Corrugated Sheet Pile Analysis on Riverbank Retaining Wall Project in Factory Area of the Sukoraharjo Street

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Abstract. This retaining wall project serves to hold the land close to the riverbank in the factory area of Sukoraharjo street, Malang. The height of the riverbank starting from the bottom to the top edge is around 7 m. The shape of sheet pile is determined using corrugated sheet pile. Calculation method using Plaxis 2D software. The stages of modeling in 2D Plaxis starts from determine the geometry of the soil profile and sheet pile. Then determine the input parameters of soil and sheet pile. After that determine the generate mesh opsi in the initial or existing geometry and conditions. After the procedure the calculation is done with the phases that have been determined. From the results of Plaxis 2D modeling and stability and strength analysis, that corrugated sheet pile type W - 500 Class B with a permanent permit moment of 299 kN m can be used as a retaining wall for riverbank with a height of 7 m in the factory area of Sukoraharjo street, Malang. The depth of the corrugated sheet pile is embedded as deep as 7 m so that the total length of the sheet pile is 14 m. The safety factor value of the corrugated sheet pile stability is 2.98. This value is in accordance with the requirements of SNI 8460 - 2017.

Keywords : Sheet pile, Plaxis Analysis, Displacement, Moment.

1. Introduction

This retaining wall project serves to hold the soil close to the riverbank in the factory area of Sukoraharjo street, Malang. The height of the riverbank starts from the bottom to the top edge of about 7 m. The project location is very possible for the procurement and implementation of pile sheet work. Within the project there is also embankment work in an area close to the riverbank. Efforts to prevent the occurrence of landslides on embankment work required a stable retaining wall planning in terms of strength to support the value of the overturning moment, shear force and carrying capacity [1]. Sheet pile is commonly used as a retaining ground because it is not easily damaged and has a lighter weight, and relatively thin dimensions making it suitable for use with moderate height heaps of soil between 2-10 meters [2]. Sheet pile is a relatively thin vertical wall that is flat and long, usually made of material, wood, steel or concrete that serves to hold the soil and also serves to prevent the entry of water into dug holes [3]. If not well planned, then the soil pressure will push the retaining wall so that it causes construction failure and landslide [4]. The sheet pile consists of parts that are prefabricated or pre-cast [5]. Sheet pile is often used to build a wall that serves as a soil retaining wall, which can be either large or small scale construction [6]. The function of Sheet pile is very large. Sheet pile is widely used for...
areas that have different elevations such as on the edge of the sea, on the edge of a river, hill, and others. Because of the easy installation and relatively low cost of implementation, Sheet pile is widely used in jobs such as: river slope / riverbank retention, temporary excavations, basements, harbor buildings, retaining walls, dams etc.

In terms of sheet pile construction, it can be divided into sheet pile without anchord and sheet pile with anchord, while in terms of material consists of sheet pile made from reinforced concrete, steel, and wood [7]. In terms of shapes on the market, concrete sheet piles that are often used are square sheet pile and Corrugated Sheet Pile. The shape of the cross section of the Corrugated Sheet Pile resembles the letter U so that if arranged lengthwise it will shape a sheet pile with a wavy shape. The specifications are in accordance with those shown from the factory made based on SNI. In general, Corrugated Sheet Pile has a greater strength than the usual Sheet Pile.

Stability in a sheet pile work needs to be noted. To obtain the stability of the sheet pile, a precise calculation or analysis of the pile dimensions must be carried out before the sheet pile is installed [8]. The safety factor for the stability of the sheet pile must meet the specified requirements. Besides the moment and shear force also need to be considered in determining the type of sheet pile. Therefore it is very important to analyze sheet piles well for their safety and stability in order to prevent harm.

In its calculations, Sheet pile is designed to withstand lateral (horizontal) soil pressure. Lateral soil pressure behind the retaining wall depends on the shear strength of the soil [9]. Soil shear strength is the resistance force applied by soil grains to pressure or pull [7]. Whereas the lateral pressure is obtained from the working ground tension. The equilibrium condition in place resulting from the stress position without the occurrence of shear stress is defined as the K0 condition [10].

