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Study of water channels and gates to improve water wheel performance

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Abstract

Glintung Water Street (GWS) in Malang City harnesses water flow in its canal to drive water wheels for electricity generation. However, the discharge of water has not been optimized, necessitating the design of the canal and sluice gate to maximize discharge while mitigating flooding risks. This research aims to determine the optimal design and operational system of the sluice gate to minimize backwater impact. Data collection involved observational techniques and literature review, including hydrology, map, and hydraulic data. Results indicated that the required discharge for the micro-hydro power plant (PLTMH) in the Glintung Water Street (GWS) area was 88 liters or approximately 0.088m3/s. The primary channel's flow rate was measured at 0.104 m3/s, with planned channel inflow at 0.088 m3/s. The sluice gate effectively prevented backwater impact, as water levels did not surpass the sluice height. Planning involved a sluice gate made of mild steel plate (100 cm x 100 cm) with a door height of 200 cm and a thickness of 0.18 cm, operated by a handlebar with a diameter of 2 cm. In conclusion, the backwater effect on the primary channel's water level was minimal, affirming the efficacy of the designed sluice gate.

Keywords: Increased performance of the windmills, Micro-hydro power plants, Water gates, Waterways

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1. Introduction

The number of ways to obtain electricity by utilizing environmental conditions continues to increase over time. One such method is harnessing water as a driving force for turbines. This practice is exemplified by the residents of Glintung Water Street (GWS) RW 05, Purwantoro Village, Blimbing District, Malang City, who utilize canal flow as a source of energy to drive water wheels, known as Micro Hydro Power Plants (PLTMH), for electricity generation. Micro hydro refers to small-scale power generation installations where water flow serves as the primary energy source (Sarminingsih, 2018). The water utilized possesses specific head heights and flow capacities.

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The Glintung Water Street (GWS) area is situated in the heart of Malang City, where the canal conditions still rely on underground pipes to transport water from the river to the existing channels. From these channels, water is directed towards the water wheels to set them in motion (Fathurrahman, 2020; Usman & Rahman (2016). The performance of these water wheels is influenced by the flow rate discharged by the intake pipes from the river. In this context, the channels play a crucial role in meeting the water flow requirements (Cahyadi & Gazali, 2022; Parse, 2018). However, the existing water channels fail to produce the necessary flow rate to meet the minimum electricity demand at the location. Hence, there is a need to design channels capable of fulfilling the water requirements for PLTMH. The planned channels will stretch along Jl. Letjend S. Parman I, leading the outlet from the channel to the existing river, considering potential backwater to prevent flooding in the area.

According to Sedyowati et al. (2022), the flow rate generated in the channels at Glintung Water Street is approximately 7.9 L/second, resulting in 9 RPM on the water wheel, with PLTMH generating about 20 volts of electricity. However, the minimum requirement for normal voltage is 220 volts. Hence, there is a necessity to design the channel to maximize the performance of the water wheels and also design sluice gates to maximize the required flow rate and reduce the potential for flooding in the area (Wijaya, 2020; Sulaecha & Setiawan, 2020) .

This research focuses on channel design to enhance the flow rate in the irrigation system within the Glintung Water Street (GWS) area, utilized as the driving force for micro-hydroelectric power plant water wheels. It is hoped that this research will result in channels that can maximize the functionality of PLTMH in that location.

Based on the aforementioned context, this study aims to address the existing flow rate requirements on-site and design channels and sluice gates to maximize the flow rate and potential of water wheels for PLTMH, derived from the conditions present in the Glintung Water Street (GWS) area.

2. Methods, Data, and Analysis

In this research, data was obtained through research results which have been analyzed using several data collection methods.

Observation

Direct observation to find out how the condition of the micro hydro power generating equipment is directly affected by the flow rate at the location. Apart from observing the condition of the water discharge, the researchers also observed changes in the water level at certain times.

Literature study

This method utilizes previously existing written sources to solve the problem being researched according to the context being discussed. Contains procedures or research flow, research location and analysis methods used in the research. The description of the methods used in the research is presented informatively, coherently and clearly.

