Eduvest – Journal of Universal Studies
Volume 4 Number 05, May, 2024
p- ISSN 2775-3735- e-ISSN 2775-3727

ANALYSIS OF BEARING CAPACITY OF PILE FOUNDATIONS USING ANALYTICAL METHOD AND FINITE ELEMENT METHOD

Ayu Nurjanah
Fakultas Teknik, Universitas Muhammadiyah Mataram, Indonesia
Email: ayunurjanah289@gmail.com

ABSTRACT

The foundation is the lower part of a structure used as a load distributor for the loads generated by the upper structure, which are then transmitted into the hard soil layers. The selection of foundation types in building construction must consider the type and characteristics of the soil at the construction site to avoid construction failures. This analysis is conducted to determine the bearing capacity of pile foundations using analytical and finite element methods. The type of foundation used in this analysis is a pile foundation with a pile length of 8 meters and a pile diameter of 0.4 meters. For the analytical calculation, Standard Penetration Test (SPT) data obtained from PT. Adhi Karya (Persero) for the Infrastructure Green House Biodiversity LIPI Cibinong-Bogor project are used, employing the analytical method (Alpha Method) and the finite element method with the assistance of Plaxis 2D V.8 software. The results of the analysis show that the bearing capacity of the group pile foundation (Qg) for a pile diameter of 0.4 meters and a pile length of 8 meters on clayey soil, based on SPT data using the analytical method (Alpha Method), is 60.432 tons. Meanwhile, the bearing capacity of the horizontal pile foundation using the Broms method is 6.03 tons. The bearing capacity obtained using the Finite Element Method yields an ultimate load on the group pile (Qq) of 57.89 tons. The bearing capacity of the group pile foundation (Qg) from both sets of data, with a difference of 2.5%, meets the requirement, being greater than the axial load (P) of 42.6 tons that must be supported.

KEYWORDS *Piling, bearing capacity, alpha method, broms, finite element*

This work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International

How to cite:	Ayu Nurjanah. (2024). Analysis Of Bearing Capacity Of Pile Foundations Using Analytical Method And Finite Element Method. *Journal Eduvest*. 4 (5): 3960-3679
E-ISSN:	2775-3727
Published by:	https://greenpublisher.id/

INTRODUCTION

The development of technology has become one of the supporting factors for the advancement of infrastructure, ranging from infrastructure in the fields of health, education, to personal housing. Infrastructure or construction is always associated with a strong foundation support, making foundation bearing capacity a crucial aspect in building construction. However, in reality, errors or mistakes in foundation work are still found in the field, which are typically caused by planning errors, thus posing a threat to construction safety.

Until now, the presence of high-rise building construction has been increasing in line with the need to fulfill public facilities supporting daily activities. Therefore, foundation bearing capacity planning must be carefully designed to withstand the construction loads above it up to the specified safety limits.

The foundation is the lower part of a structure used as a load distributor for the loads generated by the upper structure, which are then transmitted into the hard soil layers. The selection of foundation types in building construction must consider the type and characteristics of the soil at the construction site to avoid construction failures.

There are two types of foundations commonly applied in high-rise building construction, namely shallow foundations and deep foundations. Shallow foundations are used for buildings where the depth of hard soil is not far from the surface, while deep foundations are used for buildings where the depth of hard soil is considerable.

Pile foundations are a type of deep foundation that is driven or inserted to a certain depth to transmit the loads from the building's superstructure into the soil. Several factors influence the selection of the foundation type to suit the building, including the building's function, the magnitude of working loads, soil surface conditions, bearing capacity, settlement, and cost.

Analysis of foundation bearing capacity is conducted to withstand the construction loads above it. In the Green House biodiversity infrastructure development project, calculations of deep foundation bearing capacity, namely pile foundations, have been performed using conservative formulas (FK) and with the assistance of ETABS software.

The bearing capacity of pile foundations can be calculated using various methods such as the Alpha method, λ method, US Army Corps method, Tomlinson method, Paulos and Davis method, Coyle and Castello method, Kulhawy method, Broms method, and Brinch Hansen method. The choice of method depends on the soil type, as the soil type at the site is cohesive soil, and testing has provided the values of the internal friction angle (φ) and cohesion (c), thus the Alpha method and Broms method are used according to the parameters.

Therefore, there is a desire to reanalyze the bearing capacity of pile foundations using analytical methods (Alpha Method and Broms Method) and finite element methods with the assistance of Plaxis 2D V.8 software. This analysis aims to determine the bearing capacity value by comparing several different methods and using numerical methods to facilitate foundation bearing capacity planning.

Based on these considerations, there is an interest in conducting research on "Analysis of Bearing Capacity of Pile Foundation Using Analytical Methods and

Finite Element Methods." The problem formulation to be discussed includes the results of the analysis and the differences in the results of foundation bearing capacity analysis with both methods. The research objective is to determine the results of foundation bearing capacity analysis using analytical and finite element methods, as well as their differences. The scope of the problem includes foundation types, calculation methods, and data used, with the exclusion of material strength calculations. The benefits of this research include increasing knowledge about foundation bearing capacity, providing references for the Green House Biodiversity LIPI Cibinong-Bogor project, and expanding understanding of different analysis methods and the application of different software in foundation bearing capacity research.

RESEARCH METHOD

Research Location

The Green House Biodiversity Infrastructure development project is a multi-story Green House construction project consisting of 4 floors above ground level, located on clayey soil. This project is situated in the middle of the Cibinong LIPI Botanical Garden area, located on Jakarta-Bogor Highway, Km 46. Based on the points surveyed in zone 4 with 1 Standard Penetration Test (DB2) point, this building foundation uses a pile foundation type.