One way to find out the safety factor of land slice failure at the site is to use the Plaxis program [11]. Plaxis is a computer program based on a two-dimensional finite element program used specifically to carry out deformation and stability analysis for applications in the geotechnical field. This program is a graphical interface method that is easy to use so that users can quickly create 2 geometry models and elemental nets based on cross sections of the slope conditions to be analyzed [12].

2. Methodology

The research method starts from collecting data, then the data is processed and carried out a calculation and analyzed. The location of the study was carried out on the retaining wall project in factory area of Sukoraharjo street, Malang. Soil data is obtained from the project owner who has ordered a land testing company partner at that location according to the requirements needed to analyze the plan of retaining wall. The soil data includes core drilling investigations, standard penetration tests, undisturbed soil samples, ground water levels, laboratory tests of soil physical properties, and mechanical properties carried out on 3 to 17 October 2019.

The calculation method is done with the help of Plaxis 2D software. Modeling stages in Plaxis 2D starts from determining the geometry of the soil profile and sheet pile. Then determine the input parameters of soil and sheet pile. After that determine the density of the generate mesh option in the initial or existing geometry and conditions. After the procedure has been performed the calculation is carried out with the phases that have been determined.

Plaxis program procedures among others: (1) Determine the title, model, and contact elements and write down the command or purpose to be used, (2) Determine the dimensions of the ground case to be investigated, namely along to the left, to the right, up and down, (3) Adjusting the shape of the soil dimensions then under load, (4) Determine the value of soil parameters by pressing the set material button, including unit weight dry, unit weight wet, cohesion, poisson ratio, lateral axial strain or modulus elasticity and so on. Procedures furthermore it can be understood further and more clearly in the literature obtained from the Plaxis program [13]. The safety factor of the stability of the retaining wall is said to be safe if more than 1.5 [14], then if the results of the Plaxis analysis are less than 1.5 then the modeling is repeated.
2.1. Core drilling data

The number of drill points in the project is 2 points, namely DB-1 point with a depth of 10 m and DB-2 point with a depth of 20 m. The drilling method is carried out by a coring system. Based on core drilling, soil samples are obtained that are closer to the original state in the soil layer.

2.2. Standard Penetration Test (SPT) Data

The number of SPT tests is 15 times with a depth interval of 2 m. The SPT test consists of a beating test of a thick wall split tube into the ground (split spoon sampler), accompanied by the number of blows to insert a 300 mm vertical split tube. In this fall load system a hammer weighing 63.5 kg is used, which is dropped repeatedly with a height of 0.76 m. The test was divided into three stages, namely 150 mm in succession for each stage. The first stage is recorded as a stand, while the number of strokes to enter the second and third stages are summed to obtain the value of N or SPT resistance (expressed in strings / 30 cm). When the last 2x15 cm penetration is not achieved, the number of strokes must be written N = 50 / x, where x is the penetration. Correlation of NSPT values with parameters of saturated volume weight ($\gamma_{sat}$), undrained shear strength ($C_u$) and the level of density / consistency of layers expressed by the N values of the results of standard penetration tests (SPT) are shown in Table 1 [14]. The correlation of N-SPT values with modulus of elasticity is shown in Table 2 [14]. The correlation of NSPT values with poisson ratio is shown in Table 3 [14].

| SPT (N) | Consistency   | $\gamma_{sat}$ (kN/m$^3$) | $C_u$ (kN/m$^2$) |
|---------|---------------|---------------------------|------------------|
| 0 - 2   | Very soft     | 0 - 12,5                  |                 |
| 2 - 4   | Soft          | 1,6                       | 12,5 - 25       |
| 4 - 8   | Medium stiff  | 1,7                       | 25 - 50         |
| 8 - 16  | Stiff         | 1,9                       | 50 - 100        |
| 16 - 32 | Very Stiff    | 2,2                       | 100 - 200       |
| > 32    | Hard          |                           | > 200           |

