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FINDING THE OPTIMAL REINFORCEMENT FOR VERY DEEP BORED PILE FOUNDATION

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ABSTRACT

The foundation is the most important part of any structure in the construction process. A failure in the foundation can cause the entire structure to fail if cannot withstand the forces or weight of the structure above. The foundation is required to bear the external loads or weight of the structure, even though the upper structure may be strong and sturdy. Bored pile foundation is the most commonly used foundation type for building projects or multi-story structures. The distribution of forces on pile foundations is inversely proportional to its depth, and the part of the pile close to the forces will bear a greater load than the deeper part of the pile. This consideration makes the design of reinforcement for pile foundations variable according to the distribution of forces acting on the pile according to its depth. This study analyzes the reinforcement requirements for a pile foundation using laboratory-calculated soil parameters and data specific to the Jakarta area. The first step is to determine the soil parameters, then calculate the force diagram using the Matlock and Reese method, and finally, determine the reinforcement requirements based on the force diagram obtained. After that, the calculated reinforcement needs to be adjusted according to the applicable requirements for a pile with a length of 65 meters and a diameter of 1800 mm. The required reinforcement is D13-75 for transverse reinforcement, 20D32, 16D29, and 8D32 for longitudinal reinforcement according to their depth.

Keywords: *bored pile, foundation, distribution of forces, Matlock and Reese method*

1. PREFACE

Introduction

The main function of a foundation in the construction of a structure is to support the load above it. Good and careful design is necessary in designing the foundation, because failure in the foundation can result in overall structural failure, as the foundation cannot hold the load above it or the weight of the structure itself. There are two types of foundation: deep foundation and shallow foundation. Deep foundation generally requires reinforcement, which can be optimally planned through force diagrams that occur along the column. By considering the force diagrams, optimal reinforcement can be planned for the deep foundation structure.

Problem Formulation

This study analyzes the reinforcement of drilled pile foundation using force diagrams that contain deflection, slope, moment, shear, and soil reaction components. These components can be used to determine the optimal amount, location, and length of reinforcement, resulting in the most optimal reinforcement design that can be used to determine the design of the pile foundation reinforcement. Consideration is also given to the calculation or analysis results in accordance with applicable regulations regarding reinforcement.

Force Diagram

The method used to determine the force diagram is the elastic method proposed by Matlock and Reese.

The formula for the moment diagram that occurs along the pile is as follows:

$$M_z(z)=A_m Q_g R+B_m M_g$$

The formula for the lateral diagram that occurs along the pile is as follows:

$$V_z(z)=A_v Q_g R+\frac{B_v M_g}{R}$$

A_m, B_m, A_v, and B_v are coefficients that can be found in Table 1 and Table 2. Q_g is the lateral load and M_g is the moment load.

Table 1. Coefficient of A_m, B_m, A_v, and B_v. (Das, 2017)

Z	A_m	B_m	A_v	B_v
0,0	0,000	1,000	1,000	0,000
0,1	0,100	1,000	0,989	-0,007
0,2	0,198	0,999	0,956	-0,028
0,3	0,291	0,994	0,906	-0,058
0,4	0,379	0,987	0,840	-0,095
0,5	0,459	0,976	0,764	-0,137
0,6	0,532	0,960	0,677	-0,181
0,7	0,595	0,939	0,585	-0,226
0,8	0,649	0,914	0,489	-0,270
0,9	0,693	0,885	0,392	-0,312

Table 2. Coefficient of A_m, B_m, A_v, and B_v. (Continuation of Table 1)

Z	A_m	B_m	A_v	B_v
1,0	0,727	0,852	0,295	-0,350
1,2	0,767	0,775	0,109	-0,414
1,4	0,772	0,688	-0,056	-0,456
1,6	0,746	0,594	-0,193	-0,477
1,8	0,696	0,498	-0,298	-0,476
2,0	0,628	0,404	-0,371	-0.456
3,0	0,225	0,059	-0,349	-0,213
4,0	0,000	-0,042	-0,106	0,017
5,0	-0,033	-0,026	0,015	0,029

