BORE PILE FOUNDATION BEHAVIOR ANALYSIS IN MUD FLOW AREA (Case Study In Margamukti Village, Pangalengan-Bandung Regency)

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Abstract

Cracks in the soil in Margamukti village, Pangalengan, Bandung Regency caused a landslide and hit 3 pipes belonging to PT. Star Energy Geothermal so that the pipe breaks and releases hot steam. The installation of the bore pile foundation is a solution to support the 3 geothermal pipes and to withstand the movement of mud flows (colluvial soil). In this study, the researchers used two methods, namely the poulos method at a depth of 0-8 m and then continued by using the Reese & Matlock method at a depth of 8 - 35 m to determine whether the bore pile is strong enough to withstand the flow of mud. The results of the use of these two methods are then compared with the maximum allowable moment of the quality of the concrete used as a bore pile material, which is fc' = 25 MPa. Based on the results of the analysis, it is found that the maximum moment of the bore pile obtained from the Poulos and Reese & Matlock method does not exceed the maximum allowable moment, so that the bore pile is safe.

Keywords: Colluvial Soil, Bore Pile Foundation, Poulos Method, Reese & Matlock Method

Introduction

In the village of Margamukti, Pangalengan, Bandung Regency, a landslide occurred which began with a crack in the ground 1 meter wide and 5 meters deep. In addition, the cause of landslides is the condition of the soil in the form of colluvial soil and the intensity of the rain is quite large, so that the colluvial soil is saturated with water. The landslide material in the form of colluvial soil slid and hit a geothermal pipe belonging to the Star Energy Geothermal company. As a result, the three main geothermal pipelines were cut off, releasing a large amount of hot steam material and producing a sound that sounded like an explosion [1-5].

The landslide caused the company Star Energy Geothermal to suffer a large loss. In order to prevent this incident from happening again, this project decided to use bore pile foundations to withstand landslides and as a support for the three geothermal pipes. The dimensions of the foundation used are 1.2 meters in diameter and 35 meters in depth [6-10].

The purpose of this study was to determine how much force is required for the foundation due to the movement of colluvial soil or avalanche debris and to analyze the safety of the bore pile foundation[11].

Literature Review

Bored Pile Foundation Theory

Bored pile foundation is a pile foundation whose installation is done by boreing the ground at the beginning of the work then filled with reinforcement and casted concrete. A bore post is constructed by making a bore hole with a certain diameter to the desired depth.

Characteristics of Colluvial Soil

Colluvial soil is soil that is formed by the movement of soil from its place of origin due to gravity as occurs during a landslide. Generally these soils are unstable. Colluvial soils usually consist of a heterogeneous variety of rock and sediment types ranging from silt to crushed rock of various sizes. The term is also used to specifically refer to sediment deposited at the base of a slope with unconcentrated runoff.

Poulos Method

Piles that experience soil movement (lateral) on unstable slopes, cannot simply be modeled by providing an equivalent external load on the pile head. Especially for piles that experience soil movement (lateral) on unstable slopes, modeling cannot simply provide an equivalent external load on the pile head. There is often a misconception that the effect of ground motion on the pile can be estimated by applying an equivalent load to the pile head.

[12, 13] has carried out a simple analysis to illustrate the consequences of applying the concept in Figure 1.

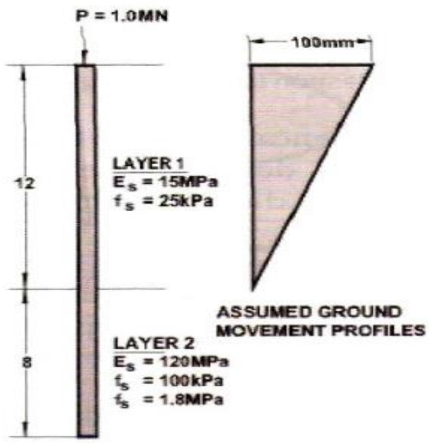

Figure 1. Typical Modeling of [12]

The analysis includes a single pile with 2 layers of soil with several kinds of loading (axial and lateral). Shows the difference in the distribution of axial forces on the pile in the case of piles that are given a direct axial load compared to those caused by vertical ground movements.

[12]have provided an elastic solution, to be able to estimate the magnitude of the deflection at the head of the pile and the maximum moment that occurs in the pile. The use of the chart will result in the value of the upper limit (Upper Bound) of the deflection and moment, with respect to the assumption used is that the soil will continue to behave elastically.

The analysis is carried out using standard movement with the assumption that the maximum movement that occurs is 0.45 x pile diameter. The effect of the ratio of the magnitude of the ground movement to the diameter of the pile is plotted in Figure 2.

