

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 of 1,2 (safety factor permit) $< 2,15$, and the bending moment that occurs, can be held by the wall with a value of 132,98 kN.m (Bending Moment) < 506 kN.m (Moment Crack). The strengthening analysis of soldier pile 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 performs 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 repairment 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.

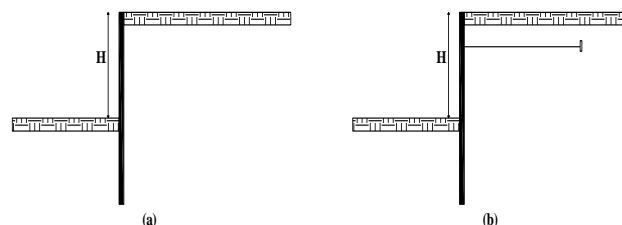


Fig. 1. Type of Pile Wall Design [2].

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).

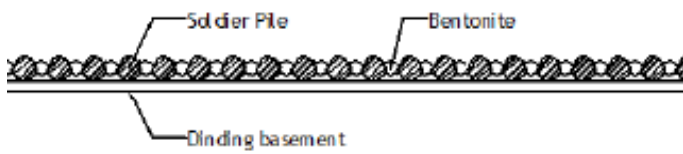


Fig. 2. Instalment scheme of soldier pile [6].

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.

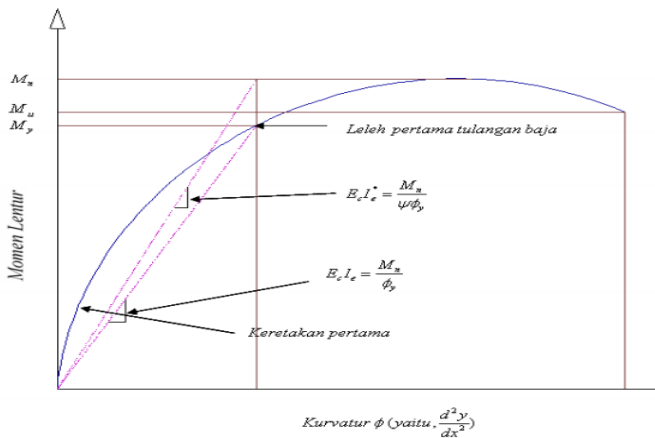


Fig. 3. Relation between moments and cracks [11].

III. METHODOLOGY

A) The analysis of wall retaining collapse

In the analysis of the collapse of the retaining wall structure of Pilangbango Madiun 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.

$$P_a = \frac{1}{2} \gamma t K_a h^2 \quad (1)$$

where

$$K_a = \tan^2 (45 - \phi/2)$$

P_a = active ground pressure

γt = Soil density

h = height of retaining wall

ϕ = sliding angle in a ground that rests against a wall

K_a = 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 al, 2015). The relationship between density and relative density, value of N SPT, q_c and ϕ is equal.

TABLE I. RELATION BETWEEN DENSITY, RELATIVE DENSITY, VALUE N-SPT, Q_c AND ϕ

Density	R Relative Density (γ_d)	N Value N SPT	Pressure of Konus q_c	S Sliding angle (ϕ)
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 (γ) FOR NON COHESIVE AND COHESIVE SOIL

	Cohesion Soil				
N	0 – 10	11 – 30	31 – 50	> 50	
Unit Weight γ . kN/m ³	12 – 16	14 – 18	16 – 20	18 – 23	
Angle of Friction ϕ	25 – 32	28 – 36	30 – 40	> 35	
State	Loose	Medium	Dense	Very Dense	
	Cohesive				
N	< 4	4 – 6	6 – 15	16 – 25	> 25
Unit Weight γ . kN/m ³	14 – 18	16 – 18	16 – 18	16 – 20	> 20
q_u , kPa	< 25	20 – 50	40 – 200	40 – 200	> 100
Consistency	Very Soft	Soft	Medium	Stiff	Hard

