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# Bored Pile Foundation Analysis Using the Meyerhof Method

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ABSTRACT

The building structure can be said to be safe if supported by a strong foundation, so it is necessary to calculate the bearing capacity of the foundation using bored piles based on sondir data, calculate the load received by the pile cap, and calculate the amount of pile cap reinforcement. The method used is analytical and descriptive, while for the calculation of the foundation using the Meyerhoff method. The foundation analyzed is a bored pile foundation with a diameter of 0.4 m and a depth of 7 m. The results of the study, the type of native soil from Tomohon, North Sulawesi according to the USCS classification is soft clay with a bored pile bearing capacity of Qg = 177.45 tons. For the maximum axial force on the pile of 421.02 kN with a shear strength of 447.214 kN. The pile cap reinforcement obtained is reinforcement with a diameter of 19 mm with a distance between reinforcement of 200 mm and a used reinforcement area of 1134.11 mm2. The shrinkage reinforcement used is Ø12 with a distance between reinforcement of 160 mm. The substructure of a building should begin with a soil and location investigation to determine the characteristics of the soil on which a building will be built

## INTRODUCTION

The 3-storey building to be built in Kumelembuai Tomohon, North Sulawesi, is an area with soft soil, so the foundation to be used is a deep foundation, Fatimah, S. (2024). One type of deep foundation is a bored pile foundation that is able to withstand loads and has an easy construction method. A bored pile foundation is a foundation in the form of a tube. The foundation is the lowest part of a building that transfers the load to the ground, Mananoma, et. al (2024). Thus, the foundation has an important role in the structure of the building. There are two types of foundations that are commonly used, namely deep foundations and shallow foundations. Usually deep foundations are used in tall buildings, but the determination of the foundation can also be based on the type of soil in the area. According to Prananda et. al (2024), the foundation is a part of a building construction that is tasked with placing the building, and transferring the load of the upper building into the ground that is strong enough to support the building structure. Furthermore, according to Arliyanto et. al (2024), foundations are divided into 2 categories, namely: shallow foundations and deep foundations based on their depth elevation. The use of foundations as a lower structure is influenced by several factors, such as: subgrade conditions, loads received by the foundation, applicable regulations, costs, ease of implementation, and so on. For details, it is necessary to calculate the bearing capacity of the bored pile cap foundation using the Meyerhoff method.

## METHODS

### Location and Time of Research

This research was conducted in Kumelembuai, Tomohon, and took place from May to July 2024.

### Research Method

This study employs a descriptive analysis method, specifically focusing on calculating the bearing capacity of bored pile foundations. This approach was chosen because it allows for an in-depth and comprehensive analysis of the data obtained, as well as the development of a detailed understanding of soil conditions and foundation bearing capacity at the research site (Jones & Smith, 2023).

### Types of Data and Data Collection Methods

Primary data were obtained through direct field research and laboratory testing. The testing was carried out at the Soil Testing Laboratory, State Polytechnic of Manado, to determine the soil type at the construction site. Soil samples were taken directly from the site to ascertain the physical and mechanical properties of the soil (Lee et al., 2022).

Secondary data were obtained from parties who had previously collected such data, such as project planners. This secondary data includes cone penetration test (CPT) data, construction drawings, upper structure loading, and acting forces. Secondary data collection was also conducted through literature reviews, scientific studies, journals, books, and previous research (Chen & Zhao, 2021).

### Bearing Capacity of Bored Pile

The calculation of the strength or bearing capacity of the foundation is based on the cone penetration test (CPT) values (qc) using the Meyerhoff method. This method was chosen because it has been proven effective in previous studies for estimating the bearing capacity of bored pile foundations (Brown & Lu, 2020).

### Allowable Group Pile Capacity

The number of piles required at a single foundation point is calculated by comparing the load acting on that point with the strength or bearing capacity of a single pile foundation. Once the number of piles is determined, the pile group configuration is established and group efficiency is calculated using the Converse-Labarre method from the Uniform Building Code AASHTO (Nguyen et al., 2019).

### Research Flow Diagram

The research flow diagram displays the process from the beginning to the end of the research to obtain research results and conclusions so as to know the characteristics of the soil that is the object of research as seen in Figure 1.