Data Availability

Data collection for this research was conducted secondarily, obtained from several sources as follows:

Table 1. Types of data and data sources used

No.	Data Type	Source
1	Geotechnical Data (2021) - Sounding data - NSPT boring data - Soil classification data - Laboratory data	Surya Jenar Mandhiri Laboratory
2	Project Structure Drawing Data (2021)	PT. Adhi Karya
3	Structure Planning Analysis Data (2021)	PT.Gitarencana Multi-plan

The secondary data obtained will be used for the following analysis purposes:

1. Geotechnical Data (2021) is used for calculating both axial and horizontal foundation bearing capacity based on several methods used. The NSPT values can only be obtained from the results of SPT testing.
2. Project Structure Drawing Data (2021) is used to determine the diameter of the foundation and the locations of the testing points.
3. Structure Planning Analysis Data (2021) is used for the calculation data of the upper structure loads, which will be used in modeling the foundation bearing capacity analysis with the assistance of Plaxis 2D software.

Flowchart

1. Data Collection

Data is one of the most important factors in the analysis process, obtained from various data sources obtained by PT. Adhi Karya (Persero) in the Green House Biodiversity Infrastructure Development Project at LIPI-Cibinong. In this study, the data used includes SPT data, structural drawings, laboratory data, and structural analysis.

2. Literature Review

Literature review is necessary as a reference for analysis after the subject is determined. This literature review is used as the theoretical basis for analysis referring to books, opinions, and theories related to the research.

3. Data Processing

Data processing is carried out on the data obtained to calculate the bearing capacity of group pile foundations using analytical methods and finite element methods using Plaxis 2D application.

4. Foundation Design

In this section, foundation design is carried out, starting from the diameter and length of the foundation used.

5. Analysis with Analytical Methods

Analysis with analytical methods uses SPT data, and the foundation bearing capacity is calculated using the alpha (α) method.

6. Analysis with Finite Element

Methods Analysis with finite element methods is carried out with Plaxis 2D V.8, inputting soil and pile parameters into this program modeling to determine the bearing capacity of pile foundations.

7. Analysis Control

Analysis control is conducted to determine whether the calculated results using the available data meet the requirements by controlling using a safety factor for foundation bearing capacity.

8. Comparison Data Analysis

After obtaining the bearing capacity calculation results with analytical and finite element methods, both results are then compared to see the differences in the results obtained.

9. Results and Discussion

In this section, the results obtained from both analytical and finite element methods are elaborated step by step until obtaining the results.

10. Conclusion

This conclusion contains a brief and precise summary of the research results.

Analytical Method Planning Steps

1. Investigate the soil at the planned building location to determine the soil type at that location.
2. Calculate the ultimate bearing capacity of the pile and check the safety factor.
3. Calculate the magnitude of the horizontal load acting on the pile.

4. Check whether the load acting on the pile transmitted by the upper structure is smaller than the calculated pile strength with the appropriate safety factor.

RESULT AND DISCUSSION

Technical Data of Pile Foundation

Table 4.1 Analysis Result of Soil Types in the Field

0.00 – 9.00 m	Clay layer, medium stiff consistency, red color. This layer has cone resistance (qc) values ranging from 10 – 15 kg/cm² and N SPT values of 4 – 8 blows/feet.
9.00 – 13.00 m	It is a layer of wandering clay, stiff costension of brownish-red color. This layer has a conus resistance value (qc) ranging from 20 – 30 kg / cm² and an N value of 8 – 12 blows / feet.
13.00–19.00 m	It is a layer of silt layer, very stiff consistency, gray color. This layer has a conus resistance value (qc) ranging from 30 - 250 kg / cm² and has an N value of 15 - 26 blows / feet. Under these conditions, in the DB 1/S5 area, a hard lens layer 2 m thick is found at depths of -15.00 m to -17.00 m from exsting elevation (qc >250 kg/cm² and N SPT 50 blows/feet).
19.00–25.00 m	It is a layer of silt layer, hard consistency, gray color. This layer has a conus resistance value (qc) ranging from 70->250 kg/cm² and has an N value of 45- 60 blows/feet.
25.00–30.00 m	It is a layer of coarse sand containing gravep, dense to very dense and has an N value of 40 – 60 blows / feet.

Source: (surya jenar laboratory)

In this study, pile foundation with the following specifications was used:

Foundation Type: Pile
Diameter: Ø 400 mm
Concrete Quality: K-500

Calculating the Bearing Capacity of the Foundation

The axial bearing capacity of the pile foundation was calculated analytically based on field data collected by PT. Adhi Karya (persero). The calculation of the pile's bearing capacity used the alpha method. The analysis was limited to Standard Penetration Test (SPT) data at point BH-4 because this location was where borehole testing was conducted in the laboratory.

The bearing capacity analysis on this clayey soil was calculated using the alpha method to determine the pile frictional resistance in clayey soil with pile lengths of 8, 10, and 12 meters (trial and error) based on the adhesion factor values collected by McClelland (1974).

From the experiment results with pile lengths of 8, 10, and 12 meters, the following results were obtained as shown in the table.

Table 4.3 Recapitulation of bearing capacity with the alpha method for pile lengths of 8, 10, and 12 meters

Pile Length (m)	Control fb < 15000 kN/m^2	Control fs < 107 kN/m^2	Qb (ton)	Qs (ton)	Qu (ton)	Eg	Qg (ton)
8 m	593,997	39,58	74,606	298,425	335,731	0,9	60,423
10 m	593,997	36,61	74,606	367,95	404,856	0,9	72,874
12 m	593,997	37,21	74,606	436,76	473,67	0,9	85,261

From the trial and error experiment, values for pile lengths of 8, 10, and 12 meters for control fs and fb were obtained. The pile length with the fs control closest to 15000 for fb and 107 for fs was chosen, which is 8 meters.

Horizontal Piling Bearing Capacity

Calculation of the horizontal (lateral) carrying capacity of piles, using the broms method (1964). This horizontal carrying capacity is calculated using the broms method with the type of soil, namely cohesive soil.

