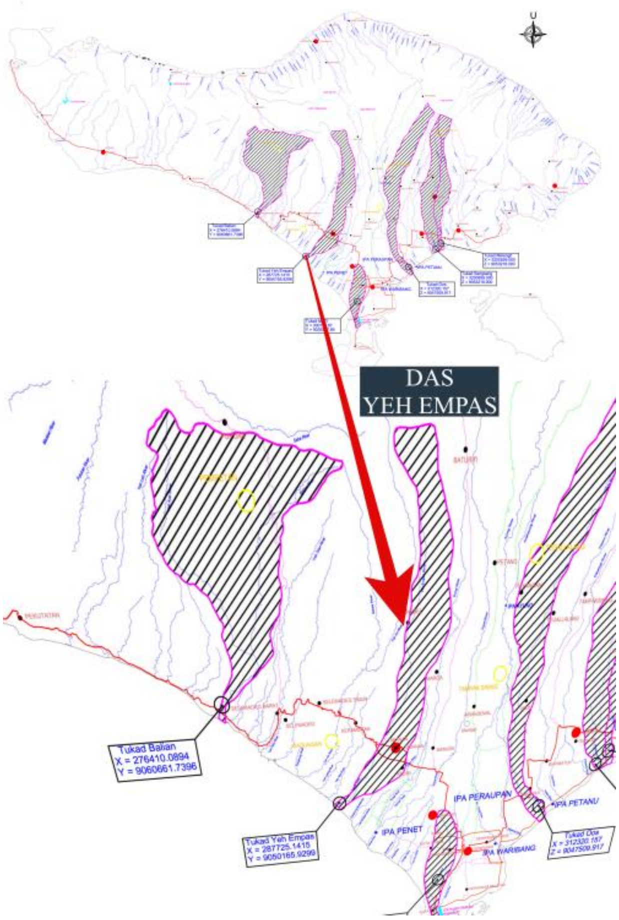

Figure 1. Location of study

2.1 Hydrological analysis

Hydrology is a science related to air on Earth, both regarding its occurrence, circulation, distribution, its properties, and its relationship with the environment, especially with living things [5]. The application of hydrology can be found in several activities such as planning and operating water structures, and supplying water for various purposes (clean water, irrigation, fisheries, erosion, sedimentation control, water transportation, drainage, and pollution control) [5]. The rainfall data that will be used is total annual rainfall data with an observation period from 2011 – 2020 with 3 (three) rain measuring stations. Data non-reference can occur due to environmental changes in the location of the rain measuring station.

Testing the validity of the data is done to determine the consistency of the data to be used in the analysis [9]. The test method that can be used is the Rescaled Adjusted Partial Sums (RAPS) method, which is a test using data from the station itself with cumulative squared deviations from the average value [9].

