The Evaluation of Failure Structure Condition with Plaxis Program on the Poso I Hydropower Barrage

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Abstract. The Poso I Hydropower Station is located on the Poso River, at the downstream section of the Poso Lake in Central Sulawesi Province. At the weir site, the catchment area is 1906.30 km², the structures are designed for a 50 year return period. Flood discharge is 1456.50 m³/s, with the mean annual release being 127.85 m³/s. The total supply water level is 510.50 m, and the minimum operating level is 506.00 m. The model uses an undistorted model with a scale of 1 to 60. The barrage needs to be reviewed for failure factors that are likely to occur similar to those used in potential failures in the construction of dams in general. The study was considered in three conditions: empty barrage condition, average level, and flood level. With the piping calculation method, the barrage used Lane and Bligh method. While the calculation of barrage sliding stability used Finite Element Method with Plaxis 2D program simulation got the safety factor at the empty condition and flood level. It is caused by water pressure at flood level conditions that influence barrage stability. Safety factor value exceeded permits made. The Poso I Hydropower Station was safe.

key words: hydraulic, failure, safety factor

1. Introduction
The Poso I Hydropower Station is about 45 km from the Poso Harbor and about 235 km from Palu, the capital of Central Sulawesi Province. The Poso I Hydropower Station takes advantage of Poso Lake to form the reservoir. The weir site is about 14 km away from the Poso Lake outlet. At the weir site, the catchment area is 1906.30 km², the mean annual discharge is 127.85 m³/s, the total supply water level is 510.50 m, and the minimum operating level is 506.00 m. The power plant is developed in two phases, with an installed capacity of 2 ×35MW for Phase I, an additional 2 ×35MW for Phase II, and a total installed capacity of 140 MW. The location of the Poso I Hydropower Station is shown in Figure 1.

The Poso I Hydropower Station applies low-gate diversion type development. The main structures include the weir, the water intake on the right bank, water diversion culvert pipes, surge chamber, steel penstocks, surface powerhouses, and tailwater structures. The water level on the barrage affects the stability of its construction.

The water resources development project often faces a complex problem, so it must be explicitly handled [1]. Safety control of the floodwater level that passes over the barrage is essential. Based on government regulations (PP No. 37 of 2010), it is necessary to regularly carry out monitoring and evaluation.
Figure 1. Poso I Hydropower Station’s Location [8]

Geotechnical is one of the stability factor's keys on the selection of the location of the barrage at the start of construction. PLAXIS software was used to analyze the calculation of barrage stability [2]. The application helps find out a structural failure. Plaxis is a finite element program for geotechnical applications where models are used ground to simulate the behavior of the soil [3]. The element program package for 2-dimensional analysis of the deformation and stability in geotechnical engineering [4]. Finite Element is used in Plaxis 2D software for simulation of the model. It is intended for two-dimensional analysis of deformation and stability in geotechnical engineering and rock mechanics [5]. Plaxis is used to find the value of the safety factor by using the phi-reduction method. The method is a method to find the safety value of a building by reducing the soil reinforcement factor, which consists of shearing strength (φ ) and cohesion (c) [6].

2. Materials and Methods

The model test aims to evaluate and achieve the perfect, safe, and optimum hydraulic design of the Hydropower Station [7]. The model uses an undistorted model with a scale of 1 to 60. Experiments were conducted at the Hydraulics Model Laboratory of Water Resources Departement, University of Brawijaya. Some characteristic operation conditions from the radial gate and stilling basin were analyzed in the physical model. The water levels, the mean velocities, and the instantaneous pressures in various flow points were measured with point gauge, pitot tube, and current meter. The capacity of the diesel pump laboratory is 150 lt/s approximately.

2.1. Hydrology Design

According to calculation results of hydrology, the design results with different flood Frequencies at the weir site of Poso I Hydropower Station are shown in Table 1.

Table 1. Results of design floods for Poso I Hydropower Station.

| No | Return period (year) | Design flood discharge (m$^3$/s) |
|----|----------------------|---------------------------------|
| 1  | 2                    | 758.1                           |
| 2  | 25                   | 1319.9                          |
| 3  | 50                   | 1456.5                          |
| 4  | 100                  | 1591.7                          |
| 5  | 1000                 | 2039.5                          |
The model was simulated by various discharge 2, 25, 50, 100, and 1000 return period years which was previously estimated to be 42.89, 74.67, 82.39, 90.00, and 115.37 lt/s, respectively in the scale model.