Checking the carrying capacity against external loads

The load that acts on the foundation is generally the load obtained from the upper structure and the soil pressure from the side of the pile foundation, this load is usually known as vertical load and horizontal load. This load is carried by several poles that are held together by pole bearing plates or *pilecap* which serves to spread the load from the upper structure to the pole which is then channeled to the soil layer.

Calculating the carrying capacity with finite elements

The carrying capacity capacity by finite element method is a calculation of the axial bearing capacity of pile foundations, in this method using the *Mohr – Coulomb* model which is a general model in soil investigation. Mode; This requires parameters such as *Young's modulus*, *stiffness modulus*, *Poisson's ratio*, shear angle in the field, cohesion factor, angle of discharge and weight of the soil content.

These parameters are obtained from the results of laboratory tests, due to limited data, some parameters are assumed based on soil mechanics theory using the *all pile program*.

Table 4.4 Finite element method calculation parameters

PARAMETERS USED IN PLAXIS				
PILE FOUNDATION				
Pile size		=	0,4	m
Pile length		=	8	m
Concrete strength (f'c)		=	41,5	Mpa
Cross-sectional area (A)	1/4πd^2	=	0,1256	m2

Pile elastic modulus (E)		=	30277,63201	Mpa
		=	30277632	kN/m2
Pile inertia moment (I)	1/48 πr4	=	0,002	m4
(EA)	E x A	=	3802870,580	kN/m
(EI)	E x I	=	50704,94107	kN.m2/m
PILE CAP				
pile cap lenght		=	2	m
pile cap width		=	0,8	m
Pile cap cross-sectional area	P x L	=	1,6	m2
Pile cap concrete strength(f'c)		=	29	Mpa
Pile cap elastic modulus (E)		=	25310,27459	Mpa
			25310275	kN/m2
Pile cap inertia moment (I)	1/12. bh^3	=	0,085333333	m4
(EA)	E x A	=	40496439,35	kN/m
(EI)	E x I	=	2159810,099	kN.m2/m
Poisson's ratio		=	0,2	
Pile self-weight per meter		=	3,77	kN/m
Saturated soil volume weight (ϒsat)		=	17,56	kN/m3
Unsaturated soil volume weight (ϒunsat)		=	12,54	kN/m3
Vertical building load (P)		=	42,6	Ton

A. Model Selection

In this modeling, a plane strain model is used for pile foundation with 15-Node elements.

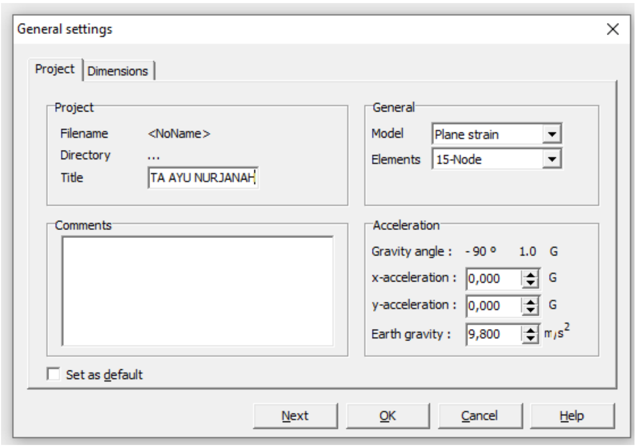


Figure 4.8 Model Selection for Plaxis Analysis
(source: Plaxis 2D V.8, 2010)

B. Dimensions

This dimension is intended for display in the space used for the depiction of soil layers and foundations to be analyzed as well as units used in the process of inputting materials and loads. The length and width are adjusted to the depth of the soil to be analyzed, for units used units m for length and satan kN for load.

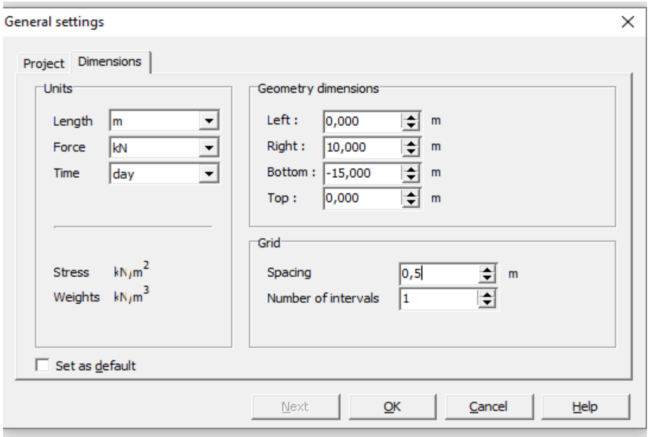


Figure 4.9 Dimensions of the Model Used
(source: Plaxis 2D V.8, 2010)

C. Soil Model

After filling in the dimensions of the drawing space, then the process of drawing the soil layer according to the depth of the soil is carried out based on the data. In this analysis there are 2 soil layers to be analyzed with soil depth 1 is 1-6 m and soil to 2 6-12 m.

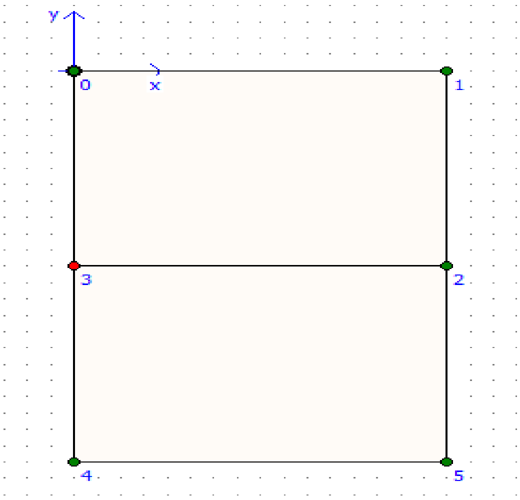


Figure 4.10 Subsoil Image
(sumber: Plaxis 2D V.8, 2010)

D. Soil Parameter Input

After the soil layer has been made, it is continued by inputting soil parameters in the *material set*, soil and interface are selected for soil material.

