PREDICTION OF BEARING CAPACITY OF PILE FROM STATIC LOAD TEST USING NUMERICAL ANALYSIS

BY

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A Thesis Submitted in Partial Fulfilment of the Requirements for the Degree of

BACHELOR OF SCIENCE IN CIVIL ENGINEERING

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

ISLAMIC UNIVERSITY OF TECHNOLOGY

Board Bazar, Gazipur

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<u>Approval</u>

The paper titled "PREDICTION OF BEARING CAPACITY OF PILE FROM STATIC LOAD TEST USING NUMERICAL ANALYSIS" submitted by Tahmid Al Munem, Fabia Omar Shoili and Nazia Afrin has been accepted as partial attainment of the requisite for the degree, Bachelor of Science in Civil Engineering.

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Declaration

It is hereby declared that this thesis report, in whole or in part, has not been submitted elsewhere for the award of any Degree or Diploma.

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Dedication

To our loving family members and revered teachers

for

their guidance, forbearance, and most notably, for believing in us.

Acknowledgement

All glory be to Almighty Allah, by whose mercy we were able to complete our research agenda. Our deepest appreciation will always be directed towards Allah, the kindest and most compassionate. We would like to convey our heartfelt thanks to our thesis supervisor, Dr. Hossain Md. Shahin, Professor & Head of the Department, Department of Civil and Environmental Engineering (CEE), IUT, without whose proficient direction we would have never been able to complete our dissertation work. Thank you for your amazing insights, continuous guidance, and endless inspiration, Sir.

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Preamble

The aim of this study was to determine the bearing capacity of pile from static load test using numerical analysis. The proposed location was for the terminal-3 building area of the Airport Expansion Project of Hazrat Shahjalal International Airport Dhaka. In this study, an analysis is conducted on the load settlement behavior of a pile foundation through the utilization of a Finite Element Modeling (FEM) program called PLAXIS 3D. The static load test result of the specified location was used to conduct the analysis. The research is titled “Prediction of Bearing Capacity of Pile from Static Load Test Using Numerical Analysis”. The research’s final goal was achieved by numerical simulation of the soil models and prediction of bearing capacity of the soil. The objectives of this study are, i) Perform numerical simulation of static pile load test, ii) Compare numerical results with filed load test data and iii) Predict the bearing capacity of the pile.

Abstract

The foundation is a component of building construction that supports and distributes the load of the building on the ground. When the soil strength is insufficient to support the overburden weight of any building, pile foundations are often used. The bearing capacity of foundations is among the most crucial aspects to take into consideration. Every structure must determine the soil's carrying capability for a particular type of foundation. Load settlement behavior is frequently required to determine a pile's bearing capacity. Static load test is often performed to identify pile load settlement behavior because it is the most common kind of pile load test. In this research, an analysis will be conducted on the load settlement behavior of a pile foundation through the utilization of a Finite Element Modeling (FEM) program called PLAXIS 3D. The Hardening Soil model and the Mohr-Coulomb model will be used to predict the load-settlement behavior of the pile foundation using data from in-situ load tests. Relevant laboratory tests and empirical equations will be used to estimate the required soil parameters, such as cohesion, angle of friction, and others. Here, the simulated load-settlement responses of both soil models will be compared to determine the best-suited model. Finally, this research aims at reducing the time required for testing and finding a cost-effective solution. Also, the generated load settlement curve will be further employed to assess the bearing capacity using a variety of techniques, and conclusions will be made accordingly.

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1 Introduction

Pile foundations are commonly utilized in geotechnical applications to provide support for structures with deep foundations that are unable to withstand heavy loads. The increasing demand for such structures has placed a significant responsibility on engineers to accurately determine the appropriate loads for construction. Unfortunately, the availability of reliable reports on pile carrying capacity is often limited. Consequently, especially in challenging soil conditions, the pile load test has emerged as the most dependable method to ascertain the bearing capacity and load-control behavior of piles.

On-site pile load tests are routinely conducted to validate design loads and assess the condition of each pile. Based on the results obtained from these tests, it is crucial for designers to meticulously confirm or adjust the design load, while considering the data acquired from ground surveys. This iterative process plays a vital role in ensuring the safe and optimal design of pile foundations (Singh, 2016).