2.2. Regional Geology and Earthquake
Poso River basin is mainly composed of low mountains and hills, with constant ups and downs and alternatively distributed trenches and relatively smooth hills. The overall terrain is high in the south and low in the northwest. The southern part consists of mountains and the northwest part of beaches. It is about 50 kilometers from the outlet of Poso Lake to the estuarine of the river course. The mean gradient of the Poso River is about 0.0001.

Poso Hydropower Station project area is about 14 km away from Poso Lake outlet. Poso River flows through the project area from south to north. The altitudes of mountains on both sides of the river are 700m. The riverbed is 480-500 m; the longitudinal gradient is about 0.011 the height difference between the mountain and riverbed is about 200 m. The river course is narrow; the valley slope gradient is 50 - 60 degrees; the valley bottom width is generally 30 - 50m. The condition of the Poso River is shown in figure 2 below.

![Figure 2. The condition of the Poso river area](image)

2.3. Water retaining structures, water release structures
According to the barrage site, the bottom slab elevations of the scouring and release sluice were selected as 494.00m. Based on the calculation results and discharge capacity, the layout scheme of the water release structure is designed as one scouring sluice and three release sluices. The bottom slab elevations of the scouring and release sluice are selected as 494.00 m. There are three release sluices, with an average gate outlet dimension of 8.0 m width and 7.0 m height.

One scouring sluice has an average gate outlet dimension of 3.0 m width and 4.0 m height. The weirs of the Project are built on a soft foundation. Joints set in the center of the weir pier are employed in the design to avoid impact on the gate operation due to the settlement and deflection of the gate bay. The detailed scheme is as follows:
- One and two release sluices are poured as a whole (the total width is 24.5 m).
- Three release sluice and scouring sluice is run as a whole (the total width is 19.5 m).
- The side pier is 2.5 m wide, the middle pier with a joint is 5.0 m wide, and the central pier without a joint is 3.0 m wide.

According to the calculation results of stable stress of weir bay and the consideration of foundation bearing capacity and requirements on the gate layout, the length of the gate bay is selected as 35 m. A concrete blanket, which is 15 m in length and 1.5 m in thickness, is arranged upstream of the gate bay. The upstream and downstream sides of the blanket bottom are all equipped with gullets.

2.4. Discharge capacity calculation of scouring sluice and release sluice
The full supply level mainly controls the dam crest elevation, and at this point, the calculated minimum dam crest elevation is 512.47 m. The proposed dam crest elevation of the gated dam of the Poso I Hydropower Station is 513.00 m.
Upstream site

Downstream site

Figure 3. Display of Weir and Intake Layout

Table 2. Discharge capacity of the scouring and release sluice

| Upstream water level (m) | Upstream depth, H₀ (m) | Discharge of 1 scouring sluice, Q₁ (m³/s) | Discharge of 3 release sluices, Q₂ (m³/s) | Total discharge, Q₃ (m³/s) | Remarks |
|-------------------------|------------------------|--------------------------------------------|--------------------------------------------|--------------------------|---------|
| 494.50                  | 0.50                   | 1.69                                       | 13.54                                      | 15.24                    |         |
| 495.00                  | 1.00                   | 4.79                                       | 38.31                                      | 43.09                    |         |
| 496.00                  | 2.00                   | 13.54                                      | 108.34                                     | 121.89                   |         |
| 497.00                  | 3.00                   | 24.88                                      | 199.04                                     | 223.92                   |         |
| 498.00                  | 4.00                   | 38.31                                      | 306.44                                     | 344.75                   |         |
| 499.00                  | 5.00                   | 53.53                                      | 428.26                                     | 481.80                   |         |
| 500.00                  | 6.00                   | 70.37                                      | 562.97                                     | 633.34                   |         |
| 501.00                  | 7.00                   | 85.22                                      | 709.42                                     | 794.64                   |         |
| 502.00                  | 8.00                   | 97.21                                      | 866.75                                     | 963.96                   |         |
| 503.00                  | 9.00                   | 107.82                                     | 1034.24                                    | 1142.05                  |         |
| 504.00                  | 10.00                  | 117.44                                     | 1211.31                                    | 1328.75                  |         |
| 505.00                  | 11.00                  | 126.32                                     | 1360.03                                    | 1486.35                  |         |
| Design flood discharge |                        |                                            |                                            |                          |         |
| 505.78                  | 11.78                  | 132.82                                     | 1459.45                                    | 1592.28                  |         |
|                        |                        |                                            |                                            |                          |         |
| 506.00                  | 12.00                  | 134.60                                     | 1486.06                                    | 1620.66                  |         |
| 507.00                  | 13.00                  | 142.40                                     | 1600.59                                    | 1742.99                  |         |
| 508.00                  | 14.00                  | 149.80                                     | 1706.53                                    | 1856.32                  |         |
| 509.00                  | 15.00                  | 156.84                                     | 1805.70                                    | 1962.54                  |         |
| Check flood discharge   |                        |                                            |                                            |                          |         |
| 509.76                  | 15.76                  | 162.79                                     | 1877.33                                    | 2040.12                  |         |
|                        |                        |                                            |                                            |                          |         |
| 510.00                  | 16.00                  | 163.58                                     | 1899.36                                    | 2062.94                  |         |
| 511.00                  | 17.00                  | 170.05                                     | 1988.39                                    | 2158.44                  |         |
| 512.00                  | 18.00                  | 176.29                                     | 2073.46                                    | 2249.75                  |         |