To obtain the value of Z in Table 1 and Table 2, the following formula can be used:

$$Z=\frac{z}{R}$$

Where z is for the characteristic depth and the length of the column (R) can be obtained through the following formula:

$$R=\sqrt[4]{\frac{E_p I_p}{k B}}$$

B is the diameter of the column, k is for the modulus of subgrade reaction, and the value of the concrete modulus of elasticity (E_p) can be found using the equation:

$$E_p=4700\sqrt{fc'}$$

The value of the inertia (I_p) can be obtained using the following formula:

$$I_p=\frac{1}{64}\pi D^4$$

D is for the diameter of the column, and the value of the modulus of subgrade reaction (k) can be found using the equation:

$$k_s^{'}=\frac{22{,}4\,E_s\,(1-\mu)}{(1+\mu)(3-4\mu)[2\ln(2L_p/B)-0{,}433]}$$

After obtaining the value of $k_s^{'}$, conversion is needed to obtain the value of k as follows:

$$k=\frac{k_s^{'}}{B}$$

E_s is the secant modulus of 650 N (Yoshida and Yoshinaka, 1972), μ is the Poisson's ratio, and L_p is the length of the pile.

2. RESEARCH METHOD

The research process can be divided into four stages, namely:

Literature Review

Collecting, analyzing, and exploring literature, related articles, and journals that support the research. This is done to understand and obtain the basic theories that support the research.

Data Collecting

Using soil data in the form of bore log data and laboratory test results. Then, the specifications of the bore pile data are determined, with a length of 65 m and $f_c^{'}$ of 35 MPa. The foundation load is also obtained, which is 1575 tons of vertical load and 157 tons of horizontal load.

Data Processing

Analyzing and calculating the collected data. Starting with determining the parameters to be used, followed by analysis and calculation. The Parameters that being used are soil parameter based in Jakarta area.

Analysis and Discussion

Analyzing and calculating the collected data. Starting with determining the parameters to be used, followed by analysis and calculation. The analysis and calculation is needed to find the force diagram used for calculation for reinforcement, the method used in this research is Matlock and Reese Method. After the force diagram being found out, it is also adjusted with exsisting regulation, so the final design for the reinforcement can be found out.

3. RESULT AND DISCUSSION

Soil Parameters

The bore log and laboratory data obtained are then processed by performing calculations and plotting graphs, resulting in soil parameters used for design, as shown in Table 3 and Table 4.

Table 3. Summary of Soil Parameters

Elevation (m)	Soil Type	Consistency	N-SPT	γ_{sat} (kN/m^3)	γ_{wet} (kN/m^3)	e_o	ϕ (°)
1-20	Clay	Stiff	21	19	19	1,6	30
20-40	Clay	Very Stiff	21	20	20	1,5	20
40-60	Clay	Very Stiff	30	20	20	1,2	9
60-80	Clay	Hard	35	21	21	1,1	9
80-120	Clay	Hard	30	20	20	1,1	6
120-150	Clay	Hard	40	20	20	1,2	3

Table 4. Summary of Soil Parameters (Continuation of Table 3)

Elevation (m)	S_u (kPa)	c' (kPa)	E_u (MPa)	OCR	k (cm/s)	*Poisson Ratio*	Ψ (°)
1-20	95	15	22	6	0,001	0,3	0
20-40	95	15	22	2	0,001	0,2	0
40-60	140	21	32	1,5	0,001	0,2	0
60-80	150	24	35	1	0,001	0,15	0
80-120	120	20	30	0,5	0,001	0,2	0
120-150	180	28	40	0,5	0,001	0,2	0

Settlement

Settlement is divided into two types, namely elastic settlement (immediate settlement) and consolidation settlement. The settlement for the foundation pile is then obtained from the calculations, as shown in Table 5 and Table 6.

Table 5. Elastic or Immediate Settlement

Elastic Settlement												Se Total
n Pile	Fz (kN)	Qa,s (kN)	Qp (kN)	Qs (kN)	FQp	FQs	Qwp	Qws	Ep	x	Se1 (mm)	(mm)
1	15750	11318,13	4191,105	34028,5	0,109659	0,890341	1727,121	14022,8786	27805,57498	0,67	10,21756	
							qwp	Es (kPa)	ms	Iwp	Se2 (mm)	
							678,7158	35000	0,2	0,85	28,48279	46,429
								Iws	Qws/PL	D/Es	Se3 (mm)	
								4,10324	38,15061	0,00005	7,72865	