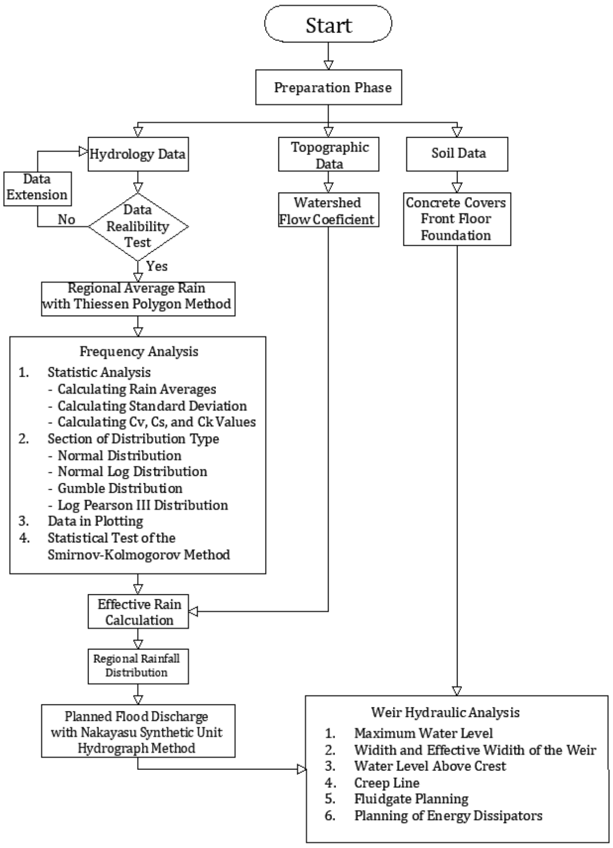

Figure 2. Flowchart of weir design

The first stage of analysis of hydrological data is to calculate the average rainfall at each rain station. After the average rainfall is calculated, then calculate the frequency of rainfall using statistical analysis. The rainfall frequency that has been calculated is then adjusted for its distribution which is then obtained by the type of Log Pearson-III distribution [8]. From the results of the rain distribution test, the data is then analyzed to determine the effective rainfall and design rainfall which will be used as the basis for unit hydrograph calculations.

In 1932, L.K Sherman introduced the concept of a unit hydrograph which is widely used to perform the transformation from rainfall to flow discharge [10][11]. In this planning, the synthetic unit hydrograph method used is the Nakayasu Method. The Nakayasu synthetic unit hydrograph was developed in Japan by Dr. Nakayasu in 1940. The following are the equations of the Nakayasu Synthetic Unit Hydrograph (HSS) [10]:

$$Q_p = \frac{1}{3.6} \times \left(\frac{A \times R_e}{0.3 \cdot T_p + T_{0,3}}\right) \quad (1)$$

$$T_p = t_g + 0.8 \cdot t_r \quad (2)$$

$$t_g = 0.4 + 0.058 \times L \text{ (for L > 15 km)} \quad (3)$$

$$t_g = 0.21 \times L^{0.7} \text{ (for L < 15 km)} \quad (4)$$

$$T_{0,3} = \alpha \times t_g \quad (5)$$

$$t_r = 0.5 \cdot t_g \quad (6)$$

where Q_p represents flood discharge, A is the area of the river basin, R_e is Effective Rainfall, T_p is The time from the onset of the flood to the peak of the flood, $T_{0,3}$ is Time from peak flooding to 0.3 times Q_p, t_g is the time of rain concentration, t_r is rain time unit, α coefficient of the river basin, L is for river length.

2.2 Weir hydraulic analysis

The hydraulic analysis of the weir includes the body of the weir itself and the supporting structures according to the purpose of the weir. The steps for analyzing the hydraulics of the weir and its complementary buildings involve analysis of the calculation of water discharge in the river, analysis of the maximum water level in the river, and Analysis of the width of the weir crest [9].

2.2.1 Maximum Water Level

The maximum water level in the river can be calculated by trial and error methods [9].

$$A = (b + mh) \cdot h \quad (7)$$

$$O = b + 2h\sqrt{1 + m^2} \quad (8)$$

$$R = A/O \quad (9)$$

$$C = \frac{87}{1 + \frac{\gamma_{basin}}{\sqrt{R}}} \quad (10)$$

$$V = C \cdot \sqrt{R \cdot I} \quad (11)$$

$$Q = A \cdot V \quad (12)$$

where A represents the wet cross-sectional area, R represents hydraulic spokes, V represents flow velocity, O represents wet around, I represent the slope of the riverbed, Q represents debit, γ_{basin} represent basin coefficient.

2.2.2 Weir Hydraulic Analysis

Weir hydraulic analysis performs hydraulic calculations of the dimensions of the river and the planned width of the weir [9].

$$B_n = b + 2\left(\frac{1}{2}h\right) \quad (13)$$

$$\mathrm{B} = \frac{6}{5} \times B_n \quad (14)$$

$$B_{eff} = \mathrm{B} - 0.2\sum b - 2\sum t \quad (15)$$

Which is:

$$\sum b = \frac{1}{10} \times B \quad (16)$$

$$\mathrm{H_e} = Q = \mathrm{C} \times \mathrm{L} \times \mathrm{H}_E{}^{3/2} \quad (17)$$

where B_n is for river width, B is for weir width, B_{eff} is for effective width, H_E is for weir height, H_e is for water level above the crest, $\sum b$ is for spillway width.