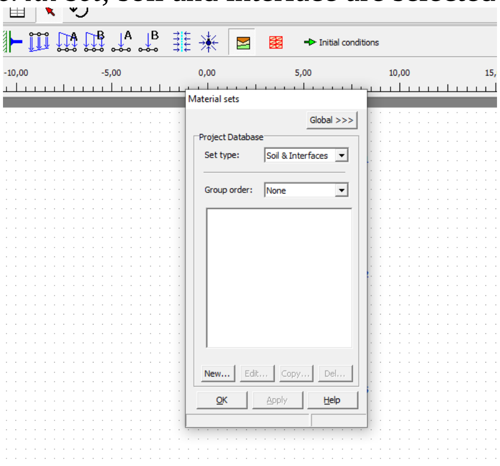


Figure 4.11 *Type Material Set* Soil

(sumber: Plaxis 2D V.8, 2010)

Then *new* to enter the soil parameters according to the layer, after that a display will appear that must be filled in according to the soil data of each layer.

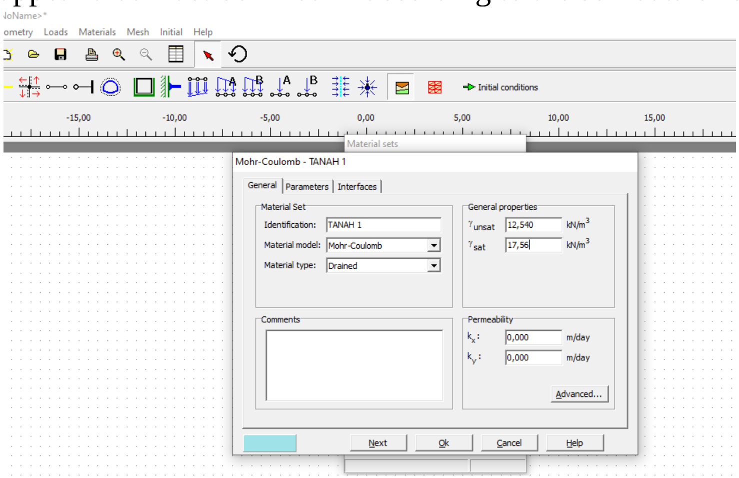


Figure 4.12 Ground Parameter Input

(sumber: Plaxis 2D V.8, 2010)

Furthermore, when all parameters have been completed, the parameters of each layer are then inputted into the image of the soil layer that has been drawn by means of the input results click then held and dragged to the soil layer according to the parameter data.

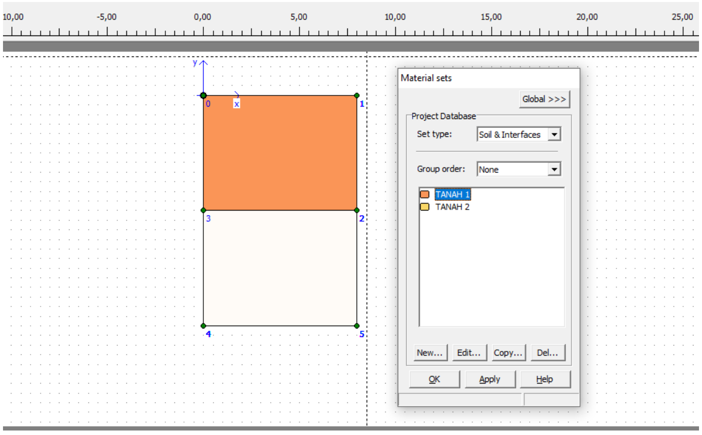


Figure 4.13 The process of entering the input parameter results according to the soil layer.
(source: Plaxis 2D V.8, 2010)

E. Pile and Pile Cap Model

After the parameters are inputted according to the soil deposit, then the drawing of the pole and pilecap is carried out according to the length of the pole and *pile cap* used.

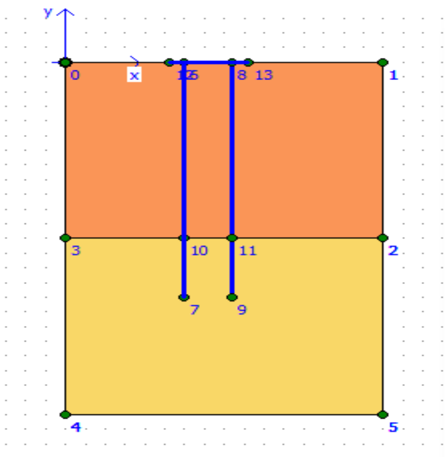


Figure 4.14 Pile and Pilecap Model
(source: Plaxis 2D V.8, 2010)

F. Pile and Pile Cap Parameter Input

After the pole and *pile cap models* are made, it is continued by inputting the parameters of the pole and *pile cap* in the *material set*, plates are selected for the pole material .