Table 6. Consolidation Settlement

Elevation	Consolidation Settlement													Sc Total
	n Pile	Fz (kN)	Ag (m²)	Ds2 (kPa)	Po'	Po'+Ds2	Pc'	Type	Cc	Cs	e_0	H (m)	Sc (mm)	(mm)
I (40 - 60 m)	1	15750	908,0178	17,34548	685,7	703,0455	720	*OVER CONSOLIDATED*	0,8	0,18105	1,2	20	17,85691	
II (60 - 80 m)	1	15750	2513,351	6,266534	899,5	905,7665	800	*NORMALLY CONSOLIDATED*	1	0,16605	1,1	20	28,71526	62,05179
III (80 - 120 m)	1	15750	6421,351	2,452755	1215,2	1217,653	600	*NORMALLY CONSOLIDATED*	0,7	0,16605	1,1	40	11,67593	
IV (120 - 150 m)	1	15750	13255,68	1,18817	1571,85	1573,038	800	*NORMALLY CONSOLIDATED*	0,85	0,18105	1,2	30	3,803689	

Based on the results obtained from Table 5 and Table 6, the total settlement value is known to be 108,48 mm. And based on calcultation it is found that the allowable settlement is 25.44 mm. Therefore, it can be concluded that the total settlement exceeds the allowable settlement.

Force Diagram

Based on the analysis and calculations carried out using the Matlock and Reese elastic method, the calculation results for lateral internal forces and moments are obtained as shown in Table 7 and Table 8. Calculations are performed for every 1 m depth to obtain accurate calculation results at each depth, resulting in a more accurate and detailed internal force diagram.

Tabel 7. Value of Moment and Shear Force per 1 m

Elevation (m)	R (m)	Z	Am	Av	moment (kNm)	Shear (kN)
0	3,48	0,00	0,00	1,00	0	1575
1	3,48	0,29	0,28	0,91	1530,436	1436,611
2	5,56	0,36	0,34	0,87	3008,4	1364,818
3	6,34	0,47	0,44	0,79	4369,57	1247,278
4	6,11	0,65	0,57	0,63	5451,316	987,281
5	5,92	0,84	0,67	0,45	6236,46	703,0849
6	6,10	0,98	0,72	0,31	6929,473	489,0112
7	7,92	0,88	0,69	0,41	8555,192	641,8772
8	7,09	1,13	0,75	0,18	8407,256	277,2924
9	5,56	1,53	0,76	-0,14	6609,079	-228,067
10	5,60	1,61	0,74	-0,20	6556,002	-310,93
11	4,11	2,43	0,45	-0,36	2946,053	-569,415
12	4,16	2,65	0,37	-0,36	2410,766	-561,975
13	4,21	2,73	0,33	-0,35	2200,594	-558,89
14	4,25	2,83	0,30	-0,35	1975,616	-555,723
15	4,31	3,02	0,22	-0,34	1495,563	-542,137
16	5,44	2,58	0,40	-0,36	3390,132	-564,378
17	5,16	2,91	0,26	-0,35	2137,176	-552,932
18	4,84	3,31	0,16	-0,27	1190,406	-432,589
19	4,76	3,57	0,10	-0,21	717,2712	-329,829
20	5,46	3,30	0,16	-0,28	1359,352	-435,883
21	6,04	3,15	0,19	-0,31	1829,536	-494,049
22	6,07	3,30	0,16	-0,28	1513,654	-436,362
23	5,89	3,56	0,10	-0,21	911,8432	-334,054
24	5,45	4,04	0,00	-0,10	-11,1984	-159,411
25	5,53	4,16	-0,01	-0,09	-45,6802	-136,663
26	5,49	4,38	-0,01	-0,06	-106,972	-95,4463
27	5,44	4,59	-0,02	-0,03	-167,816	-53,8969
28	5,73	4,54	-0,02	-0,04	-160,705	-64,0602
29	5,82	4,64	-0,02	-0,03	-192,875	-45,4842
30	5,92	4,73	-0,02	-0,02	-223,938	-28,3165
31	5,85	4,95	-0,03	0,01	-290,091	14,7286
32	5,72	5,25	-0,03	0,02	-297,154	23,625
33	5,42	5,72	-0,03	0,02	-264,654	23,625
34	6,17	5,18	-0,03	0,02	-281,974	23,625
35	6,00	5,50	-0,03	0,02	-255,022	23,625

Tabel 8. Value of Moment and Shear Force per 1 m (Continuation of Table 6)