Among the various methods available to determine the bearing capacity of piles, the static load test is regarded as the most accurate. Static load test is done by subjecting the piles to specific loads to evaluate their settlement behavior. Through static load testing the ultimate bearing capacity of the pile can be calculated, as well as its capacity to support the load without excessive or continuous displacement. The static load test is also utilized to assess the bearing capacity of the pile, estimate the working load of the pile after construction, and analyze the load-settlement relationship of the pile foundation. However, the setup of static load testing is a challenging aspect. The test is time-consuming and complex and it also requires a variety of specialized tools. These aspects contribute to its high cost, which could result in considerable impact on the project budget.

To address the limitations associated with static stress testing, a potential alternative is to construct a virtual soil model using advanced numerical analysis software such as PLAXIS. This approach involves creating a simulation model of the soil by integrating parameters obtained from tested soil samples. To ensure accuracy both Mohr-Coulomb model and hardening soil model can be used. By utilizing these virtual soil models, test results can be generated and subsequently compared with field test results acquired from static load test. Engineers and researchers can overcome the constraints of traditional static load testing by using this integrated technique. Virtual soil models and numerical analytical techniques provide an efficient and cost-effective way to determine pile bearing capacity, lowering the financial burden and time constraints associated with comprehensive physical testing. Finally, this method helps the informed decision-making required for creating a solid and dependable piling foundation.

Chapter 02

2 Literature Review

2.1 Introduction:

A pile foundation is a type of deep foundation that is used to transfer structural loads from a building or structure to the underlying soil or rock. They are formed by long, slender, columnar elements typically made from steel or reinforced concrete or sometimes timber. Pile foundations are basically used when the soil close to the surface is unable to support foundation loads due to lack of bearing capacity or potential significant subsidence. The transfer of foundation loads to deeper, stronger and less compressible soil layers is the main function of a pile. Designers mainly use the bearing capacity of individual piles to anticipate the bearing capacity of groups of piles. Unfortunately, it is not always accessible to retrieve the bearing capacity calculations of the piles. And this has long been a concern of geotechnical engineers because the bearing capacity of the pile, which gives it a fixed value, is a safety factor for the structure. This chapter includes the studies of various researchers on prediction of bearing capacity of pile considering numerical analysis from static load test.

2.2 Static Load Test & Prediction of Bearing Capacity of Pile: Case Studies

Despite the fact that practically piles are mainly used in groups, most of the research published in the United States and other countries which is compiled by (Kezdi 1965), has focused on single piles**.** Currently, one or more of the following methods - mainly static formulas, dynamic formulas and field load tests - are used to evaluate the bearing capacity of individual pile. The static formula factor relates the friction of the skin along the pile shaft and the end bearing under the pile tip to the soil shear strength which obtained by laboratory or in situ experiments.

For each selected pile diameter and length, the two factors – friction and ultimate bearing capacity – are combined to determine the bearing capacity of the pile. And as for the field load test of piles, it is generally important to validate the capacity and to ensure that the behavior of the piles conforms to the design assumptions for the pile projects. This is often accomplished by performing a static load test, which's primary purpose is usually to determine the pile capacity. Basically, static load tests are carried out to confirm the final bearing capacity of the pile for the maximum theoretical bearing capacity. In their study, Krasiński & Wiszniewski (2017) conducted static load test on instrumented pile foundation to determine the displacement characteristics of the pile head. The test was done at Odra bridge construction site, Poland where several investigations and numerical calculations were carried out to better understand the entire testing procedure and the behavior of the soil structure. In order to determine the force distribution along the pile with greater accuracy, the authors employed their own analytical solution. It could be difficult to interpret the findings of static tests on instrumented heaps as the ultimate result is influenced by a wide range of variables and procedures.

According to Singh (2016), for rapid settling that occurs when the pile collapses or when the weight is too great is called maximum capacity. Additionally, it is necessary to do thorough pile load testing and soil investigations**.** The bearing capacity of the pile, the prediction of the service load of the pile after the production of the pile, and the load-settlement ratio of the pile foundation are the application purposes of the pile load test. According to (Hasnat& Saha, 2015), it is therefore important to set the maximum load as precisely as possible because the complexity of estimating the pile load capacity and achieving sufficient load has increased due to the difficulty of doing so in static load test. And according to Więcławski (2010), in many countries around the world, the static pile load test has been considered to be the most accurate technique for evaluating the bearing capacity and settlement of piles and pile foundations. The tests involve the assessment of sedimentation at each step, also gradually increasing the weights at predefined time intervals (Rakic et. Al 2014)**.** It illustrates an experimental load test apparatus, in which the vertical compressive force on the pile is obtained by hydraulic presses and the load delivered to the top of the pile is measured. As a result, a load settlement curve is created. In addition, it is vital to have experience and confidence in achieving a high degree of accuracy in testing to ensure the precise range of motion, rotation and allowable stability of the foundation under worst-case scenarios. And as for the developing country like Bangladesh, conducting static load test is time consuming and needs a huge budget for overall purposes and also conducting tests are not only difficult, but also costly due to its complexity as well as requires large amount of equipment. Therefore, in this study, we proposed numerical analysis to interpret the findings of static load tests conducted on a single pile to save time and money to overall forecast the final outcomes.