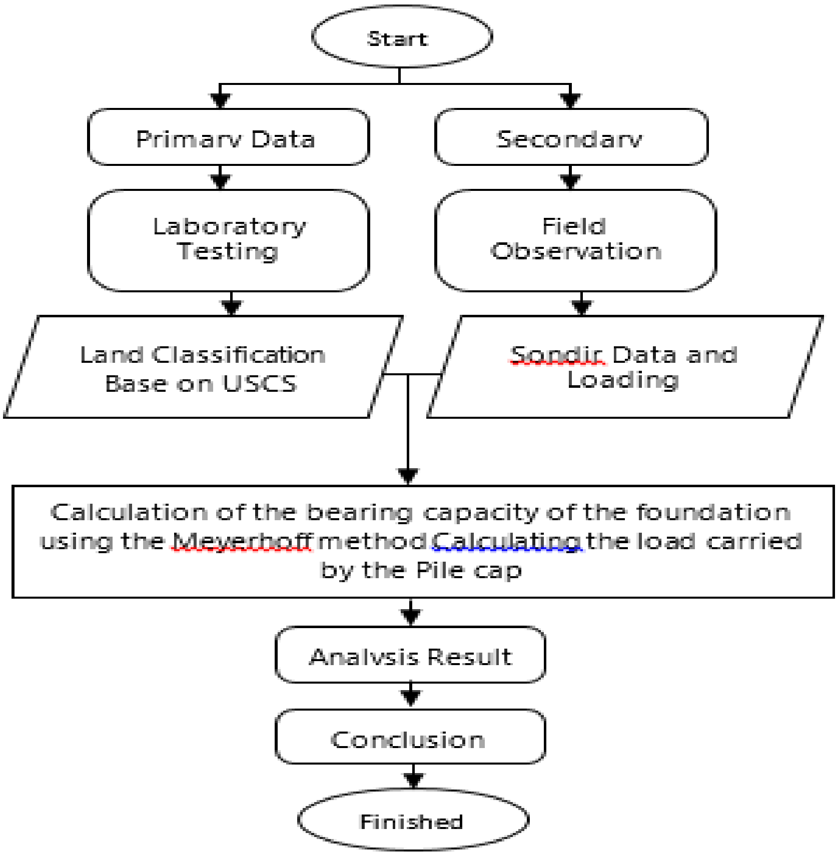


Figure 1. Research Flow Diagram

## RESULTS AND DISCUSSION

### General Conditions of the Research Location

The following is general data for the project that is the object of this research:

- Project Name: Construction of Villas at Melby's Resort Kumelembuai Tomohon
- Location: Melby's Resort, Kumelembuai, Tomohon, North Sulawesi
- Type of Construction: Reinforced Concrete
- Number of Floors: 3 Floors
- Building Area:
  - First Floor: 200 m²
  - Second Floor: 200 m²
  - Third Floor: 200 m²
  - Total Area: 600 m²
- Column Size: 300 mm x 350 mm
- Beam and Sloof Sizes:
  - Beam: 300 mm x 500 mm
  - Sloof: 300 mm x 500 mm
- Slab Thickness: 120 mm
- Type of Foundation: Bored Pile
- Foundation Size:
  - Pile Cap: 2 m x 0.8 m
  - Bored Pile Diameter: Ø 0.4 m
  - Foundation Depth: 7 m

Figure 2 shows the location as captured through Google Earth, and in Figure 3, at points A10-B1, the construction location as obtained from the project planner is depicted.

Figure 2. Construction Site, Kumelembuai Tomohon

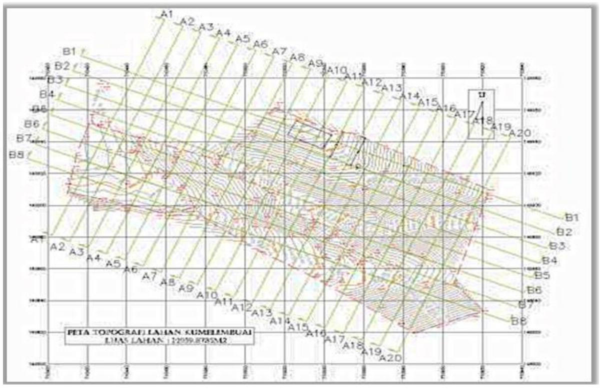

Figure 3. Topographic Map of Kumelembuai Land

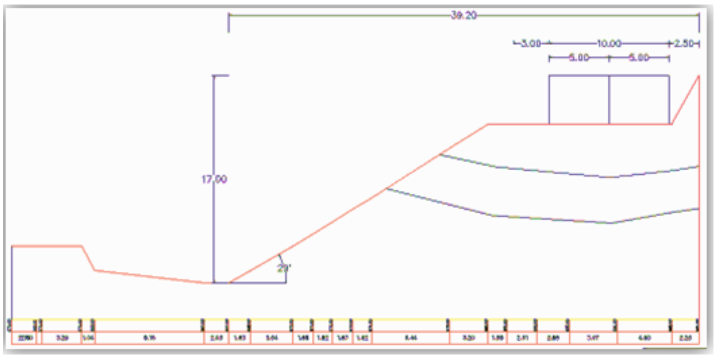

Figure 4. Slope Cut

In Figure 4 obtained from the villa development project planner, there is a blue dotted line indicating the hill where the building will be built before the cut and fill. This is done to obtain a flat ground surface so that the construction process is easier with a depth of 5 m. The sondir data was taken before the land was cut. Therefore, the Sondir data used to calculate the bearing capacity starts at a depth of 5 m. This is because the land above 5 m has been cut and is considered non-existent.

**Physical and Mechanical Properties**

The physical and mechanical properties of the soil greatly affect the determination of the type of foundation in an area. Research has been conducted according to the procedure. Table 1 shows the results of the tests carried out.