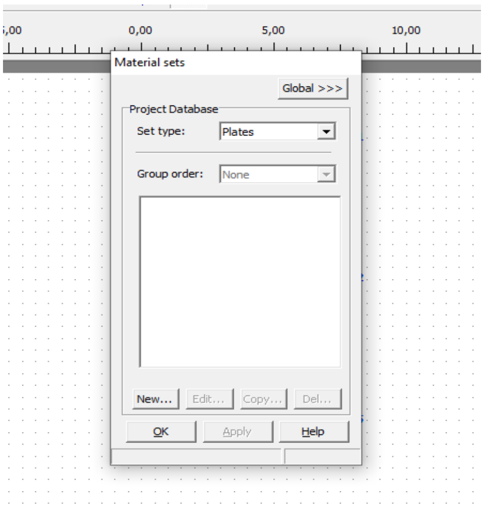
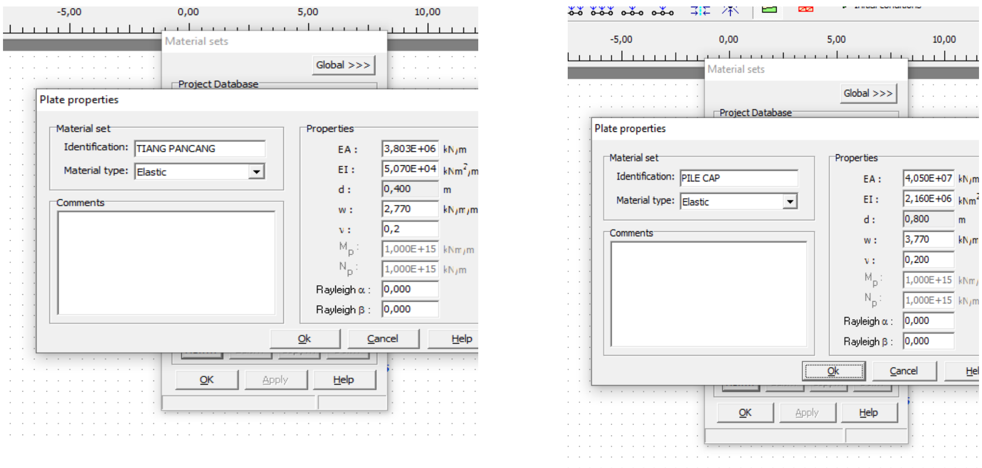


Figure 4.15 *Material Type Pile Set* and *Pile cap*
(source: Plaxis 2D V.8, 2010)

Then *new* to enter the parameters of the pole and *pile cap*, after that a display will appear that must be filled according to the pole and *pile cap data*.



(a) (b)

Figure 4.16 (a) Pile Parameter Input, (b) Pile Cap Parameter Input
(source: Plaxis 2D V.8, 2010)

Once all parameters are filled, the pile and pile cap parameters are then input into the drawing by clicking and dragging the input results onto the pile and pile cap according to the parameter data.

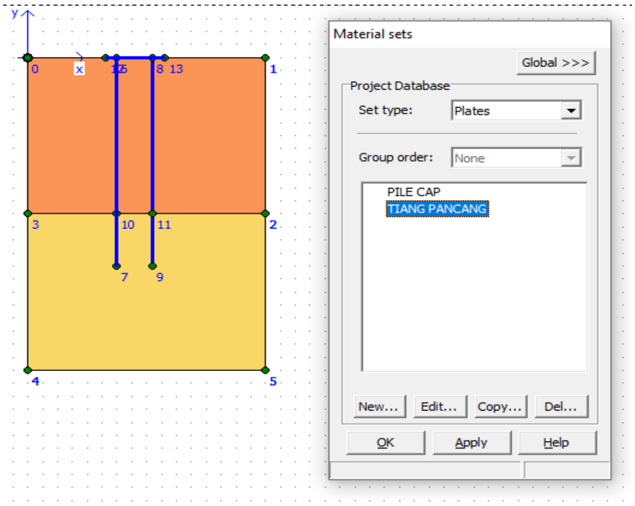


Figure 4.17 Process of Inputting Parameter Results to Pile and Pile Cap.
(source: Plaxis 2D V.8, 2010)

Next, an interface is done on the outer side of each pile, this is done to facilitate the analysis process of each pile or soil element.

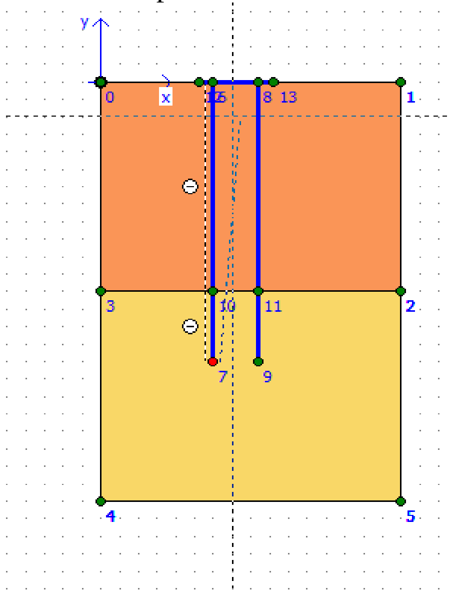


Figure 4.18 Interface on Pile
(source: Plaxis 2D V.8, 2010)

After the interface is done, standard fixities are applied to input standard boundary conditions.

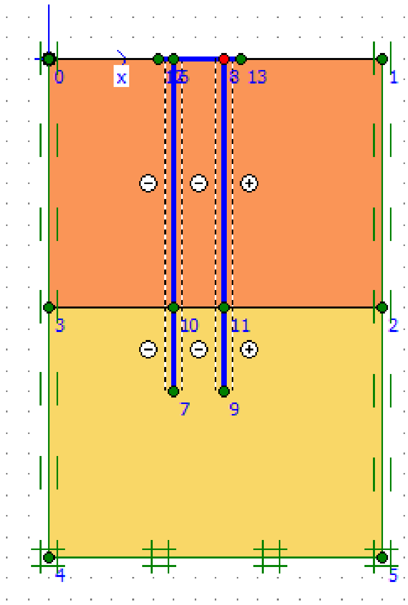


Figure 4.19 Standard Fixities
(source: Plaxis 2D V.8, 2010)

G. Load Input

After soil, pile, and pile cap have been input according to their parameters, the next step is to input loads. Loads are drawn with a centralized load image, then at the load end, double-click until a table appears to input horizontal and vertical load values, then the horizontal load value of 60.33 kN and the vertical load value of 426 kN are entered.