2.2.3 Energy Loss Over the Crest (h_a)

The energy loss above the crest is also calculated by trial and error to get the ha value of the trial = the calculated ha value [9].

$h_o = H_e - h_a$ .... (18)

$d_o = h_o + H_d$ .... (19)

$F = B_{eff} \times d_o$ .... (20)

$V_o = Q/F$ .... (21)

$h_a = (V_o)^2/2g$ .... (22)

where h_o represents water flow over the crest, d_o determines the average depth, F represents the river area, V_o represents the velocity, and h_a is for energy loss over the crest.

2.2.4 Circular Crested Type

Circular crest has 2 (two) types namely circular crest with 2 (two) spokes (Schoklitsch crest) and circular crest with 1 (one) radius (Vlughter crest). In this design, the round crest used is a round crest with 1 (one) radius, namely the Vlughter type [12].

$h_c = \sqrt[3]{\frac{q^2}{g}}$ .... (23)

If $0.5 < \frac{Z}{h_c} \leq 2.5$ *then value of* $t = 2.4h_c + 0.4Z$

If $2.0 < \frac{Z}{h_c} \leq 10.0$ then the value of $t = 3.0h_c + 0.1Z$

$a = 0.28\, h_c \sqrt{\frac{h_c}{z}}$ .... (24)

$D = R = L$ (in meters)

where h_c represents critical water depth, Z represents energy difference, D represents weir floor depth, R represents curvature radius, and L represents weir floor length.

2.2.5 Resistance Analysis of the Working Force

The force due to the weir's weight can be examined by equation [13]:

$W = b \times h.1\text{m} \times \gamma$ .... (25)

where W represents construction weight, h represents weir height, b represents weir width, Υ represents the specific gravity of materials

As a result of the earthquake force can be calculated [13]:

$K_h = f_h \times w$ .... (26)

$K_v = f_v \times w$ .... (27)

The effect of normal water pressure can be determined using the formula [13]:

$P_h = \frac{1}{2} \times h \times a \times \gamma_{water}$ .... (28)

$P_v = \frac{1}{2} \times h \times b.1\text{m} \times \gamma_{water}$ .... (29)

where γ_{water} represents water-specific gravity, P_h represents horizontal pressure, h represents normal water level, and P_v represents vertical pressure.

Due to flood water pressure [13]:

$P_{h1} = \frac{1}{2} \times h \times a' \times \gamma_{water}$ .... (30)

$P_{h2} = h \times a \times \gamma_{water}$ .... (31)

$P_{h3} = \frac{1}{2} \times c \times h_1 \times \gamma_{water}$ .... (32)

$P_{v1} = \frac{1}{2} \times h \times b \times \gamma_{water}$ .... (33)

$P_{v2} = h_0 \times b \times \gamma_{water}$ .... (34)

where γ_{water} represents water-specific gravity, $P_{h1}=P_{h2}=P_{h3}$ represents horizontal pressure, $P_{v1}=P_{v2}=P_{v3}$ represents vertical pressure, h represents normal water level, ho represents flood water level, h_1 represents downstream water level, $a=a'=b=b'=c$ represents pressure width.

Due to the mud pressure [13]:

$G_h = \frac{1}{2} \times \vartheta_1 \times h \times a \times \frac{1-\sin\theta}{1+\sin\theta}$ .... (35)

$G_v = \frac{1}{2} \times \vartheta_1 \times h \times b$ .... (36)

where ϑ_1 represent mud-specific gravity, G_h represents the force located 2/3 of the depth from the top of the mud which acts horizontally, G_v represents the force located 2/3 of the depth from the top of mud which acts vertically, h represents mud level, a represents mud pressure width, b represents mud width, θ represent the inner shear angle

Due to the water pressure uplift [13]:

$U_x = \Delta H - \frac{Lx}{\sum L}\Delta H + hx$ .... (37)

where U_x represents uplift pressure at point X, hx represents the height of point X relative to the water in front, Lx represents the length of creep line to point X (ABCX), $\sum L$ represents total creep line length (ABCXDE), ΔH represents pressure difference (Figure 3).