According to the hydraulic calculation results, the stilling basin of 45.0 m is arranged downstream of the weir bay. The former 15.0 m is a transition section with a slope of 1:10, and the latter 30.0 m is a flat section. The elevation of the bottom slab of stilling basin is 492.50 m, and gullets are arranged...
upstream and downstream. The upstream gullet is 2.0 m deep, and the downstream gullet is 34.0 m deep. To reduce the uplift pressure of the bottom slab of the stilling basin, the filtration gutter, which is connected to the downstream watercourse through a drainage hole, is arranged on the bottom slab's bottom [8].

50-year flood data is used for the design flood of the dissipation. The corresponding flood discharge is 1456.5 m$^3$/s. Calculation of stilling basin consists of depth calculation, length calculation, and thickness of the bottom slab [9]. The discharge capacity of the scouring and release sluice is shown in Table 2.

According to the limited drilling data, there are no bedrocks exposed on the river banks or in the riverbed of the weir site area. According to the water injection data of the borehole, the sandy silt with crushed gravels is weakly impermeable, and the silty sand layer with boulders and gravels is very highly impermeable. The condition of the soil in the location is shown in Table 3 and Figures 4-5.

| Formation Number | Soil Description                  | Wet density ($g/cm^3$) | Compression modulus (MPa) | Allowable bearing capacity (MPa) | Shearing strength | Cohesion |
|------------------|-----------------------------------|------------------------|---------------------------|--------------------------------|------------------|----------|
| 1                | Sandy Silt with crushed gravels   | 1.825                  | 22.50                     | 0.225                          | 24.50            | 0        |
| 2                | Silty sand with boulder and gravels | 2.00                   | 30.00                     | 0.30                           | 26.00            | 0.045    |

**Figure 4.** Cut of wall with depth 0m

**Figure 5.** Cut of wall with depth 20m
3. Results and Discussion
The initial design running test obtained the perfect flow condition with a 2-1000 years return period discharge. The paper exposed the experimental data from measurement in the laboratory. The results of barrage capacity are shown in Figure 6.

This study's primary purpose was to develop design criteria for estimating the stilling basin length located at the downstream end of the gate. Since tailwater depth is variable and entirely dependent on downstream conditions, the advantage of the present work is the elimination of the tailwater depth from the analysis.

The research results found the hydraulic performance of the original design relatively good, but it found the stilling basin problem. From the experiment, flow occurs rotating on stilling basin that happened from 2 return period years. The condition of stilling basin is shown in Figure 6.

![The upstream flow condition](image1)
![The upstream gate condition](image2)

![The downstream gate condition](image3)
![The stilling basin’s flow condition](image4)

Figure 6. The flow condition on the model

According to the experiment with various flood discharges, the average velocity from the gate is more than 15 m/s and 25% sloping on the downstream river makes the turbulence waves over the flow. To reduce these effects, it should be made at the height of the riverbed as a cascade, in addition to modifying the stilling basin [10,11]. Peterka recommended that the tailwater depth should be 10% greater than the conjugate depth. Based on model tests, detanted end sill added with 3.5m height, 2.4m width, and the distance between detanted 1.8m. The final design condition is shown in Figure 7-8.
Figure 7. The model’s change condition

The upstream flow condition

The stilling basin’s flow condition

The stilling basin’s flow condition

The cascade’s flow condition

Figure 8. Final Design’s Flow condition

4. Conclusion
The studies about stilling basins are essential for the construction, maintenance, and safety of large hydraulic structures. The increase of the efficiency of the energy dissipation has shortened the risk of the downstream. The modification of stilling basin is its simplicity in practice to increase end sill height and make a cascade structure for control the velocity of the stilling bay downstream. The safety value
of each barrage condition is 20.50 for empty barrage condition and 10.85 for maximum flood water level condition. This value is based on the presence of water pressure at the floodwater level, which affects the stability of the barrage. The safety factor value that exceeds the permit indicates The Poso I Barrage is safe.

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