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Lateral Deflection of Single Pile Caused by Lateral Loads in Clay Soils

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Abstract. The foundation functions to hold the axial load, lateral load and moment. The axial load on the pile foundation is supported by the pole end resistance and pile friction. In addition, the lateral load on the pile foundation is supported by the relation of the blanket area along with the pile with the ground in the lateral direction. Lateral load causes lateral deflection in which the deflection value must not exceed the permissible lateral deflection limit of 2.54 cm. The determining factors in lateral deflection are the type of pile foundation, soil type, and the acting force that occurs. The foundation of a single pile in which the number of one pile, when embedded in clay soil, must be investigated for the value of lateral deflection, because of the changing nature of the clay under the influence of high or low water content. The foundation of the pile uses a concrete head with a condition of a free end with a cylindrical shape with a diameter of 60 cm that is not solid with a wall thickness of 10 cm and a compressive strength of concrete of 60 MPa. Clay soil data uses soil drilling test data in Wirosari, Grobogan, Central Java. The planning method in this study is the finite element method (PLAXIS program) and the finite difference method (py curve and the ALLPILE program) with lateral load variations of 10 kN, 15 kN and 20 kN given to the top end of the pole with the principle of giving trial and error loads. The results of the calculation of the lateral deflection of the pile on the py curve method with a finite-difference resolution, the ALLPILE program, and the PLAXIS program respectively with a lateral load of 10 kN are 0.0629 cm; 1.21 cm; 0.27 cm, lateral loads of 15 kN are 0.0943 cm; 2.13 cm; 0.4051 cm, and a lateral load of 20 kN is 0.1258 cm; 3.14 cm; 0.5402 cm. Therefore, the lateral deflection load limit is 15 kN, as not to exceed the permissible lateral deflection limit of 2.54 cm.

Keywords. Lateral deflection, p-y curve using finite-difference solution, ALLPILE V7.3B, PLAXIS version 8.6

INTRODUCTION

The foundation is a part of the building that functions to distribute the building load to the ground. Based on the level of depth and width, the foundation is classified as a shallow foundation and a deep foundation. One of the examples of a deep foundation is a pile foundation, a pile foundation is a type of deep foundation that will receive relatively large building loads.

The loads on the building received by the foundation consist of axial load, lateral load, and moment. Axial loads are divided into tensile and compressive load. The situation in which the forces acting parallel on the axis of the pole is the axial load. In addition to axial loads, the foundation withstands lateral loads. The condition when the forces acting perpendicular to the pile axis from the pile foundation is called lateral load.

The foundation structure has to do with determining lateral carrying capacity and lateral load, lateral deflection and soil characteristics. Lateral loads are generally caused by winds, earthquakes, ship berths, vehicle acceleration, braking on bridges and so on related to forces that cause lateral loads. Therefore, determining the lateral load capacity of the pile foundation is one of the important things in foundation engineering. Lateral load capacity that occurs cannot exceed the permit requirements for lateral deflection of 1 inch or 2.54 cm.

The determining factors for the installation of the pile foundation in holding lateral loads are the characteristics of the pile foundation, the type of soil around the pile foundation, and the amount of force that occurs on the pile. The characteristics of the pile foundation must be in accordance with the amount of load received by the foundation. Therefore, there is no lateral deflection that exceeds the permitted lateral deflection limit.

Clay soil has varying properties when affected by high or low water levels. With regard to water content, clay soil has low permeability. Therefore, its consolidation is slow, very hard in dry conditions, plastic when water content is moderate, cohesive when water content is high, shear strength decreases when water content is high, shrink-swell capacity is high, and can to be both expansive and non-expansive conditions. Because of these properties, an analysis is needed to determine the lateral deflection of the pole.

The method used in this analysis is the finite element method (PLAXIS) and the finite difference method (py curve and the ALLPILE program). The difference between the three methods lies in the condition on the hard soil. The PLAXIS program permits movement at the lower end. Therefore, it can be called a rolling pedestal. In addition, the py and ALLPILE curve method does not allow movement at the lower pedestal, so it can be called a pins tool.

Pole foundations in Clay Soils

Foundations and soil characteristics affect each other, in general, soil conditions that are often found in the field are clay or cohesive and sand or granular soils.

The clay soil consists mostly of microscopic and submicroscopic particles (the particles cannot be seen clearly only with ordinary microscope) in the form of slabs (clay minerals), and other very fine minerals. Clay is very hard in dry conditions and is plastic at moderate moisture levels [2].