[14]

| Type of Soil                           | Modulus Elasticity ($E_s$) (kN/m$^2$) |
|----------------------------------------|---------------------------------------|
| Gravelly sand                          | $E_s = 1200 \ (N + 6)$                |
| Sand normally consolidated             | $E_s = 500 \ (N + 15)$                |
| Sand saturated                         | $E_s = 250 \ (N + 15)$                |
| Sand overconsolidated                  | $E_s = 40000 + 1050 \ N$              |
| Clayey sand                            | $E_s = 320 \ (N + 6)$                 |
| Silts, sandy silt, clayey silt         | $E_s = 300 \ (N + 6)$                 |
| Clay, clayey silt                      | $E_s = 300 \ (N + 6)$                 |

[14]

2.3. Undisturbed soil samples data.

Samples of undisturbed soils are needed to get a picture / visual directly about the description / type of soil. Soil samples are also needed for further soil testing in the laboratory to get index properties, physical characteristics, and mechanical characteristics soil, so that planning data can be obtained from the results of laboratory testing.
2.4. Water level data.

The ground water level is required for analysis of retaining walls, especially related to the lateral pressure of the soil on retaining walls. The ground water level is determined from observational data at each drilling point after the drilling has ended. From the soil investigation on this project, no ground water level was found until the final depth 10 m.

| Type of Soil   | Poisson’s ratio |
|---------------|-----------------|
| Clay saturated | 0.4 – 0.5       |
| Clay unsaturated | 0.1 – 0.3    |
| Sandy clay     | 0.2 – 0.3       |
| Silt           | 0.3 – 0.35      |
| Sand, gravel   | 0.1 – 0.2       |

2.5. Soil physical properties data

The unit weight of the soil is needed in calculating the overburden pressure in the analysis of the carrying capacity of the soil, evaluating the stability of the slope, and so on. Specific gravity is needed to obtain physical properties that do not change due to changes in water content, this value is the ratio between the unit weight of grains of land with the unit weight of water at 4 °C. Moisture content is needed to reveal the humidity of the undisturbed soil sample, to reveal the natural position land in relation to its consistency boundaries. Atterberg consistency limits are needed to determine the liquid limit and the plastic limit of the soil used in many soil classifications, using a simple equation can be obtained the liquidity index value which is more to draw the proportion of the presence of the soil in near liquid or plastic conditions.

2.6. Mechanical properties data

Soil mechanical properties are soil parameters required for data analysis. soil shear strength, these parameters include cohesion and shear angle undrained and drained conditions. soil shear test in the laboratory can use direct shear or unconfined.

2.7. Sheet pile data

The shape of sheet pile is determined using corrugated sheet pile with specifications as in Table 4. The specifications of the corrugated sheet pile refer to JIS A 5326-1988 concerning prestressed concrete sheet pile, JIS A5325-1981 concerning reinforced concrete sheet pile, and SNI 03-2847-2002 about standard code for concrete.

3. Results and discussion

3.1. Model geometry

Based on the processing of soil data, measurement data of the existing elevation and cross section of the embankment soil area near the riverbank, the geometry of the sheet pile model for this project can be seen in Figure 1. The height of the elevation difference from the river bed to the above ground surface is around 7 m. Based on SPT data with interval of 2 m, the modeling of soil layer consists of 10 layers up to a depth of 19 m from top layer. Sheet pile geometry is modeled with the length of the embedded sheet pile as deep as 1 x high elevation difference = 1 x 7 m = 7 m, so that the total length of the sheet pile is 14 m. In the embedded sheet pile, an interface is given so that it can react to the ground water level. The soil of embankment is located near the sheet pile with a subgrade or existing sloping surface.
The modeling used the Plane strain model with 15 Node elements. Acceleration of gravity 9.80 m/s² with units of meter length (m) and Newton kilo (kN). Geometry dimensions 25 x 50 with standard fixities at the edges and bottom and density of standard (medium) mesh elements. The ground water level is modeled at the elevation of the riverbed.