2.3 Numerical Analysis on Prediction of Bearing Capacity of Pile:

From various study work by researchers have shown that numerical analytic methods could be used to anticipate the pile's bearing capability for future results analysis.

A study conducted by Qing & Miao (2012) of single pile analyses on a single pile embedded in homogenous soil where proposed simple numerical nonlinear analytical approach was economical, efficient, and suitable for the analysis of a pile embedded into layered soils by considering shaft resistance degradation and base resistance hardening**.** Naveen et al. (2014) in their study, demonstrated the numerical simulation of a single pile with a vertical load for the piles' load-bearing capacity in residual soils and presented the output of the analysis results as an equivalent static load-settlement curve**.**

Unsever et al. (2015) performed a series of vertical and cyclic horizontal load experiments to examine the behavior of a 3-piled raft foundation under combined loads in dry sand. In this experiment soil model were considered as Hardening model and pile and raft were modeled as elastic model in Plaxis 3D software. To estimate the soil parameter, triaxial CD compression tests of the sand was conducted to analysis the behavior of the sand. In this analysis, the load carried by pile components varied based on the stress increment during vertical and horizontal loading. Krasiński & Wiszniewski (2017) also used Hardening Soil Model instead of traditional Coulomb–Mohr model as for simulation method in their study**.**

Gowthaman et al. (2016) analyzed settlement behavior of a pile foundation under the loads from high-rise building where soil (sandy silt type) model was also considered as Hardening soil model. From their analysis, they drew the conclusion that Hardening soil model is suitable in simulation of massive and high-rise structures as it overestimates the settlement at low working loads (up to 3000 kN) for the entire analysis due to its advanced nonlinearity. But they also concluded that MC model is not adequate to capture the settlement prediction at higher working loads though it shows good agreement with the settlement behavior obtained from field static load test at lower working loads and considered as best to predict settlement for single pile**.** A study done by Naveen et al. (2014) also showed The Mohr-Coulomb (MC) model with a medium mesh in optimum to simulate the settlement of a vertical loaded pile for residual type soil**.** Therefore, after reviewing all of these authors' studies, we have taken into account both the Mohr-Coulomb model (MC) and the Hardening Soil Model (HS) for our study in order to better interpret the results.

As for Load settlement data, it can be used to determine the bearing capacity of the pile under certain conditions. Axial compression and axial tension tests are examples of static loading studies. In their study, Rybak & Król (2018) gathered and discussed their field test experience in which analysis was based on information from 30 site logs of test loads applied to prefabricated driven piles. In their study they described how the accuracy of determining the ultimate capacity—Q—is affected by the number of measurements. Also, the traditional method of test extrapolation was considered where Chin kondner method was chosen as per the authors in which it demonstrates that the estimated capacities differ significantly from those static test data**.**

For the analysis of pile load test data to determine the ultimate bearing capacity of the test pile, several recommendations and methodologies, as well as several standards, are available in the literature. According to these techniques, the distribution of load settlement data is examined using a number of different concepts, including total failure, plastic failure, and failure / load ratios. According to Shakir (2022), following methods are mainly considered while predicting the bearing capacity of pile. They are: Davisson (1972), Hansen (1963), Decourt (1999), Chin-Kondner extrapolation (1963, 1970, 1971), Mazurkiewicz (1973), De Beer's (1968, 1972), Brazilian standard method (NBR 6122/1996), Van der Veen (1953), Shen (1980), Fuller-Hoy (1970), Buttler-Hoy (1977), Tangent's (1991), Corps of Engineers (1991), and so on. And also, as per Bangladesh National Building Code (BNBC 2020), a number of arbitrary or empirical methods are mainly used to serve as criteria for determining the allowable and ultimate load bearing capacity from static load test. Among them the ultimate failure load has been determined by the Davisson (1973). This method is basically based on offset method that defines the failure load. Though this method is too restrictive for drilled piles unless the resistance is primarily friction, it has shown better result for driven precast pile.

