An Experimental Study on Hydraulic Model of Water Intake Canal at Steam and Gas Power Plants

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Abstract. The performance of the canal water intake used in the Gas and Steam Power Plant (PLTGU) cooling system is carried out by testing the physical model of the water intake canal with a 1:15 scale model. In which, the canal water intake prototype has dimensions of length, \( L = 33.30 \) m, width, \( B = 13.40 \) m and height, \( T = 11.67 \) m, scaling the prototype dimensions to the model dimensions is done by complying with Froude's law. The purpose of this paper is to determine the flow patterns that occur in the physical model and the minimum elevation allowed based on applicable guidelines [1]. The variables measured in this study were the flow velocity in the canal and also the visual documentation of the flow pattern in the canal including the formation of vortices. Tests were carried out on three variations of tidal elevation, namely HWL, MSL and LWL. The experimental results show that the flow pattern in the channel varies with depth with an average Reynolds Number value = \( 3.5 \times 10^4 \). Vortex formation occurs at all elevations where the vortex is formed in the area near the pump. The observations show that the critical elevation of the canal is at \( H = 0.29 \) m for the model and \( H = 4.35 \) m for the prototype.

Keywords: Water intake canal, Hydraulic model, Vortex, Power plants

1. Introduction

The water intake has an important role in the smooth production of electricity, which functions to supply water to the cooling system in a power plant where sea water is pumped into the condenser tube so that the remaining steam from the turbine can condense so that the phase becomes liquid. The main component used to drain water at this water intake is a centrifugal pump. As the most engineering projects, the design of the water intake structure uses two principles, namely minimizing costs and maximizing efficiency. In fact, a common problem that causes the efficiency of this system to decrease is the occurrence of unpredictable flow patterns, such as vortex flow.

The vortex flow can occur in the suction pump or within the water intake structure itself, excessive vortex flow can cause unexpected impacts on the intake such as loss of head, ingress of air into the water flow causing cavitation and vibration in the system, increased use of material ratio, and reduce flow efficiency and increase the likelihood of impurities entering the intake. Eddies can occur on the surface or below the surface, both of which can be seen in a steady flow state (water velocity does not change). Flow pattern conditions in the intake structure are usually observed and studied by making hydraulic...
2. Research methods

The procedure of research is carried out in the following stages. First, a literature study is conducted to obtain an experimental method that must be done by examining books, journals, guidelines and standards relating to the topic of research. Second, making a hydraulic model from the Water Intake channel of the Grati PLTGU with a geometric scale of 1:15 using Froude's law, then testing all the components used for the experiment. Third, conduct experiments by taking flowrate data using flow sensors and documentation of visual flow patterns that occur within the canal. Finally, it was done a data processing and then draw conclusions from the results obtained.

2.1. Model construction

The model was built on a scale of 1:15 using steel material as a frame structure and transparent glass as the wall. The main dimensions of the model are determined using Froude's law [1].

\[ F_r = \frac{F_m}{F_p} = 1 \quad (1) \]

With \( F = \frac{V}{(gL)^{0.5}} \), where \( V \) is the characteristic flow velocity, \( g \) is the gravitational constant and \( L \) is the representative length on the test model. The ratio scale for length (L), velocity (V), discharge (Q), and time (T) given as follows.

\[ L_r = \frac{L_m}{L_p} \quad (2) \]

\[ V_r = \frac{V_m}{V_p} = L_r^{0.5} \quad (3) \]

\[ Q_r = \frac{Q_m}{Q_p} = L_r^{2.5} \quad (4) \]

\[ T_r = \frac{T_m}{T_p} = L_r^{0.5} \quad (5) \]

The notation of \( p \) denotes a prototype and \( m \) is a model, from the above equation we can determine the main dimensions of the test model as given in Table 1. Based on Table 1, the water intake canal model created has dimensions of length, \( L = 2.22 \) m, width, \( B = 0.89 \) m and height, \( T = 0.78 \) m and a flow rate of pump capacity, \( Q = 28.69 \text{ m}^3 \text{ /hour} \). In addition to scaling of the canal design elevation is given in Table 2, in which HWL is Height Water Level, MSL is Mean Sea Level and LWL is Low Water Level.

| Table 1. Water intake model scaling |
|-----------------------------------|
| Scale   | L (m) | B (m) | T (m) | Q (m3/hour) |
| Prototype | 33.30 | 13.40 | 11.67 | 25000       |
| Model    | 2.22  | 0.89  | 0.78  | 28.69       |
Table 2. Water elevation model

| Water elevation | Prototype (m) | Model (m) |
|-----------------|---------------|-----------|
| HWL             | 8.67          | 0.58      |
| MSL             | 6.67          | 0.445     |
| LWL             | 4.67          | 0.31      |

The internal details of the model are shown in Figure 1. The flow in the canal is continuous, where the water sucked by the pump is then flowed back into the canal through the circulation pipe.