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

Description	Very Loose	Loose	Medium	Dense	Very Dense
NSPT					
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
ϕ					
Fine	26 – 28	28 – 30	30 – 34	33 – 38	
Medium	27 – 28	30 – 32	32 – 36	36 – 42	< 50
Coarse	28 – 30	30 – 34	33 – 34	40 – 50	
γ_{wet} (kN/m ³)	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.

$$A_s = \rho \times 0.25\pi \times d^2 \quad (1)$$

- Transversal reinforcement

$$\rho_s = 0.45 \left(\frac{A_g}{A_{ch}} - 1 \right) \frac{f_c'}{f_{yt}} \quad (2)$$

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

IV. RESULT ANALYSIS

A) Load of Paving Block Road

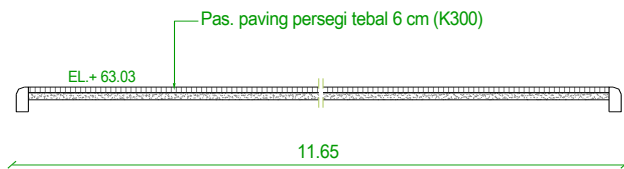


Fig. 4. Distribution of Load Road

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

= 139.75 kg/ m²

Road area/ m' = (11,65 x 1) / m'

= 11,65 m²/m'

load of people/m² = 100 kg/m²

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

$$\begin{aligned} 1,2 D + 1,6 L &= 1,2 \times 139,75 + 1,6 \times 100 \\ &= 327,7 \text{ kg/m} \\ &= 3,28 \text{ kN/ m} \end{aligned}$$

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:

$$\phi = 22^\circ$$

$$h = 4 \text{ m (height of existing wall)}$$

$$\gamma_t = 14.21 \text{ kN/m}^3$$

$$K_a = \text{active soil force coefficient}$$

$$P_a = \text{lateral active soil force}$$

$$K_a = \tan^2 (45 - 22/2)$$

$$= \tan^2 (45 - 11) = 0.455$$

$$\begin{aligned} P_a &= \frac{1}{2} \gamma_t K_a h^2 = \frac{1}{2} 14.21 \times 0.455 \times 4^2 \\ &= 51.72 \text{ kN/m} \end{aligned}$$

$$a = 0.778$$

$$F = m \times a = 51.72 \times 0.778 = 40.238 \text{ kN}$$

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	Θ (Sliding Angle) (°)	Cohesion (Cu) (Kpa)	Soil Content γt (kN/m ³)	Soil Specific Gravity γsat (kN/m ³)	E (MPa)
0 - 10	Silty Clay	9	12	33.34	16.67	18.3	23000
10 - 11.5	Sand-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 $1 \text{ (SF wall)} < 1,2 \text{ (SF permit)}$

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 SPESIFICATION

SHEET PILE	E (Mpa)	A		EA (kN)	I		EI (kNm ²)	W (kN/m)
		cm ²	m ²		cm ⁴	m ⁴		
W-400	37007.84	1598	0,1598	5913852.354	248685	0,002487	92038.49	3.8352
W-450	37007.84	1835	0,1835	6790938.091	353354	0,003534	130785.696	4.404
W-500	37007.84	1818	0,1818	6728024.768	462362	0,004624	171124.2383	4.3632
W-600	37007.84	2078	0,2078	7690228.53	765907	0,007659	283443.0236	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 $1.2 \text{ (SF permit)} < \text{(SF)}$ in accordance with Nayak's explanation (2001). Then it meets the security requirements for bolster, slide and uplift which are $1.2 < 2.15 \text{ (ok)}$.