In their paper (Olgan et al.,2017), they presented 9 graphical methods to predict the bearing capacity of the pile. The piles were loaded up to the failure load when the results were obtained to compare the experimental load. And among these graphical methods for predicting the load-bearing capacities and load-settlement behavior of piles intended to be built in weak soil layers, closest values to ultimate loads were obtained by Mazurkiewicz method where the average upper limit value was obtained by Chin method**.** But to have the precise results, performing a load test is the best method to analyze the laying behavior of the pile and determine the breaking load of the pile. But due to time and material constraints, it cannot perform the pile test until it fails.

And reviewing all these researchers work, the most well-known and frequently applied Davisson Offset limit method, Chin-Kondner extrapolation method, and Markiewicz's approach to determine the ultimate bearing capacity using load settlement curve had used in this study work for better interpretation of the results.

So, in this research we have proposed to create soil models using PLAXIS 3D software considering both Mohr- Coulomb model (MC) & Hardening Soil Model (HS) to retain the load settlement value from those models and predicted the bearing capacity of pile using our proposed 3 methods for numerical analysis from load settlement curve. In order to distinguish the variations in the data values, we have also compared the load and settlement data from the static load tests performed on each pile from our research location of the proposed Hazrat Shahjalal International Airport expansion project with the field-tested soil sample data.

Chapter 03

3 Data Collection and Interpretation of Test Report

3.1 Introduction

For this research, the test data and results of the static pile load test for the terminal-3 building area of the planned Airport Expansion Project of Hazrat Shahjalal International Airport Dhaka were used. Relevant data of the proposed location were collected and sorted accordingly. For our study, all the relevant data and test reports were collected from the Aviation Dhaka Consortium (ADC) agency. Furthermore, a subsurface investigation report was used to interpret the soil parameters of the specified location correctly. The properties of each of the soil layers were determined using a variety of empirical equations.

3.2 Site Information

According to the report, a static pile load test was performed on a pilot bored pile with the ID: TP-5.4 and borehole no. BH-31 for the proposed airport expansion project at Hazrat Shahjalal International Airport, Dhaka 1229, Bangladesh. (AVIATION DHAKA CONSORTIUM, 2021).

3.3 Pile Description and Load Detail

Table 1: Pile description

Pile	Pilot pile
Pile Id	TP-5.4
Diameter	1000 mm
Pile length	30 m
Type of pile	Reinforced concrete bored cast-in-situ pile
Design load	3432.00 kN
Target test load	2.0*design load

3.4 Soil Profile

From the subsurface investigation report, it showed that the surface soil was relatively weak and soft, making it unstable to bear the weights of the concrete blocks. A soil improvement method was undertaken to solve this issue. The method involves excavating the soft soil to a certain depth and then replacing it with granular soil and brick aggregate to improve the bearing capacity of the soil. This was done precisely in distinct layers and crushed with a vibrating roller. The soil profile of the site consists of three distinctive layers, sand, silty sand and clay layers. Finally, a plate load test was performed to determine the load-bearing capacity of the soil.