2.2. Data collection

The variable measured in this test is the flow rate in the canal at a water depth of 0, 0.5d and d for each elevation. Data collection points are shown in Figure 1 including, point A (pump area), point B (Bar Screen area) and point C (Traveling Screen area), while Figure 2 showed the bar screen area and the travelling screen are in detail. In addition, the collecting flowrate data and vortex observations that occur inside the canal are also conducted to determine the type of vortex formed at each elevation (Table 3).
Table 3. The location of the test point

| Test point | HWL   | MSL   | LWL   |
|------------|-------|-------|-------|
| 1          | 5 cm  | 5 cm  | 5 cm  |
| 2          | 30 cm | 25 cm | 17 cm |
| 3          | 58 cm | 45 cm | 31 cm |

2.3. Experimental set-up
The accuracy of experimental set-up and procedures are a major concern for obtaining accurate data. In this sub-section, the experimental set-up and procedures are explained in detail, including the tools and materials used to the workings and processing of experimental data.

The physical model is drained with water until it meets the desired water load, then turn on the electric motor so that the pump operates for a while for heating purposes, after that hook the pump by filling the volute pump housing with water. Then turn on the pump again and wait a moment until the flow stabilizes, after the flow in the channel is stable, the test can be done. Discharge data collection and vortex observations were carried out simultaneously. Where the tools and materials used are flow sensors (D = 5 cm), ink / food coloring, torn paper, and cameras.

3. Results and discussion
3.1. Flow distribution
Flow rate data are averaged for each elevation then converted to velocity at each test point using equations,

$$Q = V \times A$$

Where Q is the flowrate, V is the flow velocity and A is the cross-sectional area of the channel in this test the cross-sectional area is the flow sensor area = 0.002 m2. Then we can see the distribution of flow in the canal water intake as follows.

Figure 3 shows the average flow velocity at HWL elevation tends to increase when approaching the pump area, where the highest average velocity is at the base (t = 5cm) around the pump area. The flow on the surface is so calm that it cannot be detected by the measuring instruments used in this test.

At MSL elevation different flow patterns are shown in the traveling screen area (Figure 4c). Where the flow on the surface of the water moves in the opposite direction from the flow of water in the canal, this occurs because water hits the inhibitors in the canal such as canal walls, screens, and bulkheads between screens so that the flow direction turns and moves in various directions. In addition, the average velocity at the bottom of the canal decreases as it approaches the pump, in contrast to the average speed.
at the HWL elevation which increases when approaching the pump mouth. This shows that the pressure inside the canal affects the velocity and flow patterns that occur within the canal.

![Figure 4](image1.png)

**Figure 4.** Distribution of flow velocity inside the canal at MSL elevation

The velocity distribution at the LWL elevation has the highest average of all tested elevations. Where the highest average velocity is found at the base of the area around the pump as shown in Figure 5a. Based on observations, it occurs due to the pressure from the volume of fluid in the canal which shrinks so that the difference in velocity between the flow of water on the surface and bottom of the canal is not too significant.

![Figure 5](image2.png)

**Figure 5.** Distribution of flow velocity inside the canal at the LWL elevation

### 3.2. Vortex Visualisation

Vortex observations were carried out at three elevations, namely HWL, MSL and LWL. The results of the observations are then classified based on the strength of the vortex, as shown in Figure 6. According to ANSI/HI 9.8. [1], vortex formation is permitted if it does not carry dirt or air into the pump.

A similar limit is also recommended by [11] where the standard allowed for pump operation is the vortex depth on the surface should not exceed 0.3 ft and less than 5 RPM [11]. The observations show that vortex formation occurs at each elevation with different vortex strength levels.

At the elevation of the HWL a vortex is formed at the mouth of the pump as shown in Figure 7. The whirlpool that is formed is not too strong so the dye injected into the vortex does not rotate following the vortex. If referring to the classification of vortex types contained in [1], the type of vortex shown in Figure 6 is subsurface vortex type 1. At Mean Sea Level elevation there is the formation of subsurface vortex as shown in Figure 8.