3. Results and Discussion

The desired outcome is to plan the dimensions of the channel that can meet the water discharge requirements through PLTMH at Glintung Water Street. With proper planning, it is hoped that the desired results can be achieved, thereby enhancing the performance of PLTMH at the location.

The data used to evaluate the Existing Drainage System consists of hydrological data and technical data on the existing channels, detailed as: (1) Planned Area: 0.0061 km2; (2) Channel Type: Concrete-lined channel; (3) Channel Shape: Trapezoidal; (4) Manning's roughness coefficient: 0.016

Rainfall data is obtained from BMKG (Meteorology, Climatology, and Geophysics Agency). The highest rainfall from 2012-2021 occurred in December 2012 with 98 mm of rainfall. This data is also used as the basis for calculating rainfall discharge (Table 1).

Table 1.
Rainfall 2012-2021 Malang City, Ciliwung Station

Year	Rainfall (mm)												Xi
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2012	43	85	56	22	8	4	0	4	0	35	39	98	98
2013	46	33	64	31	29	84	28	0	0	35	29	79	84
2014	14	4	36	44	42	78	26	7	0	7	20	29	78
2015	17	17	17	31	32	0	0	0	0	0	12	19	32
2016	19	25	11	13	11	17	9	21	7	16	22	12	25
2017	14	15	18	21	24	14	55	0	11	13	17	17	55
2018	21	20	25	21	11	34	0	0	5	4	20	17	34
2019	12	26	18	21	16	0	11	0	0	0	20	22	26
2020	19	20	22	16	38	9	14	28	7	7	43	27	43
2021	24	21	20	20	21	25	14	18	38	24	18	20	38

Source: BMKG Ciliwung

Area-specific rainfall distribution

The required rainfall for planning the drainage system in the Glintung Water Street area is the average rainfall from observation points, based on the Ciliwung rainfall station. According to Alkatiri (2020) and Cahyadi & Gazali (2022), if there is only one observation point or rainfall station, there is no need for further testing. Therefore, the data obtained from the Ciliwung station can be directly processed to determine the discharge.

Frequency analysis

Frequency Analysis is conducted to determine return periods and probability values. From the rainfall data, it can be understood that the highest daily rainfall experienced at the Ciliwung station in 2012 was 98 mm. Based on the statistical parameters, a skewness coefficient (Cs) of 0.81 and a kurtosis coefficient (Ck) of 2.54 were obtained. Consequently, calculations are continued using the Gumbel method to obtain the desired planned channel conditions.

Calculating Rainfall Frequency Factors Using the Gumbel Method

The estimated plan is to use the channel for 10 years, because in the future the PLTMH area will be expanded.

Table 2.
Annual estimated rainfall calculation

Period (year)	Xr	K	Sx	Xt (mm)
2	51.3206	-0.13553	26.27815	47.75911
5	51.3206	1.058024	26.27815	79.12353
10	51.3206	1.848252	26.27815	99.88925

Calculation of designed discharge

The rainfall intensity is the amount of rainfall that falls within a certain height of rainfall (Suripin, 2004). The magnitude of rainfall intensity varies depending on the duration and frequency of rainfall events. To calculate rainfall intensity, the Mononobe formula (Eq. 1) is used.

$$I = \frac{R24}{24}\left(\frac{24}{Tc}\right)^{2/3} = \frac{99,889}{24}\left(\frac{24}{16,734}\right)^{2/3} = 5.293 \text{ mm/hour} \qquad \text{(Eq. 1)}$$

Where:
I = Rainfall intensity (mm/hour)
R24 = Maximum daily rainfall in twenty-four hours (mm/hour)
Tc = Duration of rainfall (hours)

Rainwater discharge calculation

$$Q = (1/3,6)\ C.I.A = 0,278.C.I.A \text{ (Eq. 2)}$$
$$= 0,278 \ .\ 0,390 \ .\ 5,293 \ .\ 0,0067$$
$$= 0,00355 \text{ m}^3\text{/second}$$

Designing sluice gates

The use of sluice gates at the location is aimed at preventing excessive discharge to anticipate floods in RW 05 area and optimizing the channels for better organization. Using sluice gate dimensions of 100 cm x 100 cm to prevent flooding during rainy conditions, a design suitable for the local conditions is employed.