The foundation functions so that it does not experience structural failure, it must be placed on a layer of soil that is hard or dense enough to support building loads without excessive deterioration and to find out the location or depth of the solid soil layer with a large carrying capacity, a soil investigation is needed. Building foundations are usually distinguished as shallow foundations and deep foundations, depending on the ratio of foundation depth to foundation width [3].

The condition of the pile foundation when it is in clay soils allows strong friction pile so that in general it causes strength to the pile foundation. For certain conditions, the shift and decline in the foundation can last for a long time. In the process of work, the pile foundation is placed in hard soil conditions according to the depth required depending on the load received by the foundation. The foundation load that exceeds the capacity of the pile foundation can cause a shift and collapse in the building above it [4].

Lateral Load

Lateral load can work on pile foundations due to earthquake forces, wind forces on the upper structure, wave pressure and other horizontal forces. The permissible lateral load on the pile foundation is obtained based on one of two criteria as follows [5]:

1. The lateral load of the permit is determined by dividing the ultimate load by a safety factor;
2. The lateral load is determined based on the maximum allowable deflection.

P-Y Curve Method with Finite Difference Solution

The p-y curve method defines the relationship of lateral loads and deflection between the soil and piles represented by a curve. The p axis is the lateral resistance of the soil per unit length of the pole and the y-axis is the lateral deflection of the pole. The p-y curve at a particular point on the pole depends on [6]:

1. Soil type;
2. Load type;
3. Pole diameter and shape of the Cross-section pole;
4. The coefficient of friction between the soil and the pole;
5. Depth below ground pole group interactions.

Analysis using the p-y curve method must pay attention to changes in the p-y curve at each depth. This analysis used the assist method with finite difference method which divides the pole into n intervals. An analysis requires boundary conditions. There are two conditions that are basically known to the pole: shear force or lateral force and zero moment. The equation used in solving the p-y curve method with finite difference resolution uses the help of the Lymon C. Reese and William Van Impe equations, as follows [6]:

$$Ep.Ip\frac{d^4y}{dx^4} + Px\frac{d^2y}{dx^2} - p + W = 0 \quad (1)$$

where,

E_p = pole modulus (kN/m^2)
I_p = moment of inertia of pole (m^4)
P_x = axial load (kN)
p = reaction per soil layer (kN/m^2)
W = load evenly on pole (kN)

Reaction soils per layer p is the young's modulus accompanied by pile movement per depth ($p = E_{py.y}$). For the value of $W = 0$, the value is ignored. Therefore, there is no uniform load occurring on the embedded pile. Following are the results of the equation after identifying the soil reaction, p becomes the young's modulus, Es [6].

$$Ep.Ip\frac{d^4y}{dx^4} + Px\frac{d^2y}{dx^2} + Es.y = 0 \quad (2)$$

where,

Es = young modulus per soil layer (kN/m2)
y = lateral deflection (cm)
x = depth of the pile (m)

If the pile view is illustrated as follows:

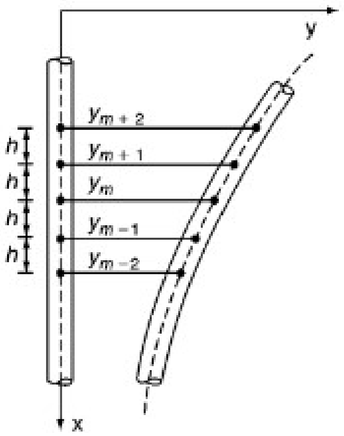

FIGURE 1. Lateral iterations and deflections that occur per depth of the pile [6]

$$(y_{m-2}.R_{m-1}) + y_{m-1}(-2R_{m-1} - 2R_m + Px.h^2) + y_m(R_{m-1} + 4R_m + R_{m-1} - 2Px.h^2 + Es_m.h^4)$$
$$+ y_{m-1}(-2R_m - 2R_{m-1} + Px.h^2) + y_{m+2}.R_{m-1} = 0 \quad (3)$$

where,

P_x = vertical load (kN)
h = length between views per pile in soil (m)
E_s = young's modulus of the soil (kN/m^2)
R_m = Flexural stiffness of the pile (kN.m^2)

The upper boundary conditions of the pile are shear forces and bending moment reactions. Then for the lower boundary conditions, there is no shear force $V0$. Determined the condition of the upper edge of the pile is the moment of bending and shear force in determining the lateral deflection of the pile.