Table 1. Test Results

| No | Test | | Unit | |
|---|---|---|---|---|
| 1 | Moisture Content | w | % | 72,63 |
| 2 | Specific Gravity | Gs | | 2,58 |
| 3 | Bulk Density | Y | $gr/cm^3$ | 1,504 |
| | Grain Size Analysis (Wet Sieve) | | | |
| 4 | Passed sieve No.10 | | | 99,026 |
| | Passed sieve No.40 | | % | 91,06 |
| | Passed sieve No.60 | | % | 86,81 |
| | Passed sieve No.200 | | % | 68,22 |
| | Grain Size Analysis (Hydrometer) | | | |
| 5 | Clay | | % | 18 |
| | Silt | | % | 65,31 |
| | Atterberg Limits | | | |
| | Liquid Limit | LL | % | 85,90 |
| 6 | Plastic Limit | PL | % | 69,19 |
| | Plasticity Index | PI | % | 16,71 |
| | Linear Shrinkage | LS | % | 3,6 |
| | Direct Shear | | | |
| 7 | Shear Angle | | | 9,369 |
| | Soil Cohesion | | $kg/cm^2$ | 0,1476 |
| 8 | Unconfined Compressive Strength | | $kg/cm^2$ | 0,2543 |

**USCS Classification**

According to the results of the study of soil properties, 68.22% passed sieve no. 200, then the liquid limit of the Atterberg test was 85.90% and was connected to the plastic limit on the USCS graph, then the type of inorganic silt or elastic silt (MH) was obtained. The soil classification system according to USCS can be seen

**Program Loading**

This data was obtained from the project planner using the ETABs version 18 program as shown in Table 2. Structural analysis was performed with the assumption of clamping placement so that there is no shift in the structure.

Table 2. Load and Reaction Data

| Foundation Load Data | | |
|---|---|---|
| Column axial force due to factored load, | Puk = | 76,5 ton |
| Moment in x direction due to factored load. | Mux = | 1,5 ton |
| Moment in y direction due to factored load. | Muy = | 1,3 ton |
| Lateral force in x direction due to factored load, | Hux = | 1,41 ton |
| Lateral force in y direction due to factored load, | Huy = | 1,39 ton |

**Calculation of Soil Bearing Capacity**

Calculation of soil bearing capacity based on sondir data using the Meyerhof method. Sondir data is used to determine the depth of the hard soil layer, and at each depth it is also possible to determine the type of soil bearing capacity and its adhesion. In addition, the Sondir test aims to determine the shear strength of the soil and penetration or cone resistance from below.

Based on the secondary data obtained, the sondir 1 data will be used as the data for calculating the soil bearing capacity because it has the deepest review point of 16 m, while sondir points 2, 3, 4 and 5 only have a depth of between 8.8 m and 13.6 m. Sondir 1 data can be seen in Table 3.

Table 3. Sondir Data

| Depth (m) | Cone Resistance ($kg/cm^2$) | Amount of Sticking Resistance ($kg/cm^2$) |
|---|---|---|
| 0,2,0 | 2 | 4,02 |
| 0,40 | 10 | 6,69 |
| 0,60 | 10 | 17,40 |
| 0,80 | 8 | 26,77 |
| 1,00 | 8 | 36,14 |
| 1,20 | 10 | 42,83 |
| 140 | 10 | 49,52 |
| 1,60 | 10 | 60,23 |
| 1,80 | 10 | 66,92 |
| 2,00 | 10 | 73,61 |
| 2,20 | 10 | 84,32 |
| 2,40 | 10 | 91,01 |
| 2,60 | 10 | 97,70 |
| 2,80 | 10 | 108,41 |
| 3,00 | 10 | 115,10 |
| 3,20 | 10 | 121,79 |
| 3,40 | 10 | 128,48 |
| 360 | 10 | 135,17 |
| 3,80 | 15 | 141,86 |
| 4,00 | 15 | 148,56 |
| 4,20 | 15 | 155,25 |
| 4,40 | 15 | 161,94 |
| 4,60 | 15 | 168,63 |
| 4,80 | 20 | 175,32 |
| 5,00 | 15 | 182,02 |
| 5,20 | 18 | 187,37 |
| 5,40 | 15 | 200,75 |
| 5,60 | 15 | 214,14 |
| 6,00 | 15 | 240,9 |
| 6,20 | 15 | 254,29 |
| 6,40 | 15 | 267,67 |
| 6,60 | 15 | 285,07 |
| 6,80 | 20 | 298,45 |