Based on Kementerian Pekerjaan Umum Direktorat Jenderal Sumber Daya Air Direktorat Irigasi dan Rawa (2013), a sliding gate with a span length of up to 1.20 m with a single-bar type and long frame for the planned channel is utilized. The type of gate used is determined based on usage standards, employing a sliding gate with a short frame type for channels with a free span between 1,000 mm x 1,500 mm in height. The gate frame is constructed using cut steel angle profiles and steel plates connected with bolts (Ma'arif, 2021; Nasir, 2019). Based on the sluice gate data obtained, calculations are performed on the sluice gate to prevent losses in channel planning.

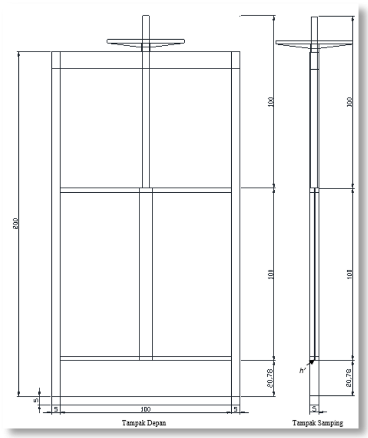

Figure 1. Calculations of the sluice gate

Sluice gates controlling

Control of sluice gates in this case is to prevent back water from occurring and also to prevent overflow of flow discharge during rain in the planned channel. Therefore, it is necessary to observe channel conditions on rainy days to find out the highest water level after rain, by collecting data within 5 days when it rains as in Table 3.

Table 3.
Data on water level height of primary channels after rain

Day	h(m)	h'(m)	Q(m^3/sec)
1	0,37	0,56	0,161232
2	0,37	0,48	0,136955
3	0,37	0,67	0,195288
4	0,37	0,66	0,19216
5	0,37	0,58	0,167365

From observations conducted between November 2022 and December 2022 (Table 3), the highest water level rise in the primary channel during rainy days increased to 0.67 m from a normal water level of 0.37 m, which did not exceed the planned sluice gate height of 1.00 m. This is due to the primary channel being connected to several other channels and receiving runoff from several roads within the city that pass through the channel. To prevent flooding, it is necessary to close the sluice gate only during heavy rainfall. Due to insufficient equipment, some data were difficult to obtain, necessitating further research on the sluice gate conditions.

4. Conclusion

Based on the discussion and analysis results, the following conclusions can be drawn: (1) The required discharge for the micro-hydro power plant (PLTMH) in the Glintung Water Street (GWS) area of RW 05, Purwantoro Village, Blimbing District is 88 liters or approximately 0.088m3/s. To meet this discharge requirement, a canal is planned with an economically feasible slope of 0.00001 and a height difference of 0.0016 m. Rainfall calculations using the Gumbel method yield a rainfall discharge of 0.0035 m3/second in an area of 6.184 m2; (2) The primary channel has a flow rate of 0.104 m3/s with a water level of 0.37 m, and it will flow into the planned channel at a rate of 0.088 m3/s; (3) The planning of the sluice gate involves the use of lightweight steel plates with dimensions of 100 cm x 100 cm and a gate height of 200 cm, with a gate thickness of 0.18 cm and a gate handlebar diameter of 1.591 or 2 cm. The effect of backwater on the water level of the primary channel is minimal. During observations after rainfall, the flow in the primary channel never exceeds the height of the existing channel. Therefore, the sluice gate effectively prevents the impact of backwater as the water level does not exceed the height of the gate. These statements indicate that the research has successfully formulated solutions in line with the objectives to meet the water discharge needs for PLTMH, optimize the channels, and prevent flooding in RW 05 Glintung Water Street area.

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