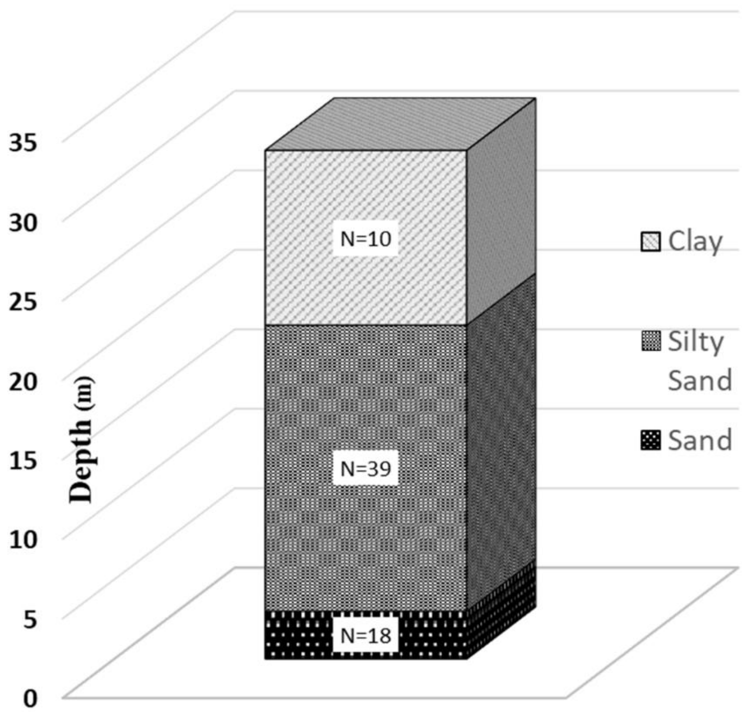


Figure 1: Soil profile

3.5 Soil Parameters Determination

The parameters of three distinctive soil layers were calculated through various empirical equations using the subsurface investigation report of the specified location. From the report, the N value from Standard Penetration Test (SPT) was used to calculate the parameters of each layer. The calculations are as follows:

3.5.1 Sand Layer

From the Sub-soil Investigation report, SPT N value = 18

Cohesion, c = 0 kPa (Terzaghi and Peck)

Angle of friction, Φ (°) = $0.3N – 0.00054N^2 + 27.1$ (Wolff, 1989)

$= 0.3*18 – 0.00054*18^2 + 27.1$

$= 32.33°$

Young's Modulus of Soil, Es, (AASHTO 2014):

For over consolidated sand, Es = 750(N) + 18000

= (750*18) + 18000 kPa

= 31500 kPa

Poisson's ratio = 0.2 (AASHTO 2004 and 2006)

3.5.2 Silty Sand Layer

From the Sub-soil Investigation report, SPT N value = 39

Cohesion, c = 0 kPa (Terzaghi and Peck)

Angle of friction, Φ (°) = $0.3N – 0.00054N^2 + 27.1$ (Wolff, 1989)

$= 0.3*39 – 0.00054*39^2 + 27.1$

$= 37.98°$

Young's Modulus of Soil, Es, (AASHTO 2014):

For Silty sand, $E_s = 300((N) + 6)$

$= 300*(39+6)$ kPa = 13500 kPa

Poisson's ratio = 0.2 (AASHTO 2004 and 2006)

3.5.3 Clay Layer

From the Sub-soil Investigation report, SPT N value = 10

Cohesion, c = 0.066N tsf (Terzaghi and Peck)

= 0.066*10*106 kPa

= 70 kPa

For undrained condition, $S_u = \tau = c + \sigma_0 \tan\phi$

$= c \ (\phi = 0)$

= 70 kPa

Angle of friction, Φ (°) $= 0.3N – 0.00054N^2 + 27.1$ (Wolff, 1989)

$= 0.3*10 – 0.00054*10^2 + 27.1$

$= 30°$

Poisson's ratio = 0.3 (AASHTO 2004 and 2006)

3.6 Static Load test

Static load tests are an essential tool for managing uncertainties in pile foundation design and construction (Liu et al., 2011). This test is used to determine the load-carrying capacity, as well as the structural integrity and safety of the material or structure. Unless there is a lot of experiential data, engineers normally do not immediately evaluate the outcomes of static load tests if the values from tests are even greater than the designed values (Liu et al., 2011).

The report used in this study is a thorough document comprising detailed information, experimental data, and results of a pile static load test performed on a sample bored pile identified as TP-5.4. Geo-Drill BD placed the piles and tested them on behalf of ADC, with assistance from Icon Engineering Services Limited. The goal of this test was to assess the TP-5.4 pile's load-bearing capacity and performance under various static loading circumstances. The paper analyzes the test results in detail, including load settlement behavior, ultimate load capacity, and pile stiffness characteristics. A pile load test was performed to assess the settlement under working load, verify the accuracy of the design bearing capacity, and determine the allowable bearing capacity.

3.6.1 Load Testing Procedure

The pile static load testing process generally includes included two cycles. The first cycle involved loading up to the specified load, while the second cycle involved loading up to the maximum applied load. The loading phase began at 25% of the maximum load capacity and increased to 100% before entering the unloading phase in the first cycle. Before beginning the unloading phase in the second cycle, the loading phase achieved a peak of 200% of the maximum load capacity. During the testing, a concrete block was used as a crib wall and counterbalance. The fluid pressure was carefully monitored with a calibrated pressure gauge, and the applied load was calculated by multiplying the fluid pressure by the hydraulic jack's ram area. Four dial gauges were used to compare pile head movement to two temporary reference beams. The entire testing procedure followed the guidelines given in ASTM D 1143.