| Depth (m) | Cone Resistance (kg/cm²) | Amount of Sticking Resistance (kg/cm²) |
|---|---|---|
| 7,00 | 20 | 311,83 |
| 7,20 | 20 | 325,22 |
| 7,40 | 20 | 338,6 |
| 7,60 | 20 | 351,98 |
| 7,80 | 20 | 365,37 |
| 8,00 | 20 | 378,75 |
| 8,20 | 20 | 392,14 |
| 8,40 | 18 | 405,52 |
| 8,60 | 20 | 418,90 |
| 8,80 | 25 | 432,29 |
| 9,00 | 30 | 445,67 |
| 9,20 | 30 | 456,38 |
| 9,40 | 30 | 467,08 |
| 9,60 | 30 | 480,47 |
| 9,80 | 40 | 493,85 |
| 10,00 | 40 | 500,54 |
| 10,20 | 40 | 507,23 |
| 10,40 | 40 | 513,92 |
| 10,60 | 40 | 527,31 |
| 10,80 | 50 | 540,69 |
| 11,00 | 50 | 554,08 |
| 11,20 | 50 | 567,46 |
| 11,40 | 50 | 580,84 |
| 11,60 | 50 | 594,23 |
| 11,80 | 60 | 607,61 |
| 12,00 | 80 | 620,99 |
| 12,20 | 90 | 634,38 |
| 12,40 | 105 | 647,76 |
| 12,60 | 100 | 671,85 |
| 12,80 | 80 | 685,23 |
| 13,00 | 80 | 698,62 |
| 13,20 | 70 | 712,00 |
| 13,40 | 70 | 725,38 |
| 13,60 | 60 | 738,77 |
| 13,80 | 60 | 752,15 |
| 14,00 | 60 | 762,86 |
| 14,20 | 60 | 773,56 |
| 14,40 | 60 | 784,27 |
| 14,60 | 50 | 797,65 |
| 14,80 | 50 | 811,04 |
| 15,00 | 90 | 824,42 |
| 15,20 | 130 | 837,80 |

| Depth (m) | Cone Resistance ($kg/cm^2$) | Amount of Sticking Resistance ($kg/cm^2$) |
|---|---|---|
| 15,40 | 130 | 851,19 |
| 15,60 | 170 | 864,57 |
| 15,80 | 170 | 877,95 |
| 16,00 | 200 | 944,87 |
| 11,80 | 60 | 607,61 |
| 12,00 | 80 | 620,99 |
| 12,20 | 90 | 634,38 |
| 12,40 | 105 | 647,76 |
| 12,60 | 100 | 671,85 |
| 12,80 | 80 | 685,23 |
| 13,00 | 80 | 698,62 |
| 13,20 | 70 | 712,00 |
| 13,40 | 70 | 725,38 |
| 13,60 | 60 | 738,77 |
| 13,80 | 60 | 752,15 |
| 14,00 | 60 | 762,86 |
| 14,20 | 60 | 773,56 |
| 14,40 | 60 | 784,27 |
| 14,60 | 50 | 797,65 |
| 14,80 | 50 | 811,04 |
| 15,00 | 90 | 824,42 |
| 15,20 | 130 | 837,80 |
| 15,40 | 130 | 851,19 |
| 15,60 | 170 | 864,57 |
| 15,80 | 170 | 877,95 |
| 16,00 | 200 | 944,87 |
| 11,80 | 60 | 607,61 |
| 12,00 | 80 | 620,99 |

Based on the explanation in Figure 4, the foundation starts from a depth of 5.20 m. The amount of adhesive resistance is taken at a depth of 12.20 m because the length of the foundation is 7 m.

**Ultimate bearing capacity (Qu)**

To calculate the bearing capacity of the soil, the following values are required:

Qu = (qc x Ap) + (JHL x Kt)

qc = (30+30+30+30+40+40+40+40+40+50+50+50+50+50+60+80+90+105+10+0+80+80+70+70+60+60)/25

= 65,91 $kg/cm^2$

Ap = ¼□x $D^2$

= ¼ x 3,14 x $(40\ cm)^2$

= 1256 $cm^2$

JHL = 634,38 $kg/cm^2$ Kt = □ x Φ x h

= 3,14 x 40 cm

= 125,6 cm

Qu = (65,91 $kg/cm^2$ x 1256 $cm^2$) + (634,38 kg/cm x 125,6 cm)

= 82781,82 kg + 79677,62 kg

= 162459,44 kG

= 162,5 ton

As for the calculation of the permitted bearing capacity of the foundation to ensure that the pole is safe enough to carry the load, the equation used is:

Q permit = (qc x Ap)/3 + (JHL x Kt)/5

= (65,91 x 1256)/3 + (634,38 x 125,6)/5

= 54153,15 kg

= 54 ton

Condition Q permit > Puk

54 ton < 76,52 ton **(Not Safe)**

From the results of the single pile calculation, it can be seen that the bearing capacity is not safe because the Q permit is smaller than Puk. Because the Q permit is smaller than Puk, the group pile permit bearing capacity will be used.

**Number of piles (n)**

N = Puk/Q permit

= 76,52/ 54

= 1,42

= 2 pile (rounded)

**Pile Group Efficiency (Ɛ)**

$$\varepsilon = 1 - \theta \frac{(2-1)2 + (2-1)2}{90\ x\ 2\ x\ 2}$$

= 0,778

**Pile group bearing capacity (Qg)**

Qg = n x Eg x Q permit

= 2 x 0,778 x 54 ton

= 84,024 ton

Condition Qg > Puk

= 84,024 > 76,52 ton **(Safe)**

From the calculation of the bearing capacity of the bored pile foundation with a diameter of 40 cm with a depth of 7 m, the results obtained are:

Qu = 162.5 tons (ultimate bearing capacity)

Q permit = 54 tons (permissible bearing capacity of single pile)

n = 2 piles (number of piles)

Eg = 0.778 (pile group efficiency)

Qg = 84.024 tons (pile group bearing capacity)

**Pile Cap Calculation**

The data for calculating the received load is secondary data obtained from the project planner. With values as in Table 4 and Table 5 below.