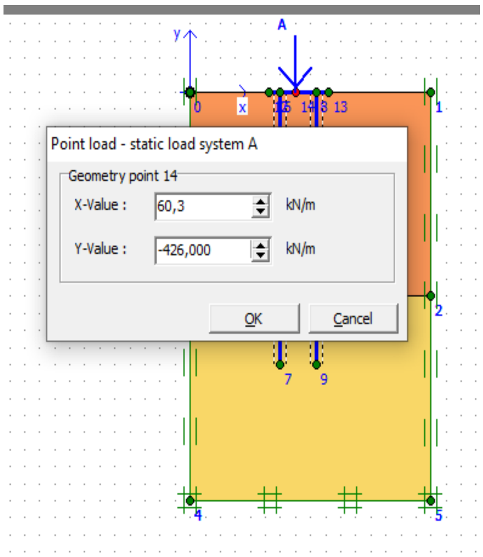


Figure 4.20 Load Value Input
(source: Plaxis 2D V.8, 2010)

H. General Mesh

After all inputs are carried out, then a general mesh or element division process is carried out to facilitate the analysis process of each element. Then a new window will appear that displays the results of the previously inputted structure in the form of a structure with a net of elements, then updated then *the initial condition* to proceed to the next step.

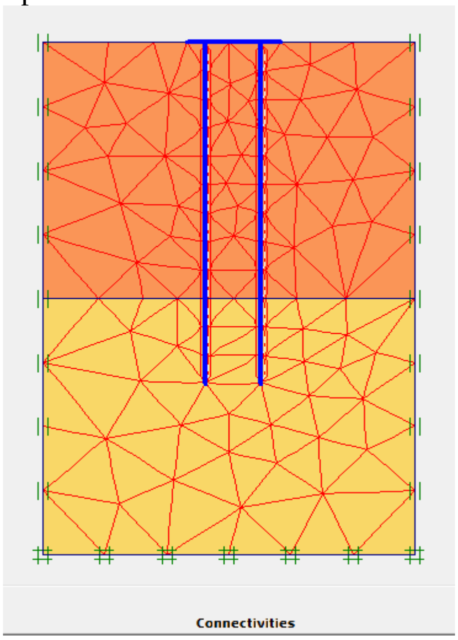


Figure 4.21 Mesh Element Model
(source: Plaxis 2D V.8, 2010)

I. Groundwater Level

The next step is to draw the groundwater level according to the depth where the groundwater level is located.

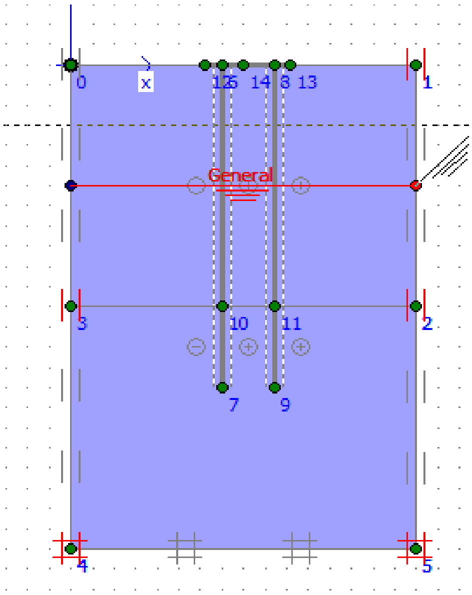


Figure 4.22 Groundwater Level
(source: Plaxis 2D V.8, 2010)

Then select general water pressure to see the extreme active pore pressure of -89,42 kN/m^2.

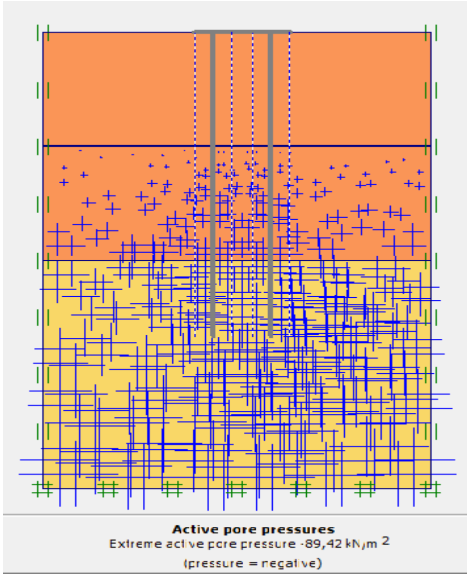


Figure 4.23 Active Pore Pressure
(source: Plaxis 2D V.8, 2010)

Next, general initial stresses are applied to know the main effective stress obtained at -105.22 kN/m2 then click calculate to proceed to the calculation step.

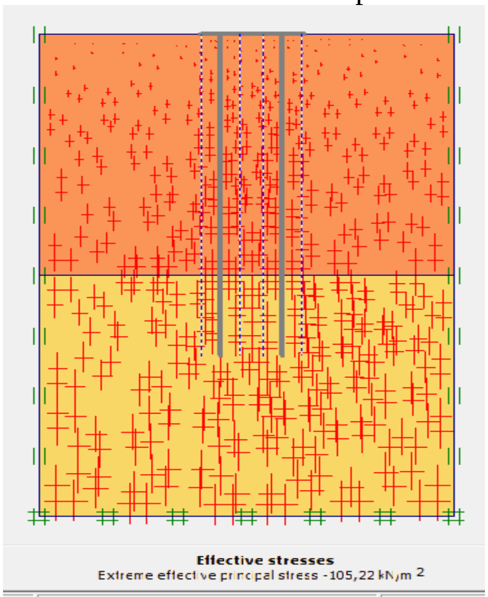


Figure 4.24 Main Effective Stress
(source: Plaxis 2D V.8, 2010)

J. Calculation

This step aims to analyze the structural safety, previously a calculation structure step was arranged starting from piles, pile caps, loads to safety factors. For piles, pile caps, and load types, the calculation type is chosen as plastic or loading, while for safety factors, the phi/c reduction or safety factor type is chosen.