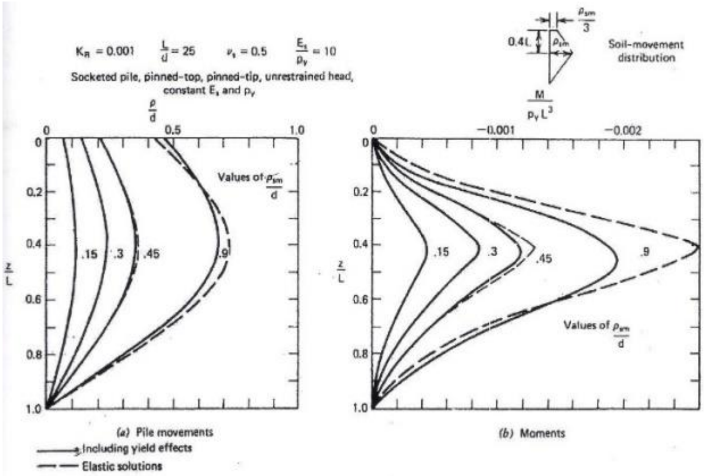

Figure 2. The Effect of the Magnitude of Ground Movements [14]

From the various studies that have been carried out, [14, 15] suggest some guidelines for simplifying the ground motion profile as input for using the chart. One of them is for landslides with relatively large ground movement (up to 0.45 x pile diameter) can adopt a uniform soil movement profile with depth.

Figure 3. is the result of the analysis by considering the effect of the distribution or profile of the ground movement. The pile response to lateral ground movement is also affected by the pile cross-sectional dimensions, as shown in Figure 4.

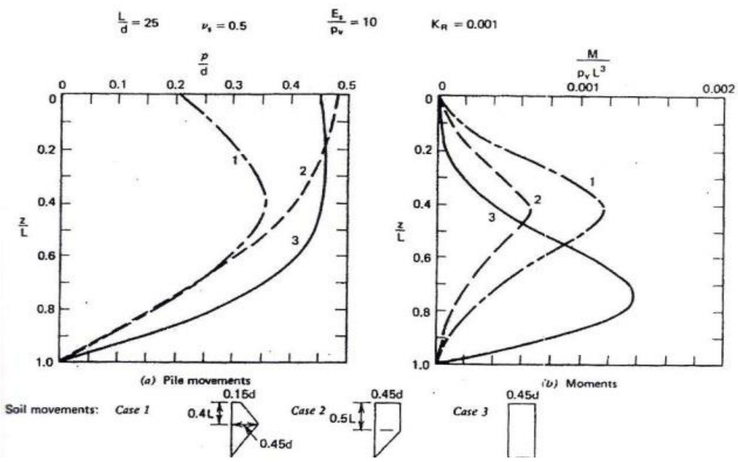

Figure 3. Distribution effect or ground motion profile

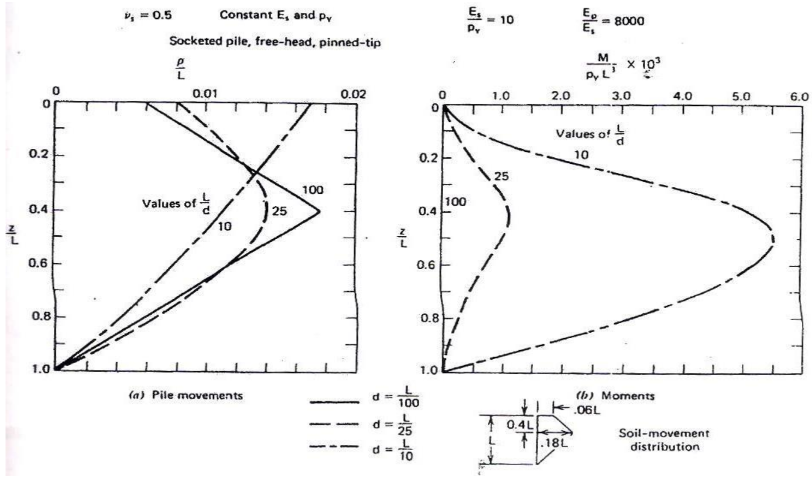

Figure 4. Effect of Pile Diameter

Reese & Matlock Method

In addition to the ultimate lateral capacity as a design criterion, a design criterion in the form of allowable lateral deflection can also be used. One of these methods is the method proposed by [16], which uses an analytical approach based on the subgrade reaction of the soil.