Table 4. Pile Cap Data

| **Pile Cap Material Data** | | |
|---|---|---|
| Compressive strength of concrete, | fc' = | 20 MPa |
| Yield strength of deformed reinforcing steel (Ø > 12 mm) | fy = | 390 MPa |
| Yield strength of plain reinforcing steel (Ø ≤ 12 mm) | fy = | 240 MPa |
| Weight of reinforced concrete | wc = | 2.44 ton/m$^3$ |
| **Foundation Dimension Data** | | |
| Width of column in x direction, | bx = | 0,40 m |
| Width of column in y direction, | by = | 0,40 m |
| Distance of pile edge to outer side of concrete, | a = | 0,40 m |
| Thickness of pile cap, | h = | 0,60 m |
| Soil thickness above the pile cap, | z = | 1,20 m |
| Volume weight of soil above the pile cap, | ws = | 1,8 ton/m$^3$ |
| Column position (depth = 40, edge = 30, corner = 20) | as = | 40 |
| **Foundation Load Data** | | |
| Column axial force due to factored load, | Puk = | 76.5 tons |
| Moment in x direction due to factored load. | Mux = | 1,5 tonm |
| Moment in y direction due to factored load. | Muy = | 1,3 tonm |
| Lateral force in x direction due to factored load, | Hux = | 1,41 ton |
| Lateral force in y direction due to factored load, | Huy = | 1,39 ton |
| Pile axial resistance, | f * Pn = | 4,8 ton |
| Pile lateral resistance, | f * Hn = | 3,2 ton |
| **Pile Arrangement Data** | | |

| Arrangement of piles in x direction: | | | | Arrangement of piles in y direction: | | | |
|---|---|---|---|---|---|---|---|
| No | Amount | x | $n * x^2$ | No | Amount | y | $n * y^2$ |
| | n | (m) | ($m^2$) | | n | (m) | ($m^2$) |
| 1 | 1 | 0,50 | 0,25 | 1 | 1 | 0,00 | 0,00 |
| 2 | 1 | -0,50 | 0,25 | | | | |
| | | | | | | | |
| n = | 2 | $\sum x^2$ = | 0,50 | n = | 1 | $\sum y^2$ = | 0,00 |
| Pile cap width in x direction, | | | | | | $L_x$ = | 1,80 m |
| Pile cap width in y direction, | | | | | | $L_y$ = | 0,80 m |

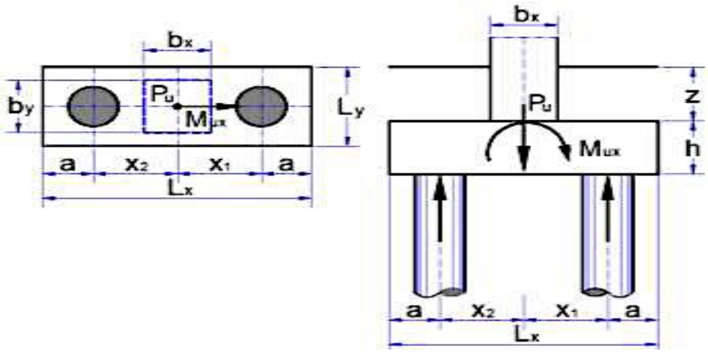

Figure 5. Pile Cap Details

The data used in the following calculations correspond to Table 4.

**Axial Force On Pile**

Weight of soil above pile cap:

Ws = Lx x Ly x Z x Ws
= 1,8 m x 0,8 m x 1,2 m x 1,8 ton/$m^3$
= 3,1 ton

Pile cap weight:

Wc = Lx x Ly x h x Wc
= 1,8 m x 0,8 m x 0,6 m x 2,4 ton/m3
= 2,074 ton

Total factored axial force:

Pu = Puk + 1,2 x Ws + 1,2 x Wc
= 76,5 ton + 1,2 x 3,1 ton + 1,2 x 2,074 ton
= 81,26 ton

The maximum arm of the pile in the x direction towards the center:

Xmax = 0,50 m

Minimum arm of the pile in the x direction to the center:

Xmin = -0,50 m

Maximum and minimum axial forces on piles:

Pu max = Pu/n + Mux x Xmax /Σx2
= 81,26 ton/2+1,471 ton/m x 0,50 m/0,50
= 42,9 ton

Pu min = Pu/n + Mux x Xmin /Σx2
= 812,62 ton / 2 + 1,471 ton/m x -05,0 m / 0,50
= 39,160 ton

Condition : Pumax $\leq$ Ø x Pn
42,9 < 48 = **SAFE (OK)**

From the results of this calculation, it is obtained that the maximum axial force of the pile is smaller than the axial resistance of the pile, so it meets the requirements.