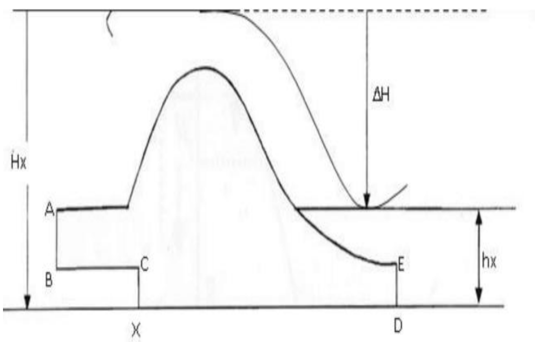

Figure 3. Water pressure uplift

The formula to calculate foundation vertical pressure is [13]:

$P = \frac{\Sigma(w)}{A} + \frac{\Sigma(w)\times e}{I} \times m$ .... (38)

where P represents foundation vertical pressure, $\sum(w)$ represents overall vertical force (including upward pressure, but excluding foundation reaction, A represents the base area, and e represents loading eccentricity (distance from the center of gravity of the base to the result intersection with the bottom, I represent the moment of inertia, and m represents the distance from the base point to the point where the pressure is desired (Figure 4).

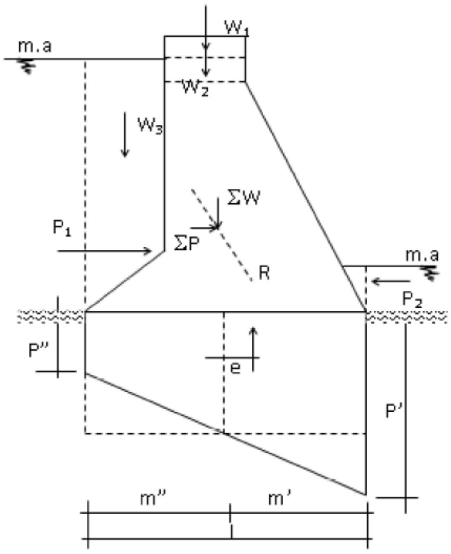

Figure 4. Foundation reaction

The equation for determining the overturning stability control [14]:

$\mathrm{SF} = \frac{\sum M_t}{\sum M_g} > 1.5$ .... (39)

where SF represents the safety factor, $\sum M_t$ represents the total moment of resistance, and $\sum M_g$ represents the number of overturning moments.

The formula for calculating the control over eccentricity [14]:

$\mathrm{a} = \frac{\sum M_T - \sum M_G}{\sum V}$ (.. 40)

$\mathrm{e} = \left(\frac{B}{Z} - \mathrm{a}\right) < \frac{B}{6}$ .... (41)

where a represents the moment difference arm, $\sum V$ represents the number of vertical forces, $\sum M_G$ represents the number of the overturning moment, $\sum M_T$ represents the total moment of resistance, e represents eccentricity, and B represents foundation width.

The control against sliding can be determined by the equation [14]:

$\mathrm{SF} = f \times \frac{\sum R_v}{\sum R_H} > 1.2$ .... (42)

where $\sum R_V$ represents total vertical force, $\sum R_H$ represents total horizontal force, and f represents friction coefficient (0.6 – 0.75)

The formula for soil carrying capacity according to Terzaghi is [15][16]:

$q_{ult} = c \times N_c \times \gamma \times N_q \times D_f \times 0.5 \times \gamma \times \mathrm{B} \times N_y$ .. (43)

where N_c, N_q, and N_y represent Terzaghi bearing capacity factor, γ represents soil density, D_f represents foundation depth, and B foundation width.