Elevation (m)	R (m)	Z	Am	Av	moment (kNm)	Shear (kN)
36	5,92	5,74	-0,025	0,015	-233,2925	23,625
37	5,65	6,20	-0,023	0,015	-204,559	23,625
38	5,46	6,60	-0,021	0,015	-180,5341	23,625
39	4,93	7,51	-0,019	0,015	-147,3961	23,625
40	4,81	7,90	-0,017	0,015	-128,8662	23,625
41	5,24	7,44	-0,015	0,015	-123,9111	23,625
42	5,58	7,17	-0,013	0,015	-114,2134	23,625
43	5,28	7,76	-0,011	0,015	-91,55572	23,625
44	4,94	8,40	-0,009	0,015	-69,99489	23,625
45	4,80	8,75	-0,007	0,015	-52,90453	23,625
46	4,68	9,19	-0,005	0,015	-36,86614	23,625
47	5,08	8,57	-0,003	0,015	-23,99633	23,625
48	5,41	8,13	-0,001	0,015	-8,524089	23,625
49	5,32	8,46	0,001	0,015	8,376504	23,625
50	5,28	8,71	0,001	0,015	8,320444	23,625
51	5,45	8,62	0,001	0,015	8,590459	23,625
52	5,57	8,62	0,001	0,015	8,769643	23,625
53	5,78	8,48	0,001	0,015	9,103554	23,625
54	5,36	9,34	0,001	0,015	8,435581	23,625
55	5,34	9,46	0,001	0,015	8,407036	23,625
56	5,59	9,12	0,001	0,015	8,804781	23,625
57	5,67	9,08	0,001	0,015	8,936831	23,625
58	5,68	9,16	0,001	0,015	8,942462	23,625
59	5,68	9,32	0,001	0,015	8,953531	23,625
60	5,63	9,58	0,001	0,015	8,873332	23,625
61	5,62	9,79	0,001	0,015	8,847964	23,625
62	5,33	10,51	0,001	0,015	8,394385	23,625
63	5,38	10,60	0,001	0,015	8,473032	23,625
64	5,39	10,77	0,001	0,015	8,482386	23,625
65	5,08	11,61	0,001	0,015	8,004263	23,625

After obtaining the values of shear and moment for every depth of 1 meter, the maximum moment and shear at each depth of 12 meters are determined, as the reinforcement for pile is varied every 12 meters, as shown in Table 9. The resulted calculation can also be translated to digram plotting as show in Figure 1 and Figure 2.

