The Analysis of Retaining Wall Strengthening on Small Reservoir at Pilangbango Madiun as an Alternative of Existing Design

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Abstract—In 2016 the government of Madiun city carried out the construction of the reservoir in Pilangbango village, Kartoharjo sub-district, Madiun, East Java. The reservoir construction work has been carried out according to the schedule, however, several wall collapse and land subsidence have arisen. To date, the condition of the Pilangbango reservoir is still damaged. The government of Madiun is planning to repair the reservoir. The analysis carried out on the retaining wall of the reservoir uses Plaxis program method to calculate the energy that occurs. The results of the analysis on the existing design using cantilever walls showed a collapse due to poor soil types and did not meet the safety requirements for rolling, sliding, and uplift with a value of 1 < 1,2 (safety factor permit). The strengthening alternative of soil retaining wall on Pilangbango reservoir is to use sheet pile and soldier pile. The result of the analysis of sheet pile walls with size W-600 with a depth of 15 m, shows that the strengthening can be applied in the field. The sheet piles that are used, meets the security requirements for rolling, sliding, and uplift with a value of 132,98 kN.m (Bending Moment) < 506 kN.m (Moment Crack). The strengthening analysis of soldier pile walls with a size of 60 cm, longitudinal reinforced 10 D19, spiral reinforced Ø12-60 also applied to 12 m, shows that the reinforcement can be applied as a reservoir wall. The results obtained from the analysis show that the soldier pile meets the safety factor for rolling, sliding, and uplift 1,2 (safety factor permit) < 1,74, and the ultimate moment that occurs, can be held by the wall with a value of 169,91 kN.m (Moment Ultimate) < 369,6 kN.m (Moment Nominal).

Keywords—Cracking moment, soldier pile, sheet pile, bending Moment, safety factor

I. INTRODUCTION

The government of Madiun city has performed the construction of the reservoir as an effort to overcome the problem of the drought on agricultural land in Pilangbango village of Madiun. Pilangbango reservoir has an area of approximately 2.2 ha and could accommodate the water volume of around 1200 m³. It is expected that the reservoir could meet the water needs for irrigation and other needs. However, the reservoir which is supposed to be an agricultural support facility is in a very poor condition at this time, and there have not been any repairmen to date by the local government. In the case of the Pilangbango reservoir project, almost all sides of the retaining wall were damaged in different conditions. Some were collapses, landslides, and a considerable land subsidence. From the background mentioned above, thus some problems can be formulated as follows: what factors cause the loss of stability of the existing retaining wall.

How to analyze the alternative design of the strengthening of the retaining wall using sheet pile and soldier pile. What is the most effective strengthening to be applied to the retaining wall of the reservoir of Pilangbango.

II. LITERATURE REVIEW

A. The stability of soil

According to Nayak (2001), he explains that there were safety factors for each soil related to the fieldwork.

- Short term pile work uses 1.0 - 1.2
- Short term excavation work uses 1.2 or more
- Pile work with long-term stability use 1.2 - 1.4
- Excavation work with long-term stability use 1.2 - 1.4
- Pile work for dams to use 1.5 or more
- Dam work with extreme conditions, withstand flooding accompanied by sediment use 1.1 - 1.25

B. Reinforcement of soil retaining wall

1) Sheet Pile: Based on PT. Wika (2017), sheet pile is one of the soils retaining methods and techniques that support the soil excavation process, using the edge of the sheet pile that has interlocking.

![Type of Pile Wall Design](image)

Fig. 1. Type of Pile Wall Design [2].

2) Soldier Pile: Soldier Pile is the construction of groundbreaking in a quarry consisting of a row of bored piles...
made of concrete cast in place (cast in situ) and does not cause noise in the implementation (Yuliani and Wulandari, 2011).

C. Bending Moment

Bending moment is the result of the multiplication of force that occurs with the distance perpendicular to the line of work of its force (Ma'arif, 2012). Analysis of the moment is performed on the structure to determine the amount of force that occurs so the plan can be made of the structure to be used.