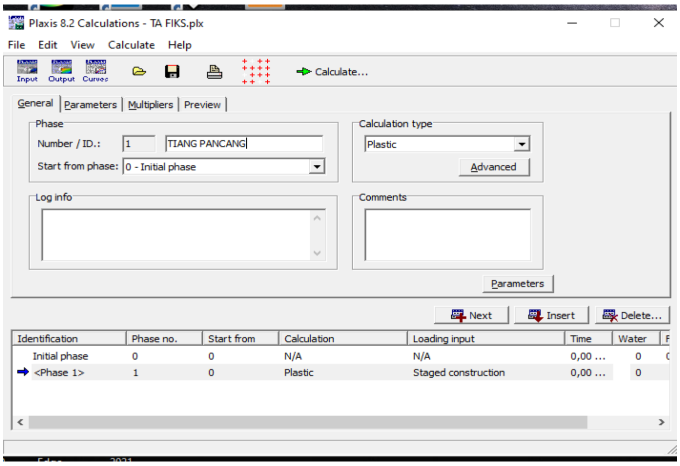


Figure 4.25 Pile Foundation Input in the Calculation Process
(source: Plaxis 2D V.8, 2010)

Continued with the parameter menu option then devine, then a new window appears containing the initial geometry image. If the input is pile foundation, then only the pile foundation is selected on the image until it turns blue.

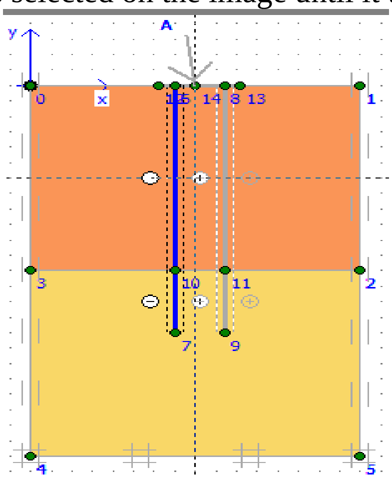


Figure 4.26 Selection of Pile Structure for Analysis
(source: Plaxis 2D V.8, 2010)

The same steps are repeated for pile cap, load, and safety factor types. After all are selected according to their respective structures, the next step is to proceed with the calculation step.

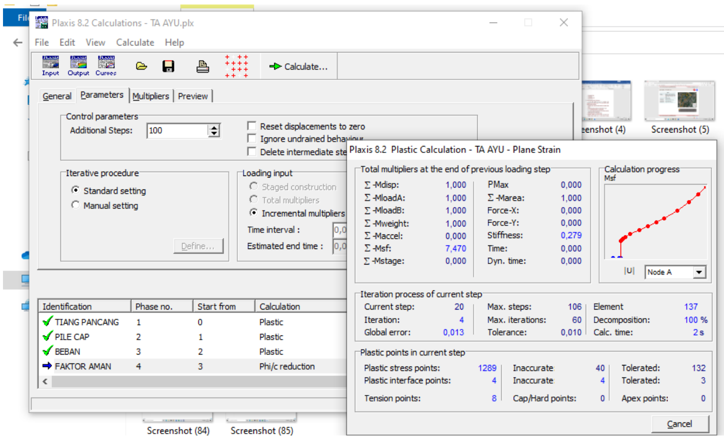


Figure 4.27 Calculation Process
(source: Plaxis 2D V.8, 2010)

The result of the calculation process is the value of $\sum Msf$ When all input structures in the calculation turn into green check marks, it means the calculation process was successful, if one of the input structures has a red check mark, then there was an error in the input process.

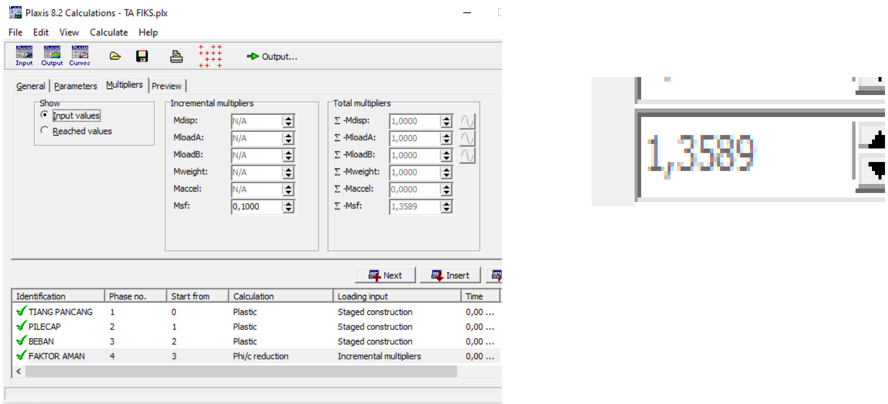


Figure 4.28 Structural Calculation Results
(source: Plaxis 2D V.8, 2010)

K. *Output Results*

The output of this result is in the form of a large decrease that occurs in the foundation due to working loads, the magnitude of the decrease occurs by 103.26 x 10^{-3} m or 0.001 m less than the allowable decrease of 1 inch or 0.0254 m.

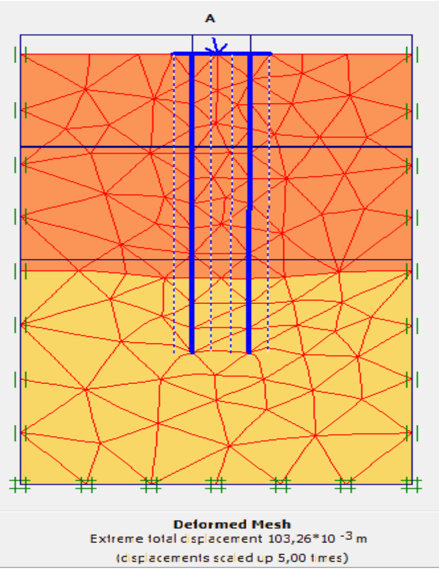


Figure 4.29 Amount of Settlement Occurred
(source: Plaxis 2D V.8, 2010)