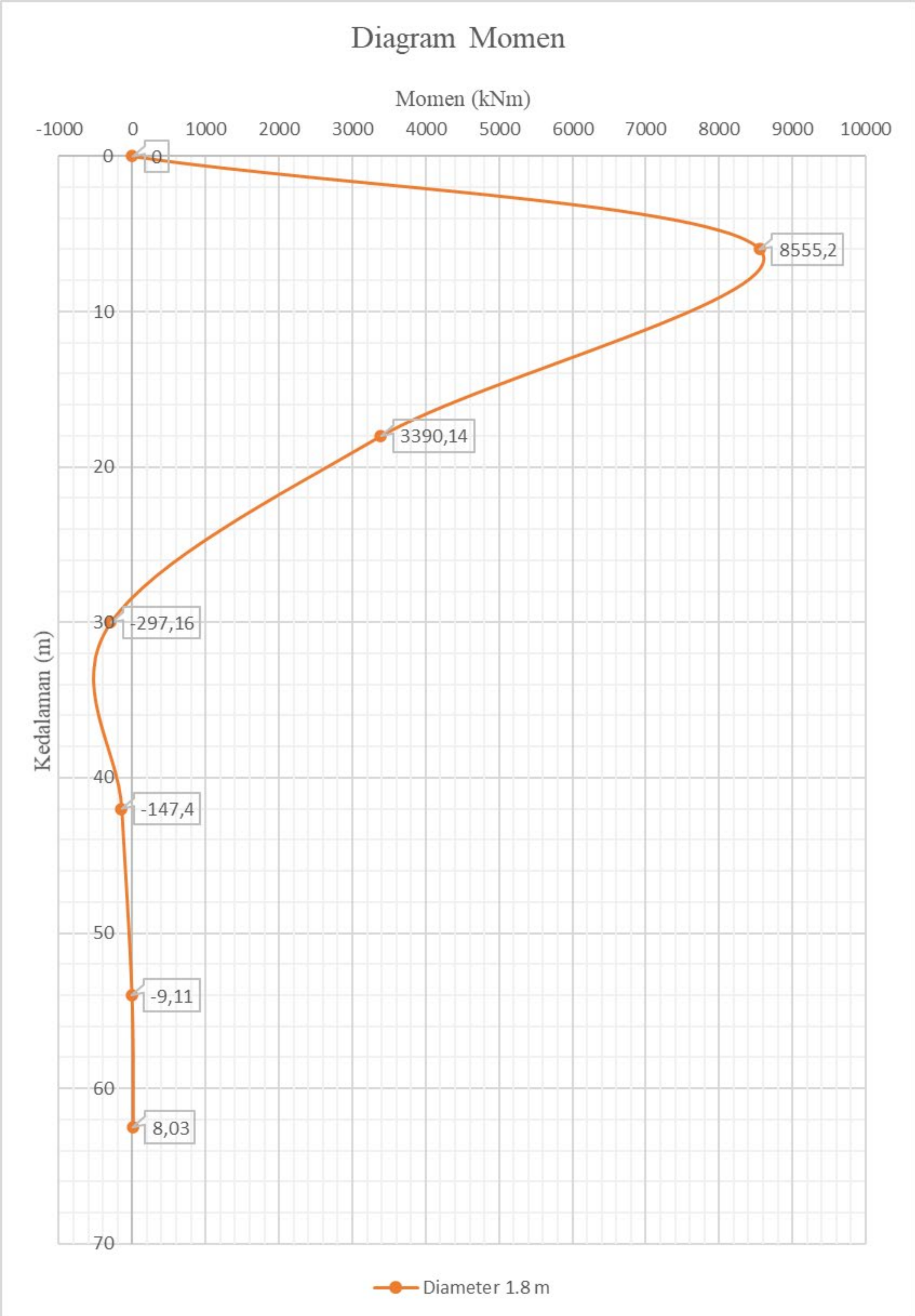

Figure 1. Plotting of Moment Diagram

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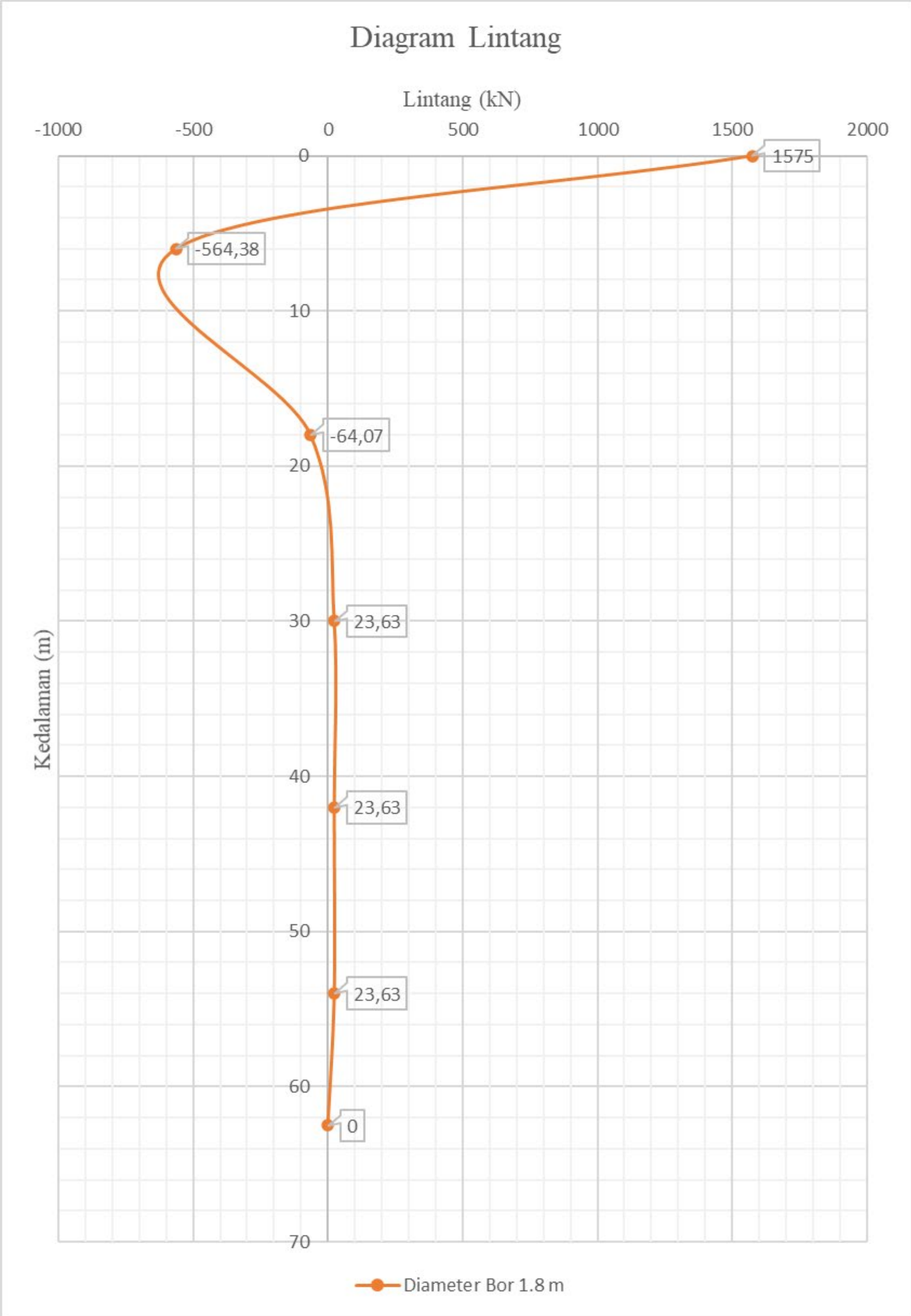