D. Cracking Moment

The Cracking moment is a condition when there is a continuous loading so that the modulus of the rupture can be exceeded and result in cracks in the concrete (Rokhman, 2012). So, if there is a large load and exceed the ability of elasticity of reinforced concrete, thus the cracks will occur.

III. METHODOLOGY

A) The analysis of wall retaining collapse

In the analysis of the collapse of the retaining wall structure of Pilangbango Madun reservoir, a modeling method was used using the supporting program finite element that is a Plaxis software.

B) Active ground pressure

In planning a retaining wall, it is necessary to assume that the shear plane is considered to be a flat surface and the friction angle of the soil and backplane is not equal to 0. Coulomb's theory explains that the active soil pressure can be known by this following calculation.

\[ Pa = \frac{1}{2} \gamma t \cdot Ka \cdot h^2 \]  \hspace{1cm} (1)

where
- \( Ka = \tan^2 (45 - \phi/2) \)
- \( Pa = \) active ground pressure
- \( \gamma = \) Soil density
- \( h = \) height of retaining wall
- \( \phi = \) sliding angle in a ground that rests against a wall
- \( Ka = \) active soil pressure coefficient

C) Soil Carrying capacity

N-SPT is a method used to determine the relative density of coarse-grained soil and is one of the ways to determine the consistency of fine-grained soil (Padagi et all, 2015). The relationship between density and relative density, value of N SPT, qc a \( \Theta \) is equal.

### TABLE I. RELATION BETWEEN DENSITY, RELATIVE DENSITY, VALUE N-SPT, QC AND \( \Theta \)

| Density         | R Relative Density (yd) | N Value N-SPT | Pressure of Komus qc | Sliding angle (\( \Theta \)) |
|-----------------|------------------------|---------------|----------------------|----------------------------|
| Very Loose      | < 0.2                  | < 4           | < 20                 | < 30                       |
| Loose           | 0.2 – 0.4              | 4 – 10        | 20 – 40              | 30 – 35                    |
| Medium Dense    | 0.4 – 0.6              | 10 – 30       | 40 – 120             | 35 – 40                    |
| Dense           | 0.6 – 0.8              | 30 – 50       | 120 – 200            | 40 – 45                    |
| Very Dense      | 0.8 – 1.0              | > 50          | > 200                | > 45                       |

### TABLE II. CORRELATION OF SOIL DENSITY (\( \gamma \)) FOR NON COHESIVE AND COHESIVE SOIL

| Cohesion Soil | Cohesive |
|---------------|----------|
| N             | 0 – 10   | 11 – 30 | 31 – 50 | > 50 |
| Unit Weight \( \gamma \), kN/m\(^2\) | 12 – 16 | 14 – 18 | 16 – 20 | 18 – 23 |
| Angle of Friction \( \phi \) | 25 – 32 | 28 – 36 | 30 – 40 | > 35 |
| State         | Loose    | Medium | Dense   | Very Dense |

### TABLE III. CORRELATION OF SATURATED SOIL DENSITY FOR NON COHESIVE SOIL

| NSPT | Very Loose | Loose | Medium | Dense | Very Dense |
|------|------------|-------|--------|-------|------------|
| Fine | 1 – 2      | 3 – 6 | 7 – 15 | 16 – 30|
| Medium | 2 – 3 | 4 – 7 | 8 – 20 | 21 – 40| > 40      |
| Coarse | 3 – 6 | 5 – 9 | 10 – 25| 26 – 45| > 45 |

| \( \Phi \) | Fine | Medium | Coarse |
|-----------|------|--------|--------|
| Fine      | 26 – 28 | 28 – 30 | 30 – 34 |
| Medium    | 27 – 28 | 30 – 32 | 32 – 36 |
| Coarse    | 28 – 30 | 30 – 34 | 33 – 34 |
| \( \tau_{se} \) (kN/m\(^2\)) | 11 – 16 | 14 – 18 | 17 – 20 | 17 – 20 | 20 – 23 |
D) Design of Sheet Pile

Sheet pile design using the PLAXIS program needs to input the data of material specification as an input data in doing an analysis of the planned structure using the application. The data of sheet pile specification is using data Wika Beton Precast.