A large bearing plate was placed on the pile head, and a solid rocker beam was placed over a hydraulic cylinder, to uniformly distribute the applied stress on the pile head. To reduce eccentricity and bending, a spherical seat was added between the hydraulic cylinder and the rocker beam. The applied force on the pile head is initially interacted to the rocker beam, which next passes the stress to the main response beam and, finally, to the spreader via a succession of subsidiary or spreader beams. As a counterbalance, solid concrete blocks were set in layers on the spreader beams.

3.6.2 Load Application and Measurement

The force applied to the pile head against the concrete block was measured with a hydraulic cylinder connected to a hydraulic power pack via a common manifold to verify that the same load was applied to each cylinder. The sum of the loads applied to the cylinder determined the imposed load on the pile. The pressure created in the hydraulic ram was measured with a calibrated pressure gauge, and the load was calculated by multiplying the developed pressure by the cross-sectional area of the ram.

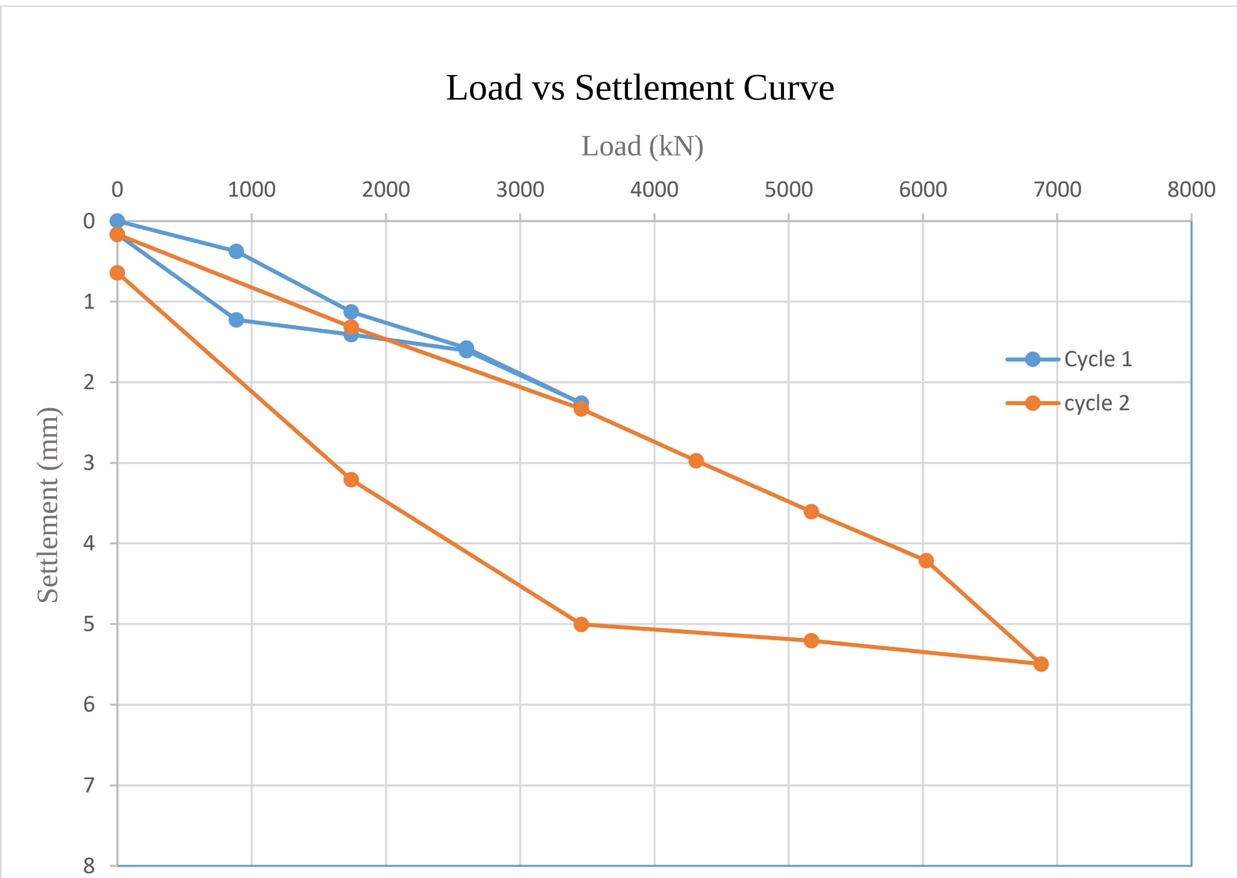
To ensure accuracy, the full load application setup, including the cylinder, pressure gauge, and hydraulic power pack, was calibrated as a whole at Bangladesh University of Engineering and Technology's (BUET) Strength of Material Lab, and any variations were accounted for in the computation. Dial gauges were used to measure the movement of the pile top against a pair of reference beams. For additional rigidity, the reference beams were secured to the ground by steel dowel bars submerged in concrete. Prior to the start of the test, all dial gauges were calibrated at the same lab.