Free Head

The distribution of pile deflection, slope or rotation angle, bending moment, shear and soil reaction along the pile due to lateral load H and moment M acting on the pile head in general can be expressed by the equation:

$$\frac{d^4y}{dx^4}+\frac{Kh\,.y}{Ep\,.Ip}=0$$

And the general solution of the equation can be expressed by the equation:

$$y = f(x,T,L,KhEp.Ip,H,M)$$

where :

x = Depth below ground level, calculated from pile head
T = Stiffness factor
L = Pole Length
Kh = h . x = Horizontal subgrade modulus
B = Diameter or side of the pile
Ep.Ip = flexural stiffness of pile
H = Lateral load acting on the pile head
M = Moment acting on the head of the pile

The following equations can be used to calculate deflection (yx), moment (Mx), rotation angle or slope (Sx), shear force (Vx) and soil reaction (Px) as follows:

$$Y_x = Y_A + Y_B = A_y\,.\frac{H\,.T^3}{E_P\,.I_P}+B_y.\frac{M\,.\,T^2}{E_P\,.\,I_P}$$

$$S_x = S_A + S_B = A_S\,.\frac{H\,.T^2}{E_P\,.I_P}+B_S.\frac{M\,.\,T}{E_P\,.\,I_P}$$

$$M_x = M_A + M_B = A_m.H.T+B_m.M$$

$$V_x = V_A + V_B = A_v\,.\,H + B_v\,.\,\frac{M}{T}$$

$$P_x = P_A + P_B = A_p\,.\frac{H}{T} + B_p\,.\,\frac{M}{T^2}$$

It is known that the pile deformation will resemble a small curvature for Zmax = 2. Therefore, a pile with a value of Zmax 2 will behave as a short pile.

Also that the front post Zmax 5 ~ 10 has the same value of deflection coefficient. Therefore, pile sections greater than 5 T will have the same deflection.

Research Methodology

Field Data Collection

The research study was taken on the project of PT. Star Energy Geothermal in Pangalengan, namely the installation of a bore pile foundation as the foundation of three geothermal pipes and as a barrier from the flow of debris (coluvial soil) so that it does not fall into residential areas. The total number of bore piles installed is 15 pieces with a diameter of 1.2 meters and the depth of immersion varies from 25 – 35 meters below the pile cap [17-21].

After completing the installation of the bore pile foundation, it was found that there was ground movement which was feared that another landslide would occur and cause the foundation to collapse so that the geothermal pipe broke again. The ground movement was monitored using an inclinometer.

From the N-SPT test in the field, N-SPT data was obtained at each soil depth. From the results of the correlation between the value of N-SPT with the relative density on non-cohesive soils, the soil type is obtained at each depth.

To facilitate this research, a research flow chart is made as follows:

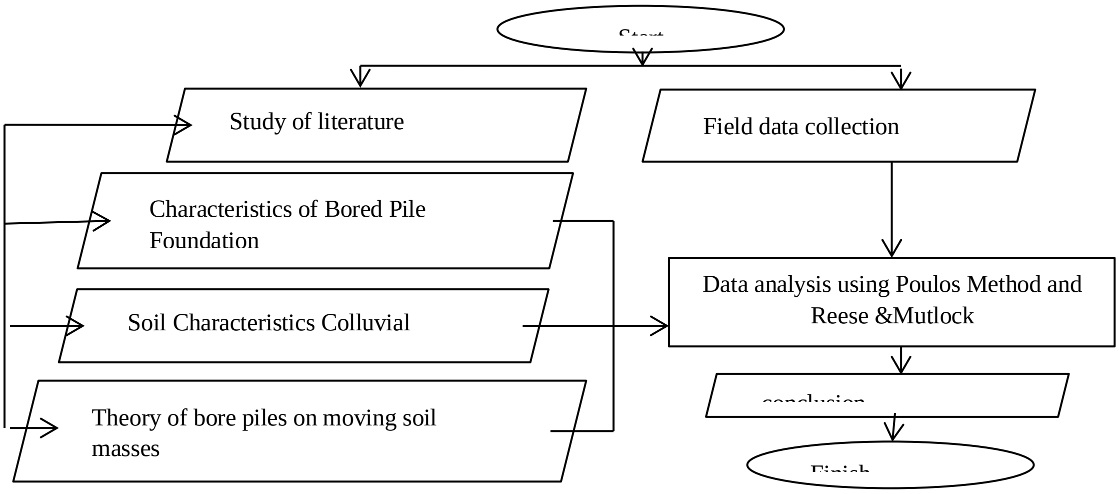

Figure 5. Research Flowchart

Analysis Method

In this study, the area to be reviewed is the Pangalengan area. The soil types reviewed are colluvial soil types in the first layer, tuff material in the second layer, and very firm clay in the third layer or base layer. Analysis of bore pile behavior using the Poulos method and the Reese & Matlock method.