**Review of shear**

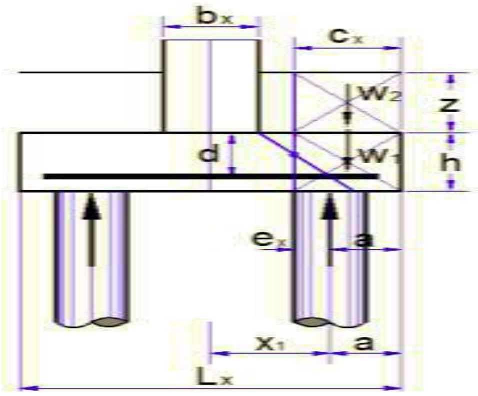

Figure 6. Pile Cap Details

Distance of the center of the reinforcement to the outside of the concrete:

d` =0,1 m

Effective pile cap thickness:

d = h-d`

= 0,6m – 0,1m

= 0,5m

Concrete weight:

W1 = cx x Ly x h x wc

= 0,45 x 0,8 m x 0,6 m x 2,4 ton/m3

= 0,5184 ton

Soil weight:

W2 = cx x Ly x z x ws

= 0,45 m x 0,8 m x 1,2 m x 1,8 ton/m3

= 0,7776 ton

X-direction shear force:

Vux =pumax - W1 - W2

= 42,102 ton – 0,5184 ton – 0,7776 ton

= 40,805 ton

Width of the sliding plane in x direction:

b = Ly = 0,8 m = 800 mm

Effective pile cap thickness:

d = 0,5 m = 500 mm

The ratio of the long side to the short side of the column:

βc = bx/by

Table 5. Pile Cap Data

| | | |
|---|---|---|
| The width of the pile cap under consideration | b=Ly | 800 mm |
| Thickness of the pile cap Distance from the | h | 600 mm |
| Distance from the center of the reinforcement to the outer side of the concrete | d` | 100 mm |
| Effective thickness of the plate | d | 500 mm |
| Compressive strength of the concrete | fc` | 20 MPa |
| Yield strength of the reinforcing steel | Fy | 390 MPa |
| Modulus of elasticity of the steel | Es | 200000 MPa |

= 0,40 m / 0,40 m

= 1,000

The shear strength of the pile cap in the x direction is taken as the smallest value of Vc.

Is known:

βc =1

b = 800 mm

d = 50 mm

Vc =[1+2/βc ] x √fc` x b x d / 6x 10-3

=[1+2/1] x √20 x 800 mm x 500 mm / 6x 10-3

= 89,4427 ton

Vc =[αs x d/b +2] x √ fc` x b x d / 6x 10-3

=[40 x 500 mm/800 mm +2] x √ 20 x 800 mm x 500 mm / 6x 10-3

=402,4922 ton

Vc = 1/3 x √ fc` x b x d / 6x 10-3

= 1/3 x √ 20 x 800 mm x 500 mm / 6x 10-3

= 59,628 ton

The smallest pile cap shear strength value is taken: Vc = 59,628 ton

Shear strength reduction factor:

Ø = 0,75

Pile cap shear strength:

Ø x Vc = 0,75 x 59,628

= 45,6

Conditions that must be met:

Ø x Vc ≥ Vux

45,6 > 40,805 SAFE (OK)

The results of this calculation show that the pile cap shear strength is greater than the shear force, so it meets the requirements.

**Pile Cover Reinforcement**

Calculation of pile cap reinforcement with known data is listed in Table 5 below.

Distance from the edge of the column to the outer side of the pile cap:

cx = (Lx-bx)/2

= (1,8 m – 0,4 m)/ 2

= 0,7 m

Distance of the post to the side of the column: $\frac{10^6}{(\text{b x}d^2)}$

ex = cx-a

= 0,7 m – 0,4 m

= 0,3 m

Concrete weight:

W1 = cx x Ly x h x wc

= 0,7 m x 0,8 m x 0,6 m x 2,4 ton/$m^3$

= 2 x 42,102 ton x 0,3 m – 0,8064 ton x 0,7 m / 2- 1,209 ton x 0,7 m / 2

= 24,555 tonm

Soil weight:

W2 = cx x Ly x z x ws

= 0,7 m x 0,8 m x 1,2 m x 1,8 ton/m3

= 1,209 ton

Moments that occur at pile cap:

Mux = 2 x pumax x ex – W1 x cx/2- w2 x cx/2

= 2 x 42,102 ton x 0,3 m – 0,8064 ton x 0,7 m / 2- 1,209 ton x 0,7 m / 2

= 24,555 tonm

The concrete stress distribution factor is assumed to be uniformly distributed in the equivalent compression area bounded by the edges of the cross-section and a straight line parallel to the neutral axis at a distance a = β1 from the fiber with maximum compressive strain:

β1 = 0,85

$$\rho b = \frac{\beta 1 \text{ x } 0{,}85 \text{ x f c}'}{\text{fy x } 600/(600+\text{fy})}$$

$$\rho b = \frac{0{,}85 \text{ x } 0{,}85 \text{ x } 20}{390 \text{ x } 600/(600+390)}$$

= 0,02245532

Flexural strength reduction factor:

Φ = 0,80

$$R_{max} = 0{,}75 \text{ x } \rho b \text{ x } ty \text{ x} \left[\frac{1-{}^{1}/_{2}\, x\ 0{,}75\ x\ \rho b \text{ fy}}{(0{,}85\ x \text{ fc}')}\right]$$

$$= 0{,}75 \text{ x } 0{,}02245532 \text{ x } 390 \text{ x} \left[\frac{1-{}^{1}/_{2} x\ 0{,}75\ x\ 0{,}02245532 \text{ x } 390}{(0{,}85\ x\ 20)}\right]$$

= 5,299

Mn = Mux x ϕ

= 24,555 tonm x 0,80

= 30,694 tonm

Rn = Mn x

= 30,694 tonm x $10^6$/(800 mm x $500^2$ mm)

= 1,53472

| | | | | |
|---|---|---|---|---|
| Condition: | Rn | < | Rmax | (Ok) |
| | 1,53472 | < | 5,299 | (Ok) |

Required reinforcement ratio:

$$\rho = \frac{0{,}85 \text{ x fc}'}{\text{fy x} \sqrt{\{1-2\ x\ Rn/(0{,}85\text{xfc}')\}}}$$

$$\rho = \frac{0{,}85 \text{ x } 20}{390 \text{ x} \sqrt{\{1-2\ x\ 1{,}53472/(0{,}85 \text{ x } 20)\}}}$$

= 0,0041

Minium reinforcement ratio according to SNI 2847-2002:

ρmin = 0,0014

Reinforcement ratio used:

ρ = 0,0041

Required reinforcement space:

As = ρ x b x d

= 0,0041 x 800 mm x 500 mm

=1652,37 $mm^2$

The diameter of the reinforcement to be used is D19. The following is the calculation of the area of reinforcement used and the distance of reinforcement used:

s = π/4 x D2 x b /As

= 3,14 / 4 x $19^2$ x 800 mm x 1652,37 mm2

= 137 mm

distance of reinforcement required:

s = 137 mm

D19 reinforcement is obtained with a distance between reinforcements of 130 mm before the dividing reinforcement is taken as 50% of the main reinforcement. The following is the calculation with dividing reinforcement:

Reinforcement area used:

As = π/4 x $D^2$ x b /s

= 3.14 / 4 x $19^2$ x 800 mm / 137 mm

= 1744,79 $mm^2$

For reinforcement, 50% of the principal reinforcement is taken:

$A_{sb}$ = 50% x As

= 50% x 1744.79

= 872,40 $mm^2$

The required reinforcement spacing:

s = π/4 x $D^2$ x b /Asb

= 3,14 /4 x $19^2$ x 800 mm x 872,40 $mm^2$

= 260 mm

Distance of reinforcement used:

s = 200 mm

Used reinforcement area:

As = π /4 x $D^2$ x b /s

= 3,14 / 4 x $19^2$ x 800 mm / 200 mm

= 1134,11 $mm^2$

D19 reinforcement was obtained with a reinforcement distance of 200 mm after the reinforcement was divided into 50% of the main reinforcement, with a used reinforcement area of 1134.11 mm2.

**Shrinkage Reinforcement**

Shrinkage reinforcement is reinforcement installed to counter shrinkage/expansion and its installation is opposite and perpendicular to the main reinforcement. The values needed to calculate shrinkage reinforcement are as follows:

Minimum milk reinforcement ratio according to SNI 2847-2002:

ρsmin = 0,0014

Shrinkage reinforcement area:

As = ρsmin x b x d

= 0,0014 x 800 mm x 500 mm

= 560 $mm^2$

The diameter of the reinforcement to be used is D12. Distance of shrinkage reinforcement:

S = π/4 x $D^2$ x b /As

= 3,14 / 4 x $12^2$ x 800 mm / 560 $mm^2$

= 162 mm

Maximum shrinkage reinforcement distance smax =200 mm

The distance of shrinkage reinforcement in the x direction (used is the smallest):

s = 162 mm

From the results of this calculation, the shrinkage reinforcement in the x direction is obtained with a diameter of 12 and a distance between the reinforcements of 160 mm.