For control [6]:

$\overline{\sigma} = \frac{q_{ult}}{SF}$ .... (44)

$\sigma_{maks} = \frac{R_V}{B}\left(1 + \frac{6e}{B}\right) < \bar{\sigma}$ .... (45)

$\sigma_{min} = \frac{R_V}{B}\left(1 - \frac{6e}{B}\right) > 0$ .... (46)

where SF represents the safety factor, R_V represents vertical forces, B represents the weir's body, σ represents generated tension, and $\bar{\sigma}$ permissible tension.

2.2.6 Load Combination Stability Control

The load combination is controlled based on the calculation of the resistance of the weir to the combination of loads acting with an earthquake or without an earthquake accompanied by an uplift or not.

3 Results and Discussion

Following the design method mentioned in section 2, the design of a fixed weir with a circle crest and Vlughter-type energy dissipator the basics of planning come from the results of the analysis that has been done (Table 1).

Table 1. Calculation of hourly rainfall for various return year periods

t	Ratio	Hourly Rainfall					
		2	5	10	25	50	100
1	0.585	26.0	33.4	38.1	43.8	47.9	52.0
2	0.368	16.3	12.3	24.0	27.6	30.2	32.7
3	0.281	12.5	16.0	18.3	21.0	23.0	25.0
4	0.232	10.3	13.2	15.1	17.3	19.0	20.6
5	0.200	8.89	11.4	13.0	14.9	16.4	17.7

Based on the design rainfall data, the calculation of the design flood discharge for the 100-year return period uses the Nakayasu method of calculation. By using equations 1 to 6, the calculation results are obtained for the time from the start of the flood to the peak of the flood (T_p) = 3.6 hours. Time from peak flooding to 0.3 times Q_p ($T_{0.3}$) = 4.6 hours. The planned flood discharge obtained from the calculation of the hydrograph unit (Q_p) is 163.29 m^3/sec (Table 2).

Table 2. The design of flood discharge

Hours	Hydrograph Unit	Effective Rainfall (R_e)					Discharge
		R1	R2	R3	R4	R5	
(t)	(U)	52.02	32.77	25.01	20.64	17.79	(m^3/det)
0.0	0.0	0.00	-	-	-	-	0.00
1.0	0.1	8.90	0,00	-	-	-	8.90
2.0	0.3	17.83	5.20	0.00	-	-	23.03
3.0	0.9	47.17	11.23	2.50	0.00	-	60.90
3.7	1.5	78.03	29.71	8.57	2.06	0.00	118.38
4.0	1.4	72.14	49.16	22.68	7.07	1.78	152.82
5.0	**1.1**	**55.52**	**45.44**	**37.52**	**18.72**	**6.10**	**163.29**
6.0	0.8	42.74	34.98	34.68	30.96	16.13	159.49
7.0	0.6	32.90	26.92	26.70	28.62	26.69	141.82
8.3	0.5	23.41	20.72	20.55	22.03	24.67	111.38
9.0	0.4	20.72	14.75	15.82	16.96	18.99	87.23
10.0	0.3	17.40	13.05	11.25	13.05	14.62	69.37
11.0	0.3	14.61	10.96	9.96	9.29	11.25	56.07

Weir hydraulic analysis includes analysis of weir dimensions. Based on the analysis results, the calculation results are presented in Table 3. The result of the high water level above the crest was shown in Table 4. Table 5 depicts the calculation of the weir creep line length. The length of the weir creep line is 12.78 m.