Data Processing and Analysis

Analysis Based on Poulos Method and Reese & Matlock Method

Data analysis was carried out using the Poulos method and the Reese & Matlcok method. The calculation begins by using the Poulos method at a depth of 0 - 8 m. Then from the results of calculations using the Poulos method, the moment value is obtained. From the Poulos method, the presentation of data and calculations begins with calculating the accumulative inclinometer data at each depth. Then proceed with calculations using the Poulos method to find the maximum moment that occurs in the bore pile. After getting the maximum moment value, enter it into the maximum stress formula so that it can be compared with the allowable stress of the concrete quality used for the bore pile foundation.

Elastic Solution [22]

Based on the elastic solution published by [22, 23], the pile behavior due to soil movement can be estimated. Pile behavior is distinguished for the 3 ground motion models, as shown in Figure 6.

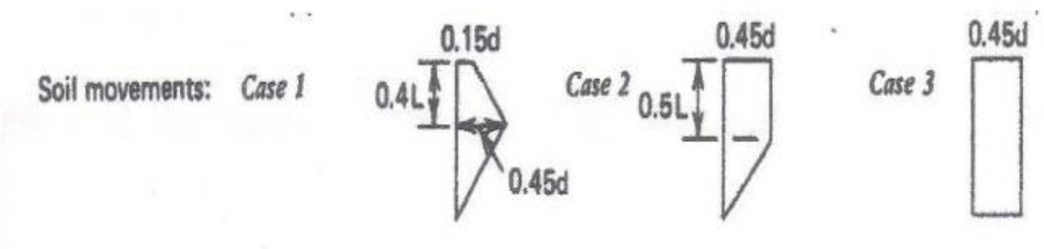

Figure 6. Soil Movement Profile Model Along the Pile

Interpretation of internal forces from inclinometer data built into the bore pile. To get the z/L value, the example calculation is as follows:

L = The height of the landslide area, which is 8 m
Z = Soil depth (m)
D = Diameter of bore pile, ie 1.2 m
sm = Soil Movement = 0.45 x bore pile diameter
so:

$$\frac{Z}{L} = \frac{1\,m}{8\,m} = 0.125$$

ρsm: 0.45 x 1.2 m = 0,54 m

so:

$$\frac{\rho sm}{d} = \frac{0.54\,m}{1.2\,m} = 0.45$$

To get the value of /d, it is plotted onto the Pile Movement graph shown in Figure 7.

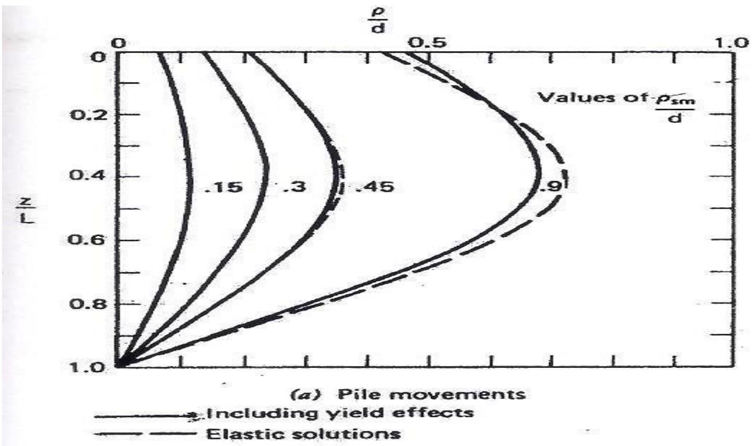

Figure 7. Pile Movement Graph.

After getting the value from Pile Movements, then look for the value obtained from the graph shown in Figure 8.

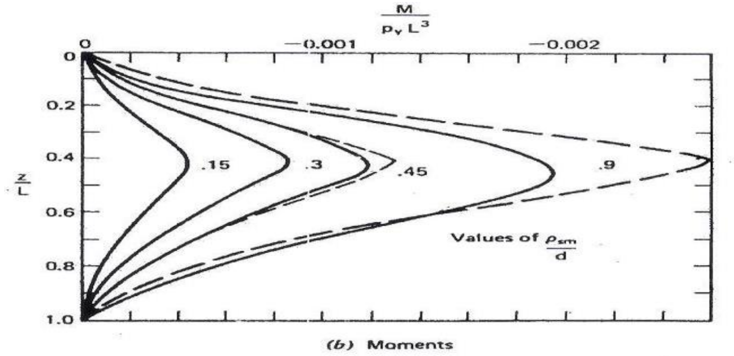

Figure 8. Moment Graph.