E) Design of Soldier Pile

Soldier pile design using the Plaxis program that requires data that need to be inputted to be able to run the structure analysis. The required data includes the quality of the concrete, the quality of steel reinforcement, and the diameter used in the location. In addition, it is necessary to design the longitudinal reinforcement and stirrup in the pile soldier based on (SNI-2847-2013).

- Longitudinal reinforcement.
  \[ A_s = \rho \times 0.25\pi \times d^2 \]  

- Transversal reinforcement
  \[ \rho_s = 0.45 \left( \frac{A_s}{A_{sh}} - 1 \right) \frac{f_{ct}}{f_{ty}} \]  

\[ \rho_s = A_s \times \text{circumference drill core pile/ concrete core volume} \]

IV. RESULT ANALYSIS

A) Load of Paving Block Road

The analysis of load road on the reservoir location is assumed using the paving block from PT. Varia Usaha with the following data:

- Paving weight: 3.25 kg/pcs
- Capacity: 43 pcs/m²
- Road thickness: 0.06 m
- Road width: 11.65 m

Road structure weight:

- Weight of paving/m² = 3.25 x 43
- Road area/ m² = (11.65 x 1) / m²
- 11.65 m²/m²
- load of people/m² = 100 kg/m²

It is assumed that the load use is evenly distributed, given a load factor of

\[ 1.2 \times 1.6 = 1.2 \times 139.75 + 1.6 \times 100 \]
\[ = 327.7 \text{ kg/m} \]
\[ = 3.28 \text{ kN/m} \]

B) Earthquake Load

The analysis of earthquake load needs to be carried out by reviewing the type of soil and the earthquake spectrum in the area. In the analysis process of classifying the land site, it was analyzed based on N-SPT on the location of Pilangbango Madiun reservoir. The parameter used is based on SNI-1726:2012 concerning the classification of land sites.

The calculation results show that the value of N’in the soil layer at the location of the Pilangbango Madiun Embung was obtained at 16,924. Based on the parameters that apply in accordance with SNI 1726: 2012, including the categories of SD or medium land. Thus the planning of the earthquake spectrum on the location is used medium soil type.

TABLE IV. EARTHQUAKE SPECTRUM

| Seismic Hazard: SD (Medium Soil) | As | 0 | 0.362 |
|---------------------------------|----|---|--------|
| T0                              | 0.139 | 0.778 |
| SDS                             | 0.2 | 0.778 |
| Ts                              | 0.696 | 0.778 |

From Table IV, on acceleration response spectrum design, Sa has obtained the same result as many 0.778. The analysis of earthquake force is distributed to be lateral active soil force (Pa) use (1), and calculate as follow:

\[ \phi = 22^\circ \]
\[ h = 4 \text{ m (height of existing wall)} \]
\[ \gamma = 14.21 \text{ kN/m}^3 \]
\[ K_a = \text{active soil force coefficient} \]
\[ Pa = \text{lateral active soil force} \]
\[ Ka = \tan^2 (45 - 22/2) \]
\[ = \tan^2 (45 - 11) = 0.455 \]

\[ Pa = \frac{1}{2} \gamma h^2 = 0.5 \times 14.21 \times 0.455 \times 4^2 \]
\[ = 51.72 \text{ kN/m} \]
\[ a = 0.778 \]
\[ F = m \times a = 51.72 \times 0.778 = 40.238 \text{ kN} \]

Process analysis use Finite Element by Plaxis method, need to input following data,