Vortex that occurs at MSL elevation is stronger and has a higher frequency when compared to vortex which occurs at HWL elevation. If the elevation of the HWL vortex occurs it has a quieter rotation and only occurs from under the pump mouth. Whereas at MSL elevation the vortex moves irregularly vertically and attaches to the canal wall.

If referring to the classification of vortex types according to ANSI/HI 9.8. [1], vortex shown in Figure 8 is the type of vortex dye core (type 2) where this type of vortex can still be accepted in accordance
with the provisions of [1]. Other observations do not show any vortex formation on the canal surface at MSL elevation.

Figure 6. Classification of vortex type [1]

Subsurface vortex formed at LWL elevation (Figure 9) has a thicker vortex center compared to vortex which occurs at MSL elevation. This indicates that the vortex strength is greater, but this vortex is still classified as a subsurface vortex type 2 because there is no air entering the center of the vortex.

In addition to forming subsurface vortex, the researchers found a vortex formation at the surface of the flow area around the pump. The vortex shown in Figure 10 is seen pulling a piece of paper towards the center of the vortex then bringing the pieces of paper into the flow. The frequency of vortex is very small and the direction of vortex moves away from the mouth of the pump.

Figure 7. Vortex formation at HWL elevation
Figure 8. Subsurface vortex at MSL elevation
3.4. Critical Submergence

The form of critical submergence is defined as the smallest depth where strong and unwanted vortices do not occur. If submergence is smaller than the Sc value, then the vortex will be formed, but the argument is not always true as long as the vortex can be formed even though that is understandable.

\[ S_c = 1.0 + 2.3F_D D \]  \hspace{1cm} (7)

By entering the value of the Froude Number at the mouth of the pump, the critical submergence value is obtained as \( S_c = 0.121 \text{ m} \). To find out what the minimum elevation is allowed so that there is no very strong vortex, the critical submergence value is summed by the distance of the pump mouth to the bottom of the canal, namely \( C = 0.17 \text{ m} \). So that the value of \( H_{\text{min}} \) can be obtained \( H_{\text{min}} = S_c + C = 0.121 + 0.17 = 0.291 \text{ m} \).

Validation of the calculation results was done by observing the vortex at the elevation below the minimum depth, at 28 cm elevation found very strong vortex occurs in the pump area as shown in Figure 12. Vortex begins to form near the pump as shown in Figure 12, the power of the vortex gets bigger and moves away from the mouth of the pump until it finally disappears. The average time needed from the beginning of the vortex formation until the vortex disappears from the surface is for 3 seconds. Apart from occurring in the area around the pump, vortex formation occurs in the area around the screen. Overall, the vortex formed at 28 cm elevation can be mapped in Figure 14 and Figure 15.
Visual observations showed that the critical elevation of the test model was 28 cm. The results of critical submergence calculations using the formula from ANSI/HI 9.8. [1] have a difference of 0.01 m

|                  | Critical Submergence (m) | Physical Test | $H_{\text{critical}}$ (m) | $H_{\text{min}}$ (m) |
|------------------|--------------------------|---------------|---------------------------|---------------------|
| **ANSI/HI 9.8. [1]** | 0.121                    | 0.11          | 0.28                      | $\geq$ 0.29         |
| **Prototype**    | 1.8                      | 1.65          | 4.20                      | $\geq$ 4.35         |

Table 4. Comparison results of critical submergence calculations and physical tests
with the experimental results. Then from the results listed in Table 4, it can be determined that the recommended minimum height in the operation of the water intake canal is 4.35 meters.

4. Conclusions
The hydraulic model experimental of water intake canal at Steam and Gas Power Plants has been done and discussed, it can be concluded as follows:
1. The flow that occurs within the canal varies with depth with an average Reynolds number of Re = 3.5 x 104, where laminar flow occurs while at a depth of 0.5 and at the bottom of the canal turbulent flow is formed. The results also showed that at HWL elevation there was the formation of subsurface vortex type 1, while for MSL and LWL elevations formed subsurface vortex type 1 and type 2 and vortex surface type 1 and type 2.
2. The recommended minimum elevation avoids the formation of undesirable vortex, which must be more than 29 cm in the test model, so that the recommended operating water intake canal is a minimum of ≥ 4.35 meter.

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Acknowledgments
The authors would like to thanks to Dwi Purnomo Hendradata S.T., M.T, M.Muhtar Arief, S.Si (alm.) and Zuhud Ubaidillah, S.Si who have helped in preparing the water intake canal test model. And the authors also would like to acknowledge the support from East Java -Divisi EPC, PT.PP (Persero) Tbk.