Calculated at each depth as shown in table 1. then plotted into a Pile Movement chart and Moments chart

Table1

Calculation of Pile Movemen, Moment and the force acting on the pile

Z(m)	Z/L	Psm/d	p/d	P(t/m)	m/py.L3	M (tm)	Q(ton)
0	0	0.45	0.2	0.24	0	0	0
0.5	0.0625	0.45	0.23	0.276	-0.0001	-.4608	-.9216
1	0.125	0.45	0.26	-.312	-0.0002	-0.9216	-.9216
1.5	0.1875	0.45	0.3	0.36	-0.0004	-1.8432	-1.8432
2	0.25	0.45	0.33	0.396	-.0007	-3.2256	-2.7648
2.5	0.3125	0.45	0.35	0.42	-0.001	-4.608	-2.7648
3	0.375	0.45	0.36	0.432	-0.00115	-5.2992	-1.3824
3.5	0.4375	0.45	0.33	0.396	-0.0012	-5.5296	-0.4608
4	0.5	0.45	0.32	0.384	-0.001	-4.608	1.8432
4.5	0.5625	0.45	0.3	0.36	-.0009-	4.1472	0.9216
5	0.625	0.45	0.27	0.324	-0.0007	-3.2256	1.8432
5.5	0.6875	0.45	0.25	0.3	-0.0006	-2.7648	0.9216
6	0.75	0.45	0.23	0.276	-0.0004	-1.8432	1.8432
6.5	0.8125	0.45	0.2	0.24	-0.0003	-1.3824	0.9216
7	0.875	0.45	0.18	0.216	-0.00025	-1.152	0.4608
7.5	0.9375	0.45	0.13	0.156	0.00018	-0.8294	0.64512
8	1	0.45	0	0	0	0	1.65888

At a depth of z = 1 m, the following calculation results are obtained:

$\frac{M}{py.L^3}$ = - 0.0002

To get the py value, then look at table 2.

Table2

Relationship between K1 and Cu

Consistency	Unaltered shear strength, Cu (kg/cm2)	Range.K1 (kg/cm2)
Firm	1.0 – 2.0	1.8 – 3.8
Very Firm	2.0 – 4.0	3.6 – 7.2
Hard	4.0	7.2

Because the consistency of the soil in Pangalengan is firm, Cu = 1 kg/cm^2

py = 9 . cu
py = 9 . 1 kg/cm^2
py = 9 kg/cm^2

To get the moment value, then:

M = -0.0002 x py . L^3
M = -0.0002 x 9 . 8^3
M = -0.9216 tm

After the moment value on the pile is plotted into a graph, then find the force acting on the pile using the graph using the following formula:

Q = Mx/Δx

Divided into segments every 0.5 meter depth. Here is an example calculation:

$$Q = \frac{\Delta Mx}{\Delta x} = \frac{M2 - M1}{0.5} = \frac{-0.4608 - 0}{0.5} = -0.9216\ ton$$

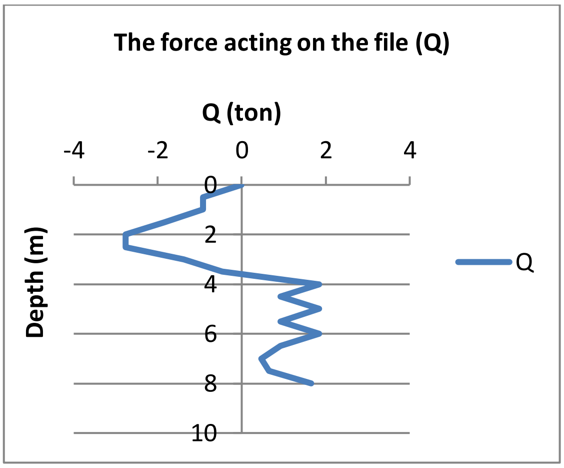

Figure 9. Force acting on the pile

After calculating the force acting on the pile at a depth of 0.5 meters, the area and height of the segment can be calculated.

Table3

The results of the calculation of the area and center of gravity of the segment.