Table 3. Flow component values over the weir crest

Information			Units
Q_d	=	163.29	m^3/det
B_{eff}	=	26.31	m
h=d	=	2.65	m
h_o	=	2.00	m
h_a	=	0.10	m
H_d	=	3.30	m
H_e	=	2.10	m
H_D	=	3.90	m

Table 4. Value interpretation of H_e

Formulas	He Value Interpretation (m)				
	1.50	1.80	2.00	2.10	3.00
Nilai H_d/H_e Slope 1 : 1	2.20	1.83	1.65	1.57	1.10
C_1	2.10	2.70	2.24	2.07	1.80
h_d	3.30	3.60	3.80	3.90	4.80
Nilai $(h_d+d)/H_e$	3.20	2.83	2.65	2.57	2.10
Nilai h_d/H_e	2.20	2.00	1.90	1.86	1.60
C_3	1.00	1.00	1.00	1.00	1.00
C	2.10	2.70	2.24	2.07	1.76
H_e	2.06	1.74	1.97	**2.08**	2.30

Table 5. Hydraulic analysis of weir dimensions

Information			Units
Round dots (Cd)	=	1.00	m
Vlughter-type energy dissipators			
D = L = R	=	5.7	m
Creep line	=	12.78	m

The analysis is continued by calculating the effects of loading on the body of the weir which includes the effects of self-weight loading. the effects of earthquake loads, mud pressure, hydrostatic pressure, and the effects of uplift pressure. Weir stability control is carried out to obtain buildings with economical dimensions but still capable of supporting heavy loads (Tables 6 and 7).

Table 6. Weir stability control without earthquake force

Stability Condition	Stability Value			
	SF > 1.5	SF > 1.2	Max < 26	Min > 0
Normal water with uplift-pressure	2.90	1.09	6.31	6.27
Flood water with uplift-pressure	2.89	1.42	9.75	5.67

Table 7. Weir stability control with earthquake force

Stability Condition	Stability Value			
	SF > 1.5	SF > 1.2	Max < 26	Min > 0
Normal water with uplift-pressure	2.38	1.20	6.20	6.38
Flood water with uplift-pressure	2.40	1.49	9.75	5.67
Normal water without uplift-pressure	3.34	2.30	11.68	4.18
Flood water without uplift-pressure	3.28	2.56	13.90	4.36

The stability value of the weir re-design analysis exhibited a higher stability standard condition. The long and cross-section of the weir design result can be seen in Figures 5 and 6.