![Figure 1. Model geometry](image)

| Type   | Section Area (cm²) | Section Inertia (cm⁴) | Unit weight (kg/m) | Allow. Momen permanent (t m) | Length (m) |
|--------|--------------------|-----------------------|--------------------|----------------------------|------------|
| W-325A | 1315               | 134264                | 329                | 6,74                       | 8-15       |
| W-325B | 1315               | 134264                | 329                | 8,64                       | 8-16       |
| W-350A | 1468               | 169432                | 368                | 10,14                      | 9-17       |
| W-350B | 1468               | 169432                | 368                | 11,54                      | 10-18      |
| W-400A | 1598               | 1248691               | 400                | 13,08                      | 10-18      |
| W-400B | 1598               | 1248691               | 400                | 16,38                      | 11-20      |
| W-450A | 1735               | 353363                | 439                | 18,04                      | 11-20      |
| W-450B | 1735               | 353363                | 439                | 21,84                      | 12-21      |
| W-500A | 1818               | 462373                | 455                | 24,76                      | 12-22      |
| W-500B | 1818               | 462373                | 455                | 29,96                      | 13-24      |
| W-600A | 2078               | 765907                | 520                | 36,19                      | 14-25      |
| W-600B | 2078               | 765907                | 520                | 45,19                      | 15-27      |

3.2. Soil parameters

From the results of drilling in the startification of land dominated by clayey silt starting from a depth of 0-20 meters. Soil parameters based on the results of soil data processing can be seen in Table 5. The liquid limit (LL) at a depth of 2 m is 44% and 52% at a depth of 6 m with a plastic limit (PL) of 30% and 36%, so that it includes land with high compressibility. The unit weight of saturated soil (γsat) is obtained from the correlation of physical properties of soil, namely specific gravity,
moisture content, and soil pore ratio. While parameters or mechanical properties of soil such as undrained shear strength \( (C_u) \), poisson ratio \( (v) \), and modulus of elasticity \( (E_s) \) are obtained from the correlation of N-SPT with these parameters. The soil pile parameter uses soil of embankment with unit weight \( (\gamma) \) 18 kN / m\(^3\), shear angle (\( \phi \)) 30\(^o\), and modulus of elasticity \( (E_s) \) 8000 kN / m\(^2\).

| Depth (m) | \( \gamma_{\text{sat}} \) (kN/m\(^3\)) | \( C_u \) (kN/m\(^2\)) | \( v \) | \( E_s \) (kN/m\(^2\)) |
|-----------|-----------------|-----------------|-----|-----------------|
| 1         | 16,5            | 50              | 0,3 | 4200            |
| 3         | 15,5            | 25              | 0,3 | 3000            |
| 5         | 15              | 12,5            | 0,3 | 2400            |
| 7         | 20,25           | 143,75          | 0,3 | 8700            |
| 9         | 20,5            | 150             | 0,3 | 9000            |
| 11        | 15,75           | 31,25           | 0,3 | 3300            |
| 13        | 15,5            | 25              | 0,3 | 3000            |
| 15        | 15,5            | 25              | 0,3 | 3000            |
| 17        | 21,75           | 181,25          | 0,3 | 10500           |
| 19        | 20,5            | 150             | 0,3 | 9000            |

3.3. **Corrugated sheet pile parameters**

The corrugated sheet pile type used is W-500A or W-500B with dimensions as shown in Figure 2. In the specification of the corrugated sheet pile cross section area is 1,818 cm\(^2\) with a weight of 455 kg / m. Cross-section inertia of 462.37 cm\(^4\) with 62 MPa concrete compressive strength. In the modeling of concrete quality, 50 MPa is taken. From these specifications the corrugated sheet pile parameters can be calculated as Plaxis data as in Table 6.