**Bored Pile Reinforcement**

From the data above, the calculation for the main reinforcement can be calculated as follows:

1. **Effective thickness of outermost reinforced concrete cover:**

$$d' = concrete\ cover\ thickness + D_{stirrup\ reinforcement}$$

= 50 + 16 + ($\frac{1}{2} x\ 16$)

= 74 mm

$$d_{effective} = D_{pillar\ reinforcement} - (2\ x\ d')$$

= 400 – (2 x 74)

= 252 mm

2. **Cross-sectional area of the well pile**

$$A_g = \left(\frac{1}{4} \times \pi \times D_{in}{}^2\right) - \left(\frac{1}{4} \times \pi \times D_{outside}{}^2\right)$$

$$= \left(\frac{1}{4} \times 3{,}14 \times 400^2\right) - \left(\frac{1}{4} \times 3{,}14 \times 350^2\right)$$

$$= 29437{,}5$$

3. **Steel cross-sectional area of reinforcement**

$A_{st}$ = 3% x $A_g$
= 3% x 29437,5
= 883,125 mm

4. **Number of main reinforcements**

$$n = \frac{A_{st}}{\frac{1}{4} x\, \pi\, x\, D^2}$$

$$n = \frac{883{,}125}{\frac{1}{4} x\; 3{,}14\; x\; 16^2}$$

= 4,39 ≈ 5 main reinforcements

5. **Distance of main reinforcement**

$$s = \frac{\pi \times d_{effective}}{n}$$

$$s = \frac{3{,}14 \times 252}{n}$$

= 158 mm

**Spiral Reinforcement Calculation**

From the data above, the calculation for spiral reinforcement can be calculated as follows:

1. **Spiral cross-sectional area**

$$A_s Spiral = \frac{1}{2} \times \pi \times D_{\text{spiral reinforcement}}{}^2$$

$$= \frac{1}{2} \times 3{,}14 \times 10^2$$

$$= 100{,}48$$

2. **Core diameter of the well pile**

$$D_c = D_{pillar\ reinforcement} - (2 \times Concrete\ covers)$$

$$= 400 - (2 \times 50)$$

= 300 mm

3. **Well core cross-sectional area**

$$A_c = \left(\frac{1}{4} \times \pi \times D_{in}{}^2\right) - \left(\frac{1}{4} \times \pi \times D_c{}^2\right)$$

$$= \left(\frac{1}{4} \times 3{,}14 \times 350^2\right) - \left(\frac{1}{4} \times 3{,}14 \times 300^2\right)$$

= 25512,5 mm

$$\rho_{need} = 0{,}45 \times= \left(\frac{A_g}{A_c} - 1\right) \times \left(\frac{F_{c'}}{F_y}\right)$$

$$= 0{,}45 \times= \left(\frac{29437{,}5}{25512{,}5} - 1\right) \times \left(\frac{20}{390}\right)$$

$$= 0{,}4\ mm$$

4. **Distance between spiral stirrups**

$$S_{max} = \frac{1 \times A_{s\ spiral} \times (D_c - D_{\text{spiral reinforcement}})}{D_c \times \rho_{need}}$$

$$= \frac{1 \times 100{,}48 \times (300 - 10)}{300^3 \times 0{,}4}$$

With the calculation of Bored Pile foundation reinforcement, the main reinforcement used is 5 D 16 and spiral reinforcement Ø 10 – 50

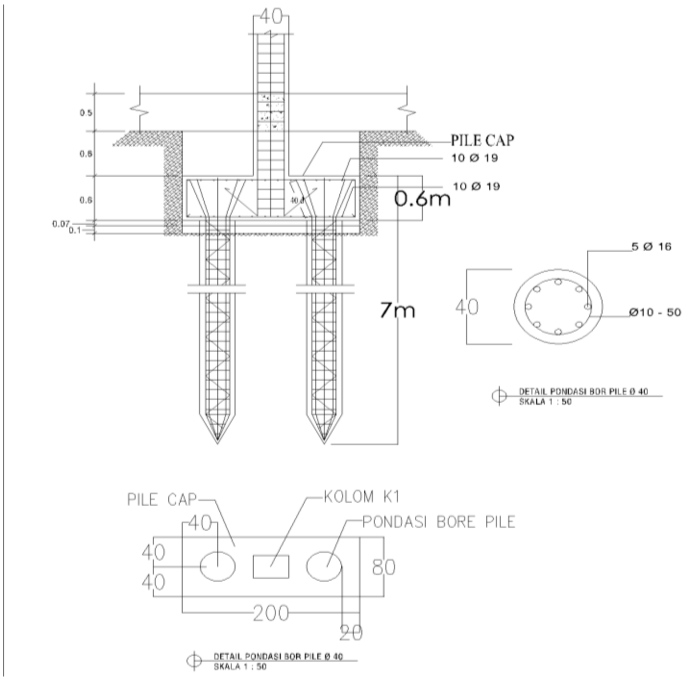


Figure 7. Bored Pile Reinforcement

## CONCLUSION

From the analysis results above, several conclusions can be obtained as follows:

1. The bearing capacity of the bored pile foundation with a diameter of 40 cm and a depth of 7 m at point C-2 is: a) Qu = 162.5 tons b) Qijin = 54 tons c) n = 2 piles d) Eg = 0.778 e) Qg = 84.024 tons
2. The load received by the 2 m x 0.8 m pile cap is: a) Pumax (axial force) = 42.9 tons b) Shear strength of the pile cap = 45.6 tons 3. The pile cap reinforcement obtained is reinforcement with a diameter of 16 mm with a total of 5 reinforcements and the spiral reinforcement used is a diameter of 10 with a total of 10 reinforcements.

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