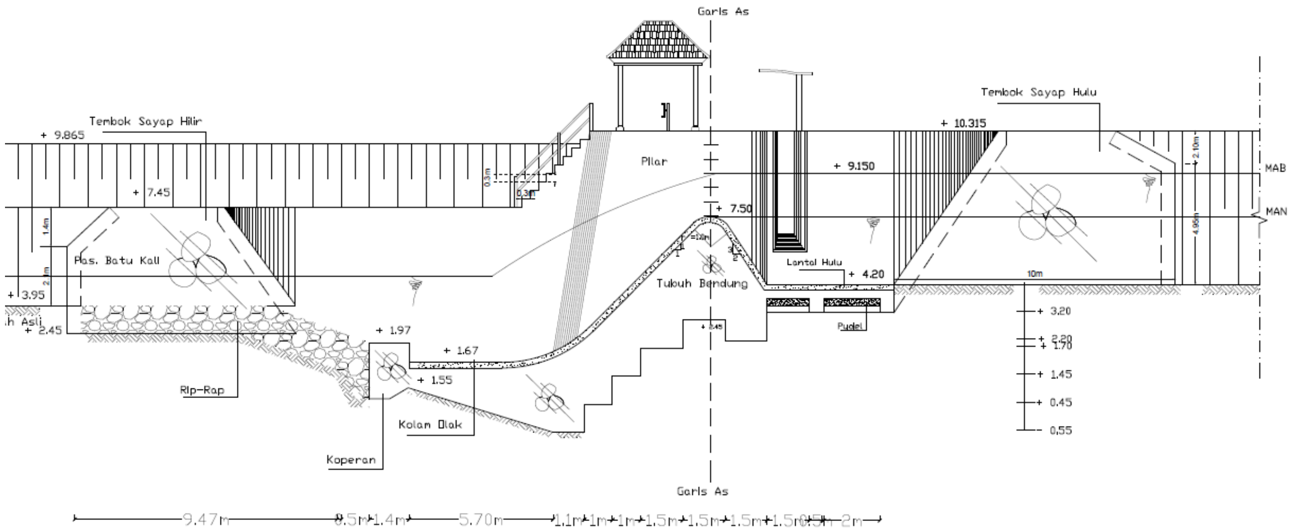

Figure 5. The long section of the weir

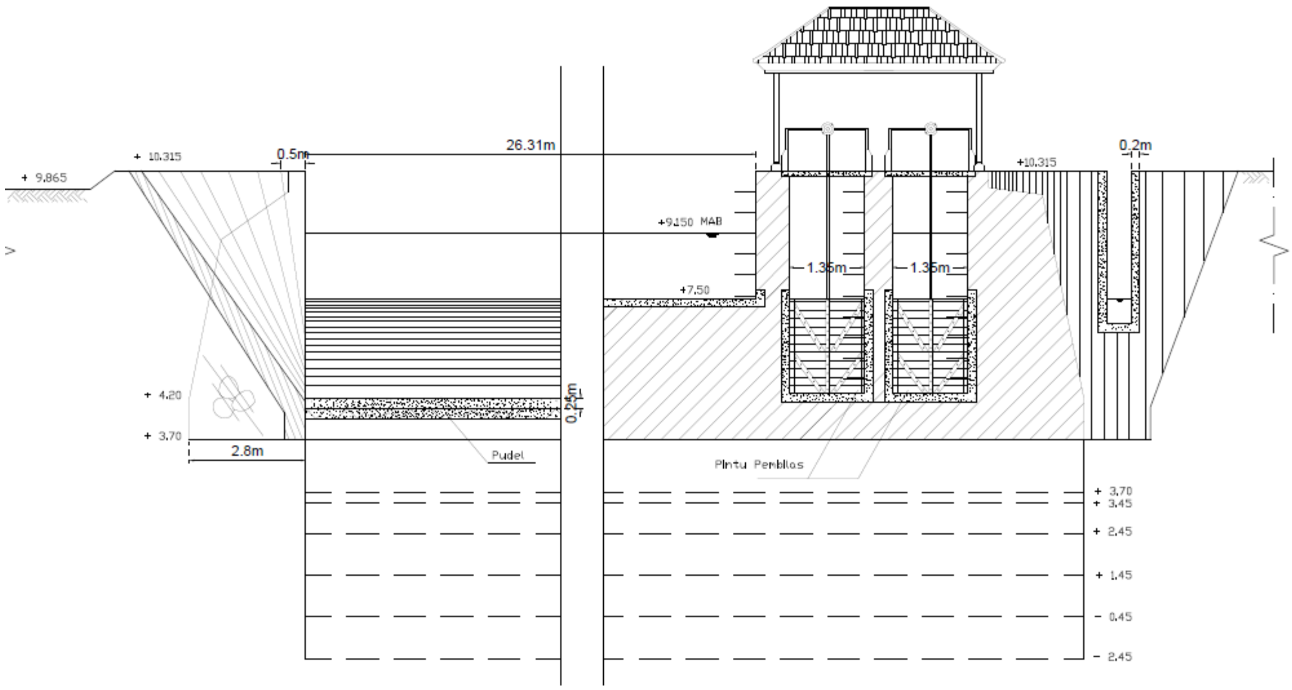

Figure 6. The cross-section of the weir

4 Conclusion

The re-design of the fixed weir by using circular crested and vlughter type energy dissipators is expected to be able to figure out the problems of cost and construction time. This alternative design is applied without changing the function of long storage. The results of hydrological and hydraulics analysis obtained weir dimensions that can withstand the forces that occur. The weir was planned with a 100-year return period flood discharge of 163.29 m^3/dt in consideration. The design analysis result shows the dimensions of weir elements consisting of the crest radius, the crest height, the energy dissipator length, the upstream slope, the downstream slope, and the effective width is 1.00 m, 3.30 m, 5.70 m, 2:3, 1:1, and 26.31 m, respectively.

On this occasion. the author conveys some suggestions for research. future studies are expected to create alternative weirs with economical and environmentally friendly materials without reducing the main function of the weir.

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