| Type of Sheet Pile         | W - 500 A | W - 500 B |
|----------------------------|-----------|-----------|
| Concrete compresive strenght, fc (MPa) | 50        | 50        |
| Modulus elasticity, E (kN/m\(^2\)) | 33234019 | 33234019 |
| Section area, A (m\(^2\))    | 0,1818    | 0,1818    |
| Inertia, I (m\(^4\))         | 0,00462373| 0,00462373|
| Weight, W (kN/m)              | 4,55      | 4,55      |
| E x A (kN/m)                  | 6041944   | 6041944   |
| E x I (kN m\(^2\) / m )      | 153665    | 153665    |
| Poisson ratio, v              | 0,20      | 0,20      |
| Ultimate moment (kN m)        | 704       | 808       |
| Moment of crack (kN m)        | 352       | 404       |
| Temporary allowable moment (kN m) | 322,2     | 374,2     |
| Permanent allowable moment (kN m) | 247,6     | 299,6     |
Figure 2. Corrugated sheet pile section

3.4. **Corrugated sheet pile calculation**

The sheet pile calculation phase in Plaxis consists of 3 calculation phases. The first calculation phase is the initial conditions wherein the calculation of the lateral coefficient value of the soil at rest. In the initial conditions sheet pile material, when pile have not been included. The second calculation phase when the sheet pile is activated in modeling with Plastic calculation type, while for the third calculation phase uses \( \phi \) / reduction calculation type.

3.5. **Corrugated sheet pile strength of bending moment**

Based on the results of calculations from 2D Plaxis modeling with a depth of embedded 7 m corrugated sheet pile obtained ultimate moment (\( M_u \)) working on the corrugated sheet pile area of 254.72 kN m with the moment diagram as in Figure 3. The value of moment ultimate (\( M_u \)) is quite safe because moment from result of Plaxis is smaller than the allowable Moment (\( M_n \)) according to the specifications / brochure sheet pile W-500 B which is 299 kN m.

3.6. **Corrugated sheet pile strength of shear force**

Nominal shear strength / corrugated sheet pile resistance (\( V_n \)) consists of concrete shear strength (\( V_c \)) and steel yield strength for shear force (\( V_s \)). The value of Nominal shear strength (\( V_n \)) must be greater than the shear force resulting from Plaxis (\( V_u \)), so that \( V_c + V_s > V_u \) [17]. Based on the shear force results from Plaxis (\( V_u \)) is equal to 130.30 kN. From that value, then the concrete shear strength (\( V_c \)) alone have satisfies to receive the shear force results from Plaxis, \( V_c > V_u \). So the steel yield strength (\( V_s \)) for shear force does not need to be calculated and can installed practically.

\[
V_c = \sqrt{f_c \cdot b \cdot d / 6} \\
= \sqrt{50 \cdot 1000 \cdot 120 / 6} \\
= 141.42 \text{ kN}
\]

From the calculation of the shear strength above shows that the value of the concrete shear strength (\( V_c \)) is greater than the shear force resulting from Plaxis (\( V_u \)), so that the corrugated sheet pile is safe against shear forces and shear reinforcement can be installed practically.

3.7. **Safety factor of corrugated sheet pile stability**

From the calculation results of Plaxis 2D with a depth of 7 m corrugated sheet pile obtained the value of the stability factor of corrugated sheet pile stability of 2.98 with a maximum displacement of less than 10 cm in the landfill area and less than 5 cm in the meeting area of the existing soil with the soil of embankment as shown in Figure 4. The safety factor value of the stability of the corrugated sheet pile is quite safe because it is greater than 1,5 according the requirements listed in SNI 8460 - 2017.
4. Conclusions

From the results of Plaxis 2D modeling and stability and strength analysis of the corrugated sheet pile, the corrugated sheet pile type W - 500 Class B with an allowable permanent moment of 299 kN.m can be used as a retaining wall for the riverbank height of 7 m and the depth of the corrugated sheet pile embedded as deep as 7 m. The safety factor value of the stability of the corrugated sheet pile is quite safe because it is greater than the requirements listed in SNI SNI 8460 - 2017, where the value of the safety factor in SNI 8460 - 2017 must be greater than 1.5.

5. References

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