3.6.3 Test Results

Table 2: Test results

Design load	3432 kN
Estimated test load	6864 kN
Maximum applied load	6880.73 kN, slightly increased due to rounding up the pressure
Maximum settlement	5.468 mm
Net settlement	0.631 mm

Design load 3432 kN is less than estimated allowable capacity, hence the design load is satisfactory. From the obtained data, load-settlement curve was generated.



Graph 1: Load-settlement curve generated from field load test

In order to generate a numerical model, the load data extracted from the report was employed in both the Mohr-Coulomb and Hardening Soil models. Additionally, a virtual soil profile was constructed utilizing the soil layer information obtained from the site.

Chapter 04

4 Methodology: Numerical Model Development and Bearing Capacity Determination

4.1 Introduction

This study's main goal was to evaluate the soil's ability to support loads for the proposed airport expansion project. So, the purpose of evaluating the soil's capacity to support loads, a substantial amount of data from static pile load tests were obtained and systematically compiled. After a thorough analysis of a comprehensive subsurface investigation report, the essential soil characteristics required for the Mohr Coulomb and Hardening Soil models were created using the relevant empirical equations. And after that numerical analysis was conducted to simulate the behavior of the piles under various loads using the PLAXIS 3D, a finite element program and the chosen soil models.

The results of the numerical analysis and the data from the field load test were then carefully compared while enabling a detailed assessment of both the accuracy and the dependability of the numerical simulation. Various methods that were applied to the load settlement curve were used to estimate the soil's capacity to support the anticipated loads in the surrounding areas of the proposed location. So finally, it could be concluded that our thesis work seeks to advance the development of accurate and dependable procedures for numerically simulating pile bearing capabilities.

4.2 Work Flow of the Numerical Analysis

The work flow diagram of the numerical analysis that we have conducted is demonstrated here:

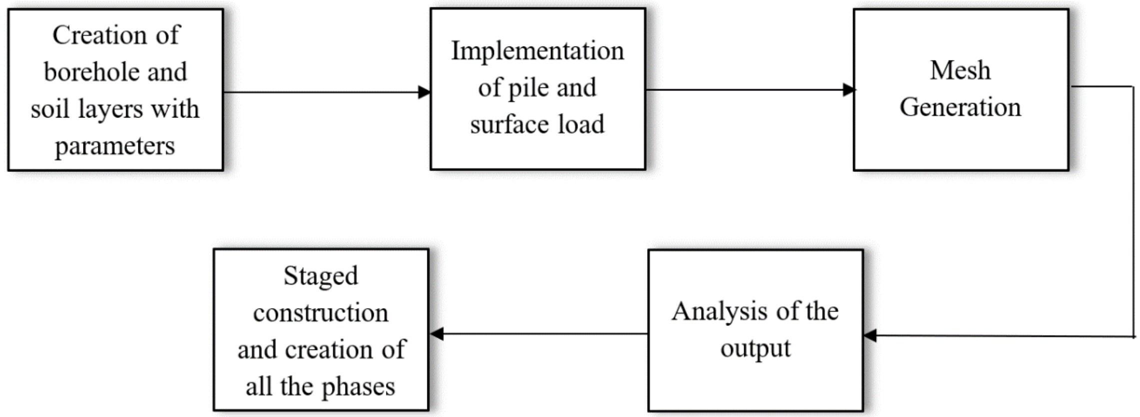


Figure 2: Work Flow Diagram

4.3 Soil Model

In this research, the numerical analysis is done using finite element method software PLAXIS 3D. The analysis has been conducted using both Mohr-Coulomb model and Hardening Soil model.