Segmen	P (t/m)	Y (m)	Segmen	P (t/m)	Y (m)
1	0.23	0.167	10	0.426	0.222
2	0.46	0.25	11	0.426	0.222
3	0.69	0.22	12	0.426	0.222
4	1.152	1.27	13	0.426	0.222
5	1.38	0.25	14	0.426	0.222
6	q.036	0.44	15	0.106	0.222
7	0.46	0.21	16	0.074	0.236
8	0.023	0.033	17	0.575	0.873
9	0.368	0.13			

After getting the force and center of gravity at each depth from the calculation (then the following values are obtained:

$P_A = P1 + P2 + P3 + P4 + P5 + P6 + P7 + P8$

$= 0.23 + 0.46 + 0.69 + 1.152 + 1.38 + 1.036 + 0.5 + 0,023 = 5,471$ Ton

$P_B = P9 + P10 + P11 + P12 + P13 + P14 + P15 + P16 + P17 = 0.368 + 0.42 + 0.42 + 0.42 + 0.42 + 0.42 + 0.106 + 0.074 + 0.57 = 3.223$ Ton

After getting the total force, the lateral load acting on the pile head can be obtained. $H = \Sigma P = P_A - P_B = 5.471$ Ton $- 3.223$ Ton $= 2.248$ Ton

Then find the total center of gravity of each segment, the equation is as follows:

$Y_A = 0.1667 + 0.2 + 0.222 + 1.265 + 0.25 + 0.44 + 0.208 + .033 = 2,78$ m

$Y_B = 0.133 + 0.222 + 0.222 + 0.222 + 0.222 + 0.222 + 0.222 + 0.236 + 0.873 = 2.564$ m

After getting the total value of the force, lateral load acting on the head of the pile, and the total center of gravity in each segment, the center of gravity can be obtained as follows: $H_A\ \bar{y}_A = \Sigma P_A Y_A$

$2.248\ \bar{y}_A = 5.471 \times 2.78$

$\bar{y}_A = 6.765$ m

$H_B\ \bar{y}_B = \Sigma P_B Y_B$

$2.248\ \bar{y}_B = 3.22 \times 2.56$

$\bar{y}_B = 3.66$ m

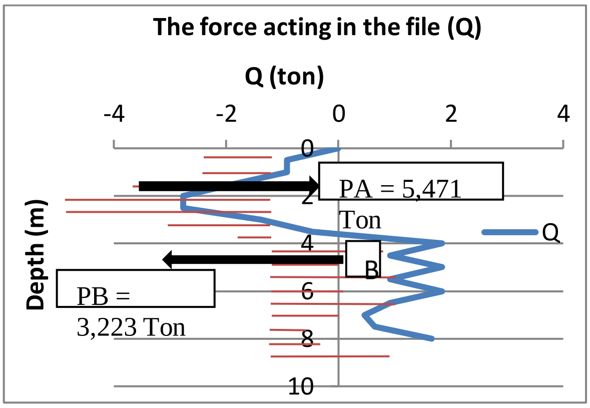

Figure **10.** The location of the force acting on the pile

Figure 10 shows that a coupling moment of 3,223 tons is formed. Then the coupling moment is multiplied by so that the equation is as follows:

$M = 3.223$ ton $\times\ \delta$

$= 3.223$ ton $\times 3.105 = 9.998$ ton m

There is a moment remaining which is 2.25 tons then multiplied by . Here's the equation:

$\Delta M = 2.25 \times \delta = 2.25 \times 6.765$

$= 15.22$ ton meters

So that the total moment is obtained, i.e.,

$M + M = 9.998 + 15.22 = 30.44$ T m

In normal consolidated soft clays and coarse-grained soils, the value of the subgrade modulus generally increases linearly with depth, so another criterion is used, namely the T factor as follows: $T = \sqrt[5]{\frac{Ep\ .\ Ip}{\eta h}}$ (in units of length)

where :

T = Stiffness Factor

Ep = Modulus of elasticity of pile (ton/m2)

Ip = Moment of Inertia of Pile (m4)

H = The constant of the soil subgrade modulus
or the constant of horizontal subgrade reaction.

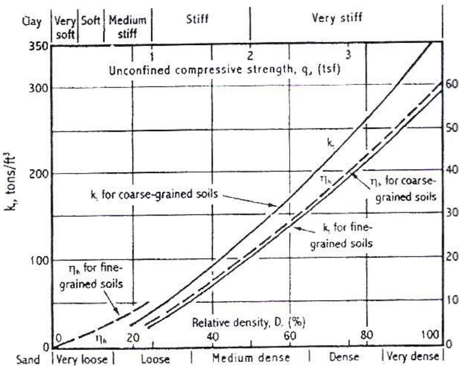

Figure 11. h is obtained from the graph.

From Figure 11. we get the value of h = 50 tons/ft3. The unit h is converted to tons/m3, the following is the calculation

1 ft = 0.305 m

ηh = 50 tons/ft^3 = 163.93 ton/m^3

Ep = 4700 $\sqrt{fc'}$ = 4700 $\sqrt{25}$ = 23500 Mpa

Ip = $\frac{1}{64}$ π D^4 = $\frac{1}{64}$ π (1,2 m)^4 = 0.1017 m^4

So that the value of the stiffness factor can be obtained, namely:T = $\sqrt[5]{\frac{Ep\,.\,Ip}{\eta h}}$

$$T = \sqrt[5]{\frac{23500\,.\,0{,}1017}{163.93}}$$

T = 1.709 m

The criteria for short or long piles are determined based on the calculated R or T values as shown in Table 4.