TABLE V. SOIL DATA CORRELATION

| D (m) | Type of Soil | N-SPT | Shearing Angle (°) | Cohesion (Cu) (kPa) | Soil Content (kN/m³) | Soil Specific Gravity (kN/m³) | E (MPa) |
|-------|--------------|-------|-------------------|---------------------|---------------------|-----------------------------|---------|
| 0 - 10 | Silty Clay   | 9     | 12                | 133.34              | 16.67               | 18.3                        | 23000   |
| 10 - 11.5 | Sandy - Silt | 12    | 24                | 16.67               | 14.21               | 18                          | 5789.5  |
| 11.5 - 15 | Silty Clay   | 20    | 14                | 29.42               | 15.9                | 20                          | 12105   |
| 15 - 18  | Silty Sand   | 10    | 19                | 23.54               | 16                  | 17.5                        | 20000   |
| 18 - 21.5 | Silty Clay   | 20    | 10                | 35.3                | 17.78               | 20                          | 72222   |
| 21.5-24  | Sandy Clay   | 50    | 17                | 26.48               | 23                  | 23                          | 100000  |
The results of the plaxis calculation show that collapses occur in the structure of the retaining wall. Some of factors that cause the collapse are because the structure that is not meet the security requirements were 1 (SF wall) < 1.2 (SF permit)

C) Sheet pile wall design

The Alternative design of retaining walls in the Pilangbango reservoir used sheet pile with the specification from PT. Wika Beton. The sheet pile is a pre-cast structure or design derived from fabrication.

**TABLE VI. DATA OF SHEET PILE SPECIFICATION**

| SHEET PILE | E (GPa) | A | EA | I | EI | W (KIN/m) |
|------------|--------|---|----|---|----|----------|
| W-400      | 37.007.84 | 1598 | 0,1598 | 5913802.254 | 246085 | 0,002487 | 92038.49 | 3.8352 |
| W-450      | 37.007.84 | 1835 | 0,1835 | 6790809.601 | 353354 | 0,003584 | 130785.966 | 4.404 |
| W-500      | 37.007.84 | 1818 | 0,1818 | 6728024.708 | 462242 | 0,004628 | 171124.283 | 4.8032 |
| W-600      | 37.007.84 | 2078 | 0,2078 | 7600226.513 | 765007 | 0,007650 | 283440.026 | 4.9872 |

W-600 is used with a depth of 15 m, and the results show that it meets the security requirements used for earthworks in reservoir 1.2 (SF permit) < (SF) in accordance with Nayak's explanation (2001). Then it meets the security requirements for bolster, slide and uplift which are 1.2 < 2.15 (ok).

**Fig. 5. Bending Moment on Sheet Pile**

D) Design of Soldier Pile wall

Soldier pile design is one of the alternatives to strengthen the retaining wall of Pilangbango reservoir need data as follow:

- Concrete quality, fc = 35 Mpa
- Steel quality, fy = 400 Mpa
- Diameter = 60 cm

E) Longitudinal Reinforced

Use $\rho_{\text{min}}$ as many 1% because the ratio of the reinforced PCACOL analysis minimum of 1% and the maximum value of 8% so $\rho$ minimal is used.

As $= \rho_{\text{min}} \times 0.25 \pi \times d^2$ = $1 \% \times 0.25 \times 3.14 \times 0.6^2$ = 2826 mm$^2$

used (10 D19 As =2833,85 mm$^2$)

**Fig. 6. Bending Moment on Soldier Pile**

F) Spiral Reinforced

used rho spiral, try with $\varnothing$ 12

$$\rho_s = 0.45 \left( \frac{A_y}{A_{ho}} - 1 \right) f_y \times \frac{1}{f_y'} = 0.45 \left[ \frac{0.25 \times 3.14 \times 600 \times 600}{0.25 \times 3.14 \times 500 \times 500} - 1 \right] \times \frac{35}{400} = 0.017325$$