Shear force:

$$R_t / 2h^3(y_{t-2} - 2y_{t-1} + 2y_{t+1} - y_{t+2}) + P_x / 2h (y_{t-1} - y_{t+1}) = P_t \quad (4)$$

Moment bending:

$$Rt / h^2(yt-1 - 2yt + yt + 1) = M_t \quad (5)$$

where: Rt = pile bending stiffness (kN.m2)

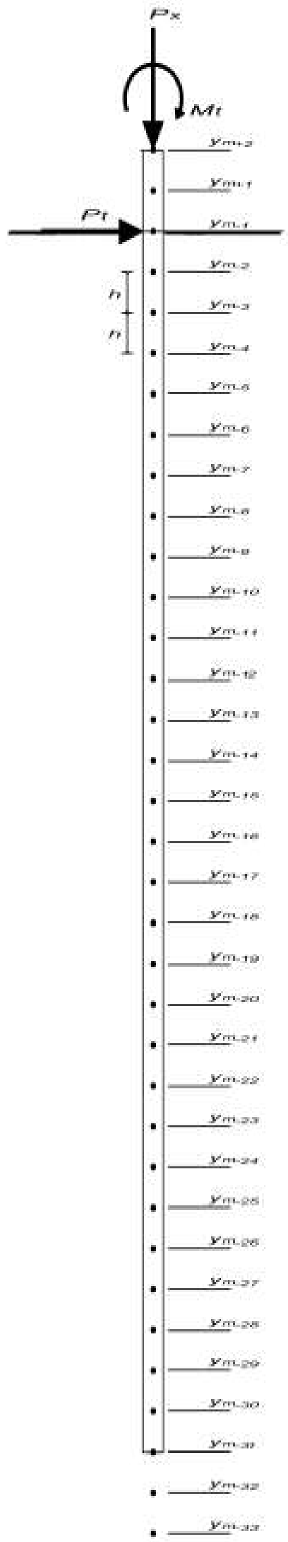

FIGURE 2. Finite difference for single piles to lateral loads

Analysis Lateral Load with the ALLPILE Program V7.3B and the PLAXIS Program version 8.6

The ALLPILE Program is a special software program for pile foundation analysis. The software is used to identify the type of pile foundation, pile foundation data, load, soil data and what types of calculations applied either in the form of vertical or lateral results. The final result expected from the ALLPILE program is knowing the amount of bearing capacity in holding the lateral load by identifying the amount of pole deflection that occurs.

The PLAXIS program is used facilitate the work other than numerical methods. PLAXIS version 8.6 is a finite element program that has been developed to analyze geotechnical deformation and stabilization in civil engineering planning, one of which is lateral load analysis of pile foundations on clay. In general, the workings for lateral pole deflection analysis from PLAXIS program version 8.6 are as follows [1]:

1. Modeling phase
   Modeling was performed by entering the soil geometry model in the form of soil coating, structural elements, construction stages, loading and other boundary conditions that can be done in detail.
2. Calculation phase
   After going through the modeling stage, the geometry entered the stage of the preparation of new elemental nets into the calculation phase. The calculation phase is the process of calculating the load on the lateral load with the type of plastic analysis calculation.
3. Output phase
   The expected is the value of the pile deflection due to given load.

RESEARCH METHODOLOGY

The data used are secondary data in the form of land investigation test data in Wirosari, Grobogan, Central Java. Based on the clay soil data, 60 cm diameter (not solid) poles are used with a wall thickness of 10 cm and the depth of the pillar goes into the ground 30 meters.. The method used is the p-y curve method with finite difference resolution, the ALLPILE program, and the PLAXIS program.

Soil Data

Soil data is secondary soil data which is clay soils from soil investigations at Wirosari, Grobogan, Central Java.