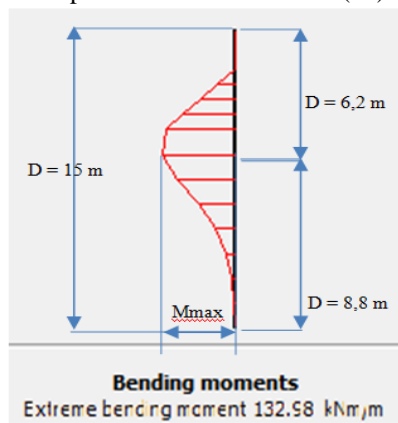


Fig. 5. Bending Moment on Sheet Pile

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, $f_c = 35 \text{ Mpa}$
 Steel quality, $f_y = 400 \text{ Mpa}$
 Diameter = 60 cm

E) Longitudinal Reinforced

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

$$\begin{aligned} A_s &= \rho_{\min} \times 0,25 \pi \times d^2 \\ &= 1\% \times 0,25 \times 3,14 \times 0,6^2 = 2826 \text{ mm}^2 \\ \text{used (10 D19 } A_s &= 2833,85 \text{ mm}^2) \end{aligned}$$

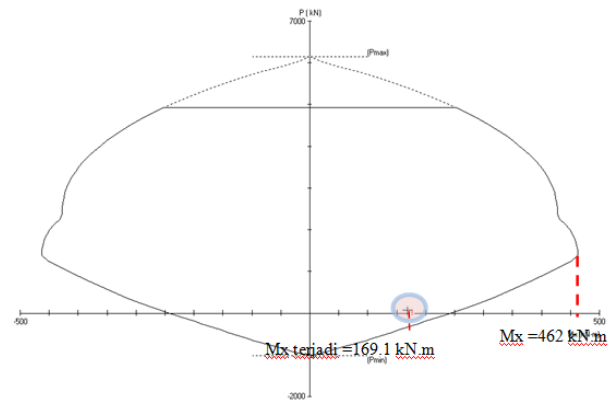


Fig. 6. Bending Moment on Soldier Pile

F) Spiral Reinforced

used rho spiral, try with $\phi 12$

$$\begin{aligned} \rho_s &= 0.45 \left(\frac{A_g}{A_{ch}} - 1 \right) \frac{f_c'}{f_{yt}} \\ &= 0.45 \left[\frac{0.25 \times 3.14 \times 600 \times 600}{0.25 \times 3.14 \times 500 \times 500} - 1 \right] \times \frac{35}{400} \\ &= 0.017325 \end{aligned}$$

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

$$0.017325 = 113,04 \times \pi \times 600 / (0.25 \pi \times 500^2 \times S)$$

$$S = 62,34 \text{ mm} \approx 60 \text{ mm}$$

Used spiral reinforced $\phi 12- 60$

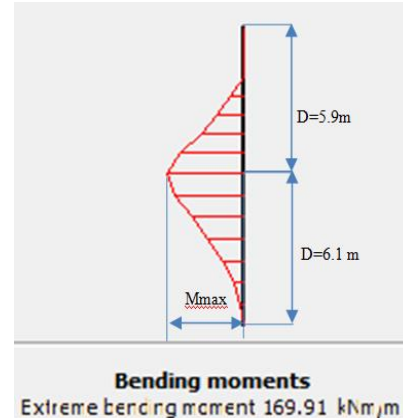


Fig. 7. Bending Moment on Soldier Pile

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 ρ 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 (ϕM_n). $M_n = 462 \times 0.8 = 369.6 \text{ kNm}$.

Then the nominal moment qualifies with the ultimate moment value of $169.91 \text{ kNm} < \text{nominal moment } 369.6 \text{ kNm}$.

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	0.6 m P = 12 m
2	SF permit = 1.2	SF permit < 2.15	SF permit < 1.74
3	Bending Moment (moment ultimate)	132.98 kNm	169.91 kNm
4	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	Implementation 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 $1.2 \text{ (SF permit)} < 2.15$ and material testing in accordance with the brochure of PT. Wika Beton shows that the profile meets the requirements, that is $132.98 \text{ kN.m (Bending Moment)} < 506 \text{ kN.m (Moment Crack)}$. 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 $\varnothing 12-60$. The resulting security factor is equal to $1.2 \text{ (SF permit)} < 1.74$ thus it meets the requirement. The material test use PCACOL shows that the design has met the requirement that is $169.91 \text{ kN.m (Moment Ultimate)} < 369.6 \text{ kN.m (Moment Nominal)}$.

- 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 effectivity 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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