Figure 2. Plotting of Shear Force Diagram

As shown in Figure 1 and Figure 2, after the calculations and results are obtained, the moment diagram and shear force diagram can be plotted to illustrate the forces acting on the pile. Both of these figures can show the distribution of reinforcement sections and indicate at what depth the largest moment or shear force occurs. From both of these figures, it was found that in accordance with the theory described earlier, the top section of the pile experiences the greatest force and it decreases as the pile gets deeper.

Tabel 9. Maximum Moment and Shear Force per 12 m

Depth (m)	Moment (kN.m)	Shear (kN)
0 – 12 m	8555,1916	1575
12 – 24 m	3390,1315	-564,3778
24 – 36 m	-297,1539	-64,0602
36 – 48 m	-147,3961	23,625
48 – 60 m	-9,103554	23,625
60 – 65 m	8,021029	23,625

It can be seen from Table 9 that the largest moment and shear force occur at a depth of 0-12 m, after obtaining the moment and shear force results, the calculation of the required reinforcement is then carried out.

Reinforcemen Design

After obtaining the internal forces of moment and shear, the design for the reinforcement of the foundation pile can be carried out. After the calculation is done, corrections and comparisons with the applicable regulations are also necessary, so that the final design that is most optimal for use in the construction process can be obtained as shown in Table 10.

Table 10. Summary of Reinforcement Based on Calculation and Regulation

Depth (m)	Diameter (m)	Requirement		Regulations	
		Longitudinal	Transverse	Longitudinal	Transverse
0 – 12 m	1,8	20D32	D13 - 75	20D32	D13 - 75
12 – 24 m	1,8	16D29	D13 - 300	16D29	D13 - 75
24 – 36 m	1,8	4D25	D13 - 300	8D32	D13 - 75
36 – 48 m	1,8	4D25	D13 - 300	8D32	D13 - 75
48 – 60 m	1,8	4D13	D13 - 300	8D32	D13 - 75
60 – 65 m	1,8	4D13	D13 - 300	8D32	D13 - 75

4. CONCLUSIONS AND RECOMMENDATIONS

Based on the calculation and analysis results obtained in this study, the following conclusions and recommendations can be drawn.

Conclusion

- Used pile foundation with a diameter specification of 1800 mm and a pile length of 65 m.
- The total settlement obtained is 108.48 mm, which exceeds the allowable settlement of 25.44 mm.

- Based on the calculation results, the largest moment that occurs is 8555.191 kNm and the largest lateral force that occurs is 1575 kN.
- Based on the analysis and calculation results, the longitudinal reinforcement variations used (and adjusted to applicable regulations) are 20D32 for depths of 0-12 m, 16D29 for depths of 12-24 m, and 8D32 for depths of 24-65 m. Meanwhile, the variation of transverse reinforcement is D13-75.

Recommendations

- When searching for force diagrams, it is recommended to use programming applications because manual calculations using the elastic method require varying parameters and may result in less accurate analysis.
- Based on the calculation results, it is found that the total settlement exceeds the allowable settlement. A solution or recommendation that can be applied is to add pile length until reaching a depth with a hard layer (N-SPT >60).

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