SUMMARY LABORATORIUM TEST											
No.	**Hole No.**	**Depth (m)**	**Nspt**	**Water Content**	**Unit Weight**		**Specific Gravity**	**Permeability Lab**	**Unconfined**	**Direct Shear**	
					γ Wet	**γ Dry**					
				(%)	gr/cm3	gr/cm3	Gs	cm/sec	kg/cm2	c	φ
1	**BH-1**	4.50-5.00	11-20	28.76	1.83	1.42	2.78	2.10×10^{-7}	0.470	0.366	21.58
		9.50-10.00	11-20	27.55	1.76	1.38	2.73	-	1.116	0.518	1.28
		14.50-15.00	20	40.64	1.88	1.34	2.77	2.09×10^{-7}	1.211	0.270	10.73
		19.50-20.00	26	32.81	1.74	1.31	2.73	-	0.797	0.822	10.11
		24.50-25.00	13	24.57	1.91	1.53	2.79	2.02×10^{-7}	0.588	0.372	14.97
		29.50-30.00	12 - > 60	45.07	1.61	1.11	2.80	-	0.875	0.670	12.25
		34.50-35.00	> 60	50.59	1.70	1.13	2.75	-	1.586	0.479	6.67
		39.50-40.00	> 60	47.76	1.65	1.12	2.76	-	1.532	0.490	17.62
2	**BH-2**	4.50-5.00	30	21.94	1.90	1.56	2.78	-	4.642	0.817	24.82
		9.50-10.00	11-13	29.27	1.82	1.41	2.74	2.11×10^{-7}	1.058	0.372	10.73
		14.50-15.00	16	32.20	1.77	1.34	2.79	-	0.881	0.315	26.12
		19.50-20.00	17-26	31.68	1.73	1.31	2.83	2.17×10^{-6}	1.880	0.648	26.89
		24.50-25.00	21 - > 60	27.69	1.88	1.47	2.72	-	2.409	0.783	12.26
		29.50-30.00	21 - > 60	39.29	1.82	1.31	2.73	-	1.556	0.440	14.00
		34.50-35.00	> 60	40.96	1.83	1.30	2.81	2.08×10^{-7}	0.353	0.208	15.27

RESULT AND DISCUSSION

Lateral deflection solution is performed by comparing three methods: the p-y curve method with Finite Difference, ALLPILE program V7.3B and PLAXIS program version 8.6. Comparison of the results of the method is when the pile is given a lateral load of 10 kN, 15 kN and 20 kN. The maximum load was analyzed when deflection was 2.54 cm in each method.

1. Solution of the P-Y Curve Method with Finite Difference Solution

Equation matrix:

a. Main matrix per pile segment

$(y_{-2}.R_{-1}) + y_{-1}(-2R_{-1} – 2R_1 + Px.h^2) + y_1(R_{-1} + 4R_1 + R_{-1} – 2Px.h^2 + Esy_1.h^4) + y_2 (-2R_1 – 2R_2 + Px.h^2) + y_3.R_{-1} + W_1.h^4 = 0$ (6)

TABLE 1. Values per segment pile main equation

Equation to the -	Value equation main
y-2	185761.8367
y-1	-743047.3469
y1	Table 4
y2	185761.8367
y3	-743047.3469

b. Boundary condition matrices for conditions are only placed layers area the upper end points and the end lower of the pole to-upper

- Conditions limit of the shear force

$Rt / 2h^3(yt_{-2} - 2y_{t-1} + 2yt_{+1} - yt_{+2})+ Px / 2h (yt_{-1} - yt_{+1})= Pt$ (7)

where,
$Rt / 2h^3 = 92880.9183629097$

TABLE 2. Equation values of the upper boundary conditions for the shear force equation

Equation to the -	Value of the upper boundary conditions for the shear force
y2	92880.91836
y1	-185761.8367
y-1	0
y-2	185761.8367
y-3	-92880.91836

- Conditions for the moment

$Rt/h^2(y_{t-1} – 2y_t + y_{t+1}) = Mt$ (8)

where,
$Rt/h^2 = 185761.836725819$

TABLE 3. Value of the upper boundary condition equation for the moment

Equation to the -	Value of the upper boundary condition for the moment
y1	185761.8367
y-1	-371523.6735
y-2	185761.8367

The main equations per pile segment in table 1 are arranged according to the pile point review to the 33 pile point, thus forming a series of numerical figures forming a matrix. Boundary conditions in table 2 and table 3 are placed on the top of the pole, the upper boundary conditions include shear forces and moments. The mean matrix y1 in Table 4 is the difference equation value of each equation because there are different soil reaction values or soil modulus per soil layer.

TABLE 4. Middle value of the equation per pile segment

Soil layers to the -	y1
1	1125371.02035492
2	1119971.02035492
3	1121171.02035492
4	1122971.02035492
5	1128671.02035492
6	1129871.02035492
7	1134371.02035492

- Lower boundary conditions: Lower boundary conditions serve to clamp the lower pile.

$$y_{-1} - 2y_0 + y_1 = 0 \quad (9)$$

TABLE 5. The value equation under the boundary conditions for flops pedestal

Equation to the -	Value equation of the under boundary conditions for flops pedestal
y30	1
y31	-2
y32	1

At the bottom end of the pile, there is no shift. Therefore, it must be balanced with the pile balancing equation.

$$R0/2h^3 (y_{-2} - 2y_{-1} + 2y_{+1} - y_{+2}) + Px / 2h (y_{-1} - y_{+1}) = V0 \quad (10)$$

TABLE 6. The value equation balancer

Equation to the -	Value equation of the under boundary conditions for balancing
y28	1
y30	-2
y31	0

y32	2
y33	-1

Table 5 and Table 6 is the lower boundary conditions are placed on the bottom of the pole to be in a state sandwiched and balanced conditions. Maximum lateral deflection that occurs with the p-y curve method with different settlement until when a load of 10 kN is given is 0.0629 cm, 15 kN is 0.0943 cm, and 20 kN is 0.1258 cm.