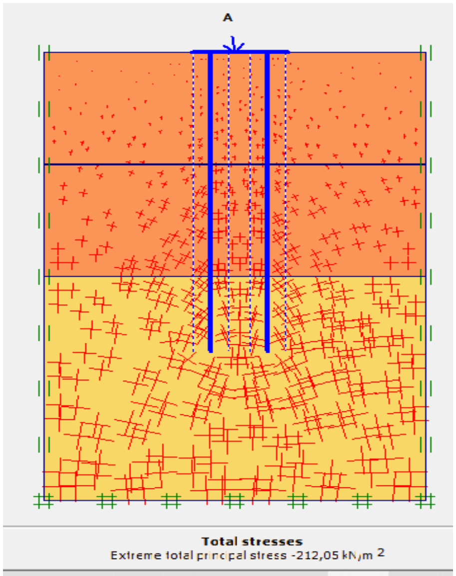


Figure 4.29 Total Working Stress
(source: Plaxis 2D V.8, 2010)

From the input process of material data for pile foundation, pile cap, and working load, the calculation process or calculation is carried out until the value of $\sum Msf$ is obtained, which is then multiplied by the vertical load working on the upper structure to obtain the ultimate load value using equation 2.47

$Qg \quad = \sum Msf \; x \; P$

with,

$\sum Msf \quad = 1{,}359$

$P \quad = 42{,}6$ ton

so,

Qg $\quad = \sum Msf$ x P

= 1,359 x 42,6 ton
= 57,89 ton

Comparison of Piling Bearing Capacity of Analytical Method and Finite Element Method

Analysis of the carrying capacity of the group pile foundation with a diameter of 0.4 and a pile length of 8 m The *Green House Biodiversity Building of* LIPI Cibinong-Bogor analytically using the Alpha (α) method obtained the ultimate carrying capacity of the pile group (Qg) of 60,432 tons and using the broms method obtained a lateral carrying capacity of 6.03 tons while with 2D V.8 plaxis using the *Frame Element* method(FE) obtained the ultimate carrying capacity of the pole group (Qg) of 57.89 tons with a difference in ratio of 2.5%.

CONCLUSION

Based on the analysis of carrying capacity using the Alpha method and finite elements on PC 2 group poles with a diameter of 0.4 m and a length of 8 m, the results show that the bearing capacity of the pile foundation (Qg) is 60.432 tons based on the Alpha method, 6.03 tons using the Broms method, and 58.60 tons with the Finite Element method. The comparison between analytical methods and finite elements shows a difference of 2.5%. The suggestion for more accurate calculations is to have complete technical and laboratory data, as well as to conduct detailed field and laboratory tests to avoid inaccuracies in results and ensure compliance with established standards.

REFERENCES

Anonim. 2010. Plaxis Version 8 Material Models Manual.

Aprilita, F. 2022. Analisa Daya Dukung Pondasi Tiang Pancang Pada Proyek Stadion Tipe B. Jurnal Teknik Sipil. Universitas Baturaja.

Bowlesh, J. E. 1991. Analisa dan Desain Pondasi, Edisi Keempat Jilid 1, Erlangga, Jakarta.

Das, M. B. 1995. Mekanika Tanah (Prinsip-Prinsip Rekayasa Geoteknik). Jilid 1. Jakarta: Erlangga.

Hardianty, B. 2015. Analisis Daya Dukung dan Penurunan Tiang Pancang Pada Bore Hole II Dengan Metode Analitis dan Elemen Hingga. Jurnal Teknik Sipil. Universitas Sumatera Utara.

Hardiyatmo, H. C. 2002. Teknik Pondasi II. Edisi Kedua. Yogyakarta: Beta Offset.

Hardiyatmo, H. C. 2014. Teknik Pondasi I. Edisi Ketiga. Yogyakarta: Gajah Mada University Press.

Hardiyatmo, H. C. 2015. Teknik Pondasi II. Edisi Ketiga. Yogyakarta: Gajah Mada University Press.

Kadarusman, A. N. 2021. Analisa Kapasitas Daya Dukung Metode Mayerhoff dan Penurunan Pondasi Tiang Pancang Terhadap Variabel Dimensi. Tugas Akhir. Universitas Islam Indonesia

Khairi, M., Sundary, D. dan Gunawan, H. 2021. Daya Dukung Pondasi Tiang Pancang Dengan Metode Statis Menggunakan Data Lboratorium. Jurnah

Teknik Sipil. Universitas Syiah Kuala Banda Aceh.

Prahastini, D. 2010. Analisa Daya Dukung Pondasi Tiang Pancang Kelompok Pada Proyek Pembangunan Gedung DPRD Sumatera Utara Medan. Tugas Akhir. Universitas Sumatera Utara.

PT. Adhi Karya. 2021. Metode Pelaksanaan Pekerjaan. Bogor: Adhi Beyonce Construction.

PT. Geociptaeka Setia, 2020. Plaxis 2D Version 8 Material Models Manual. Bandung: PT. Geocipta Optima.

Surya Jenar. 2021. Laporan Hasil Penyelidikan Tanah. Jakarta Selatan: Surya Jenar Mandhiri.

Soerdarmo G. D. 1993. Mekanika Tanah 1. Malang: Kanisius.

Sosrodarsono, S., dan Nakazawa. 2000. Mekanika Tanah dan Teknik Pondasi. Jakarta: PT. Pradnya Paramita.

Tomlinson, M. J. 1997 Pile Design and Construction Pratice. Edisi Pertama. View Point Publishing. London.

Wijaya Karya Beton. 2008. Presentasi Tiang Pancang. Jakarta: Wika Learning Center.

Yuati, A. 2014. Analisis Daya Dukung Pondasi Tiang Pancang Diverifikasi Dengan Hasil Uji Pile Driving Analyzer Test dan Capwap. Tugas Akhir. Universitas Bangka Belitung