$\rho_s$ = $A_s \times$ circumference of core drill / volume of core concrete

$0.017325 = 113.04 \times \pi \times 600 / (0.25 \pi \times 500^2 \times S)$

$S = 62.34 \text{ mm} \approx 60 \text{ mm}$

Used spiral reinforced $\varnothing 12-60$

**Fig. 7. Bending Moment on Soldier Pile**

The Analysis using plaxis provides information that SF meets the security requirements for rolling, sliding and uplifting of 1.2 < 1.74. Furthermore, analysis of the material to be used using PCACOL provides information that the results meet the security requirements shown in the value of $\rho$ is at a value of 1% meeting the reinforcement ratio requirements. In addition, the analysis is carried out on the force that occurs on the soldier pile wall by examining between the ultimate moment ($M_u$) and the nominal moment ($\phi M_n$).

$M_n = 462 \times 0.8 = 369.6 \text{ kNm}$
Then the nominal moment qualifies with the ultimate moment value of 169.91 kNm < nominal moment 369.6 kNm.

| TABLE VII. | ANALYSIS RESULT COMPARISON OF SHEET PILE AND SOLDIER PILE |
|------------|----------------------------------------------------------|
| No | Analysis Result | Sheet Pile | Soldier Pile |
| 1 | Strengthening dimensions | W-600 | P = 15 m |
|   | SF permit = 1.2 | SF permit < 2.15 | SF permit < 1.74 |
| 2 | Bending Moment (moment ultimate) | 132.98 kNm | 169.91 kNm |
| 3 | Moment Crack (Moment Nominal) | 506 kNm | 369.6 kNm |

| TABLE VIII. | COMPARISON OF SHEET PILE AND SOLDIER PILE |
|-------------|------------------------------------------|
| No | Description | Sheet Pile | Soldier Pile |
| 1 | Dimensions | Thickness up 600 mm Depth to 27 m | Diameter more than 1 m Depth more than 30 m |
| 2 | Material Quality | Can be controlled when produced Neat results | Need to be controlled Casting results are not necessarily precision Can be mixed with other materials |
| 3 | Implementa\_tion Method | Hammer Vibrator Water Jet | Drill |
| 4 | Period | Relatively fast | Relatively long |
| 5 | Cost | More expensive | Cheaper |

V. CONCLUSION

Based on the results of the analysis and calculations, it can be concluded that:

- The results of structural analysis on the existing design show that the events that occurred at the reservoir of Pilangbango Madiun were in accordance with the events in the field. The reason is that the retaining wall is not able to withstand the deformation of the soil and the load on it, other than that the retaining wall design does not meet the security requirements for bolstering, sliding and uplifting ie 1 < 1.2 (SF permit).
- The Results of the strengthening of retaining walls using Sheet Pile and Soldier Pile show the desired results. Both alternatives can be applied in locations with dimensions that have been designed according to calculations. Sheet Concrete piles that can be used in locations are the W-600 for reasons of material efficiency and ease of work in the field. In addition, the safety factor that is produced in accordance with the security requirements for the bolster, sliding, and uplift are 1.2 (SF permit) < 2.15 and material testing in accordance with the brochure of PT. Wika Beton shows that the profile meets the requirements, that is 132.98 kN.m (Bending Moment) < 506 kN.m (Moment Crack). Soldier Pile with a diameter of 0.6 m and a length of 12 m can be applied to the field with 10 D19 longitudinal reinforcement and spiral reinforcement Ø12-60. The resulting security factor is equal to 1.2 (SF permit) < 1.74 thus it meets the requirement. The material test use PCACOL shows that the design has met the requirement that is 169.91 kN.m (Moment Ultimate) < 369.6 kN.m (Moment Nominal).

- The alternative of strengthening that would be applied as retaining wall on the small reservoir at Pilangbango Madiun need to assess several aspects to determine the effectiveness of both alternatives. For faster and practical work then sheet pile of concrete W-600 can be used as retaining wall.

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