2. Completion with the ALLPILE program V7.3B

In general, the ALLPILE program works by entering the Pile Type data, Pile Profile, Pile Properties, Load and Group, and Soil Properties. In the pile data input process, the ALLPILE V7.3B program identifies the condition of the pile by complete starting from the type of piling, pile cap height, pile length, the slope of the pile, type or shape of the pile, and allows different pile shapes in each depth.

TABLE 7. Input parameter data soil in ALLPILE V7.3B

Depth of Soil Layers - meter	G - kN/m^3	Phi - ^{o}	c - kN/m^2	k - (MN/m^3)	ε_{50} or Dr	Nspt
0 – 5	19	1	81	61	0.8	30
6 – 12	18	1	36	135	0.007	12
13 – 16	18	1	31	135	0.007	16
17 – 20	17	1	64	135	0.007	22
21 – 22	19	1	77	135	0.007	45
23 - 30	18	1	45	135	0.007	45
31 - 40	18	1	20	135	0.007	60

Lateral deflection for the calculation results of the ALLPILE program when a load of 10 kN is 1.21 cm, 15 kN is 2.13 cm, and 20 kN is 3.14 kN.

3. Completion with the PLAXIS Program version 8.6

Modeling the PLAXIS program for the calculation of lateral deflections requires complex soil and pile parameter data and in its application requires considerable modeling steps.

TABLE 8. Input pole parameter data in PLAXIS version 8.6

Parameter	Symbols	Value	Units
Normal stiffness	EA	308605432.55	kN/m
Flexural stiffness	EI	185761.8367	kNm^2/m
Equivalent thickness	d	0.085	M
Weight	w	14.4	kN/m/m
Poisson ratio	μ	0.15	

The model Geometry uses the model strain field where the pile is placed in the middle between right and left of the land area. Layered soil modeling with parameters from the Bohr-Coulomb model. The Bohr-Coulumb model requires five main parameters, namely Modulus young E, Poisson V numbers, Shear angle φ, and Dilatation angle ψ.

Deflection that occurs in the calculation of the PLAXIS program successively when given a load of 10 kN, 15 kN, and 20 kN is 0.27 cm, 0.4051 cm, and 0.5402 cm.

CONCLUSION

The conclusions of the lateral deflection analysis of piles in clay are as follows:

1. The results of the calculation of lateral deflection of the pile on the p-y curve method with finite-difference solution, the ALLPILE program and the PLAXIS program respectively with a lateral load of 10 kN are 0.0629 cm; 1.21 cm; 0.27 cm, lateral loads of 15 kN are 0.0943 cm; 2.13 cm; 0.4051 cm, and a lateral load of 20 kN is 0.1258 cm; 3.14 cm; 0.5402 cm.
2. The largest lateral deflection by giving the same load occurs in the calculation of the ALLPILE V7.3B program, followed by calculations from the PLAXIS program version 8.6 then the p-y curve method with finite-difference settlement. Based on these results, it is recommended to use the ALLPILE program to better obtain the level of safety of the lateral deflection of the pile when applied in the field.

REFERENCES

[1] Brinkgreve. R. B. J et al, *PLAXIS 2D – Versi 8*. Delft University of Technology & PLAXIS b.y, Netherlands, 2007.

[2] Das. B. M, *Principle of Geotechnical Engineering*. Brooks/Cole Engineering Division, Monterey, California. 1988. Terjemahan N. Endah and I.B. Mochtar. *Mekanika Tanah.* Jilid Satu, Erlangga, Jakarta, 1995.

[3] Gunawan. R, *Pengantar Teknik Pondasi.* Cetakan Kelima. Kanisius, Yogyakarta, 1991.

[4] Hardiyatmo. H. C, *Teknik Pondasi 1.* PT Gramedia Pustaka Umum, Jakarta, 1996.

[5] McNulty. J.F, dan Matlock. H, *Thrust Loading on Pile Proc. Journal Soil Mech and Foundation*. DIV LXXII, ASCE, 1956.

[6] Reese. L. C. and Impe. V. W, *Single Piles and Pile Groups Under Lateral Loading*. 2nd Edition, CRC Press/Balkema, Rotterdam, 2011.