Table4

.

Criteria for Types of Pole Behavior

Behavior Type	Criteria	
Short (Stiff)	L≤ 2 T	L ≤ 2 R
Length (Elastic)	L ≥ 4 T	L ≥ 3.5 R

After getting the value of T, then look for the type of behavior of the pole, namely:

Short (Stiff) = L ≤ 2 . T
= 27 ≤ 2 . (1,709)
= 27 ≤ 3,418....... (Tidak oke)

Length (Elastic) = L ≥ 4.T
= 27 ≥ 4 . (1,709)
= 27 ≥ 6,836......(Oke)

After getting the type of pile behavior, then determine the Reese & Matlock method for the free head of the pile. Then incorporated into the equations of deflection, slope, moment, shear force, and soil reaction. Here are the similarities:

$$Y_x = Y_A + Y_B$$

$$= A_y\,.\,\frac{H\,.\,T^3}{E_P\,.\,I_P} + B_y\,.\,\frac{M\,.\,T^2}{E_P\,.\,I_P}$$

$$S_x = S_A + S_B$$

$$= A_S\,.\,\frac{H\,.\,T^2}{E_P\,.\,I_P} + B_S\,.\,\frac{M\,.\,T}{E_P\,.\,I_P}$$

$$M_x = M_A + M_B$$
$$= A_m \cdot H \cdot T + B_m \cdot M$$
$$V_x = V_A + V_B$$
$$= A_v \cdot H + B_v \cdot \frac{M}{T}$$
$$P_x = P_A + P_B$$
$$= A_p \cdot \frac{H}{T} + B_p \cdot \frac{M}{T^2}$$

After entering into the above equations, the maximum value of Deflection, Slope, Moment, Shear Force and Soil Reaction is obtained. Here are the results obtained:

Deflection = 0.00074 m

Slope = -0.00044

Moment = 31.337 tons m

Shear force = 2.248 ton/m

Soil reaction = 2.951

Used The moment capacity of concrete quality fc' = 25 MPa is permit = 300 kg/cm^2.

The allowable stress is converted to:

σ permit = 300 kg/cm^2 = 3000 ton/m^2

After knowing the allowable stress on the concrete quality fc' = 25 MPa, it can be checked whether the bore pile foundation can withstand the maximum moment or not. Here's the calculation:

$$\sigma_{momen\ maks} = \frac{M\ maks\ .\ R}{I} = \frac{31{,}337\ .\ 0{,}6}{0{,}10178} = 184{,}73 \text{ ton/m}^2$$

So,

σ maximum moment < σ permit

183,73 ton/m^2 < 3000 ton/m^2 ......(okay)

From these results, the stress on the bore pile foundation is safe to withstand the maximum moment so that the bore pile foundation does not break or collapse.

Inclinometer Data Analysis on Borpile

From the results of the regression every 3 meters depth, it can be analyzed using the Poulos method. The following calculation results can be seen in table 5.

Table5

Calculation results from WW-08 . inclinometer data

Z	A (m)	Slop (%)	Momen (tm)	Geser (t/m)
30.5	-0.0001			
27.5	0.00012	6.78208E-05	19.988388278	
24.5	0.00029	0.000100438	-71.97491358	-0.087164438
21.5	0.00072	0.000134367	17.89643628	9.95356995
18.5	0.00109	1.84175E-05	166.9107663	-4.703946472
15.5	0.00083	-2.67008E-05	-94.99827906	-11,21432749
12.5	0.00093	9.70433E-05	-102.1330934	0.006253702
9,6	0.00142	0.000220693	-94.8481902	-1.263469275
6.5	0.00226	0.000363368	-123.556356	5.415927735
3,5	0.0036	0.000424492	35,13407544	
0.5	0.0048			

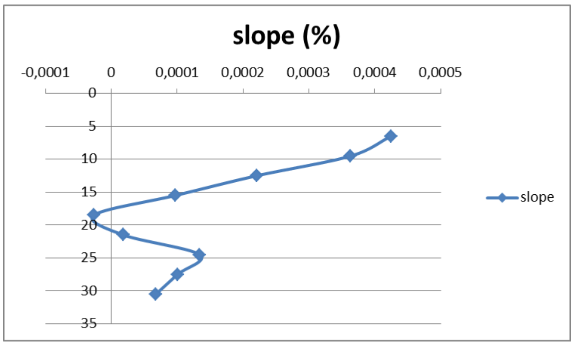

Figure 12. Slope Graph

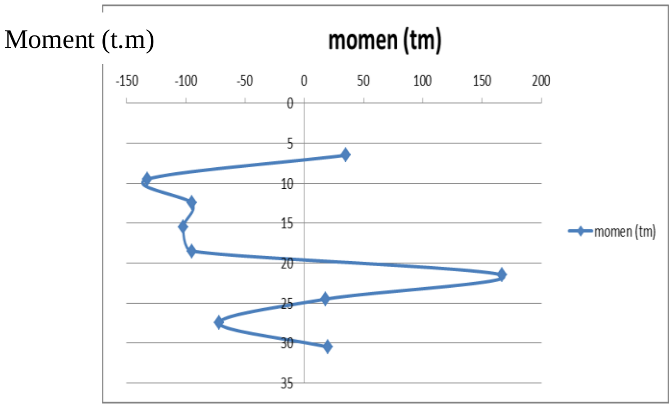

Figure 13. Moment Graph

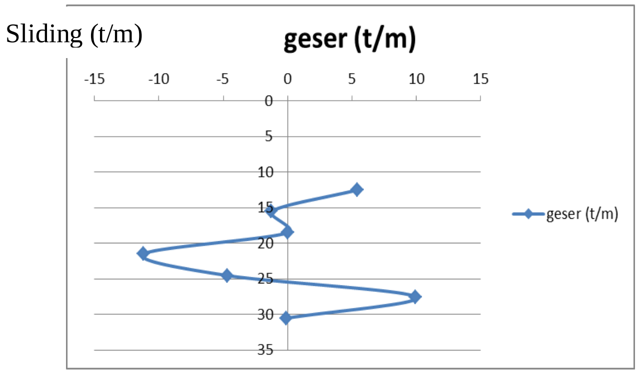

Figure 14. Sliding Style Graph

From the graph of the slope, moment and shear force, the maximum value can be obtained, following the calculation results:

Maximum Slope = 0.00042

Maximum Moment= 166.91 Ton m

Maximum Shear Force = 9.95 Ton/m

The moment capacity of concrete quality fc' = 25 MPa is permit = 300 kg/cm^2.

The allowable stress is converted to:

permit = 300 kg/cm^2 = 3000 ton/m^2

After knowing the allowable stress on the concrete quality fc' = 25 MPa, it can be checked whether the bore pile foundation can withstand the maximum moment or not. Here's the calculation:

$$\sigma_{\text{max moment}} = \frac{M\ maks\ .\ Y}{I} = \frac{166{,}91\ x\ 0{,}6}{0.10178} = 983.945\ \text{ton/m}^2$$

So

$$\sigma_{\text{max moment}} < \sigma_{\text{permit}}$$

$$983.945\ \text{ton/m}^2 < 3000\ \text{ton/m}^2 \text{......(okay)}$$

From these results, the stress on the bore pile foundation is safe to withstand the maximum moment so that the bore pile foundation does not break or collapse.

Conclusions

Intended to obtain an overview of the behavior of piles with a pile diameter of 1.2 m and an immersion length of 8 m due to a soil mass movement of 0.45 x pile diameter, using the Poulos and Davis (1997) method and the Reese & Matlock method where the results can be described. as follows:

- Assuming Poulos, the position of the ends of the piles is hinged, consequently the end points do not move and the entire length of the pile is flexed.
- From the results of the analysis using the Reese & Matlock method, the maximum values obtained are as follows:

Deflection = 0.00074 m
Slope = -0.00044
Moment = 31.337 tons m
Shear force = 2.248 ton/m
Soil reaction = 2.951

From these results, it can be obtained the maximum moment value to be entered into the stress formula and then compared with the allowable stress fc' = 25 mpa. Then the following results are obtained:

maximum moment < permission

183.73 ton/m^2 < 3000 ton/m^2 ......(okay)

So, from these results, the stress on the bore pile foundation is safe to withstand the maximum moment so that the bore pile foundation does not break or collapse.

- From the results of the analysis using the Poulos method, the maximum values obtained are as follows:

Maximum Slope = 0.00042
Maximum Moment= 166.91 Ton m
Maximum Shear Force = 9.95 Ton/m

From these results, it can be obtained the maximum moment value to be entered into the stress formula and then compared with the allowable stress fc' = 25 mpa. Then the following results are obtained:

maximum moment < permission

983.945 ton/m^2 < 3000 ton/m^2 ......(okay)

So, from these results, the stress on the bore pile foundation is safe to withstand the maximum moment so that the bore pile foundation does not break or collapse.

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