4.3.1 Mohr-Coulomb Model

Mohr-Coulomb model is a widely used soil model. This model is a first-order approximation of real-world soil behavior (Naveen et al., 2014). According to Mohr-Coulomb model, the soil's behavior is elastic until it reaches the yield point, beyond which it exhibits plastic deformation. Under varied loading situations, the model can forecast the stress-strain behavior of soil, shear deformation and failure process. The Mohr-Coulomb soil model has several limitations. It assumes isotropic and homogeneous soil behavior, which may not be true for all soil types. In order to solve this problem, Hardening Soil and other models should have been used to undertake sophisticated FEM simulations of the bearing capacity problem (Józefiak et al., 2015).

4.3.2 Hardening Soil Model

The Hardening Soil model is relatively precise soil model. It represents the actual soil properties accurately. The Hardening Soil Model is a more advanced method than the standard Mohr-Coulomb model and better describes soil behavior due to its hyperbolic stress-strain relation (Krasiński & Wiszniewski, 2017). Based on the concept of plasticity, this model implies that the soil experiences both elastic and plastic deformation. Under cyclic loading conditions, the hardening soil model can forecast the soil's stress-strain behavior, deformation features, and failure process.

4.4 Parameters

For both models, a three-layer soil profile was used, consisting of sand, silty sand, and clay layers. The parameters of these soil layers are as follows:

4.4.1 Mohr-Coulomb Model Parameters

The linear elastic perfectly-plastic Mohr-Coulomb model needs a total of five parameters, two stiffness parameters and three strength parameters, which can be obtained from basic tests on soil samples.

Table 3: Mohr-Coulomb Model Parameters

Symbol	**Name**	**Unit**	**Soil Layers**		
			Sand	**Silty Sand**	**Clay**
E	Young's modulus	[kN/m^2]	31500	14000	10500
v	Poisson's ratio	[-]	0.2	0.2	0.3
c	Cohesion	[kN/m^2]	0.1	1	70
φ	Friction angle	[°]	33	38	-
ψ	Dilatancy angle	[°]	3	8	-

4.4.2 Hardening Soil Model Parameters

The Hardening Soil model has several parameters that need to be specified for a given soil type.

Table 4: Hardening Soil Model Parameters

Symbol	Name	Unit	Soil Layers		
			Sand	Silty Sand	Clay
c_{ref}	Cohesion	[kN/m^2]	0.1	1	70
φ	Angle of internal friction	[°]	33	38	-
ψ	Angle of dilatancy	[°]	3	8	-
E_{50}^{ref}	Secant stiffness in standard drained triaxial test	[kN/m^2]	31500	14000	10500
E_{oed}^{ref}	Tangent stiffness for primary oedometer loading	[kN/m^2]	31500	14000	10500
E_{ur}^{ref}	Unloading / reloading stiffness (default $E^{ref} = 3E^{ref}$)	[kN/m^2]	94500	42000	31500
v	Poisson's ratio	[-]	0.2	0.2	0.3

4.4.3 Pile Properties

The pile parameters used in the numerical analysis are as follows:

Table 5: Pile Properties

Symbol	Name	Unit	pile
E	Young's modulus	[kN/m^2]	27.8E06
v	Poisson's ratio	[-]	0.15
c	Cohesion	[kN/m^2]	2500
φ	Friction angle	[°]	47
ψ	Dilatancy angle	[°]	17

4.5 Finite Element Model Development

PLAXIS 3D software had been used for finite element modeling in this study. It is a three-dimensional program that is specifically developed for the simulation of complicated soil and rock structures, as well as their interactions with adjacent structures. To run the simulation, the soil profile information as well as loading and unloading components were provided. Then the settlement value was compared to that of the field test.

4.5.1 Borehole and Soil Layer Creation

The research involves the creation of a model based on test report data that was used to investigate the behavior of a pile subjected to cyclic loads. To generate the model, a borehole was created at the soil section and the soil layers were then specified. Three separate soil layers, namely sand, silty sand, and clay, were found for the particular pile of interest, TP-5.4. The empirically interpreted soil parameters were added into the Mohr-Coulomb and Hardening Soil models. The groundwater table was considered to be at the top.

4.5.2 Pile Formation

A single pile was generated in the model's structure section using a volume pile with the proper dimensions and material characteristics defined. A positive interface was established around the pile to appropriately resemble the interaction between the soil and the pile.

4.5.3 Mesh Generation

For the model, a medium mesh was generated and the output was thoroughly checked to ensure accuracy.

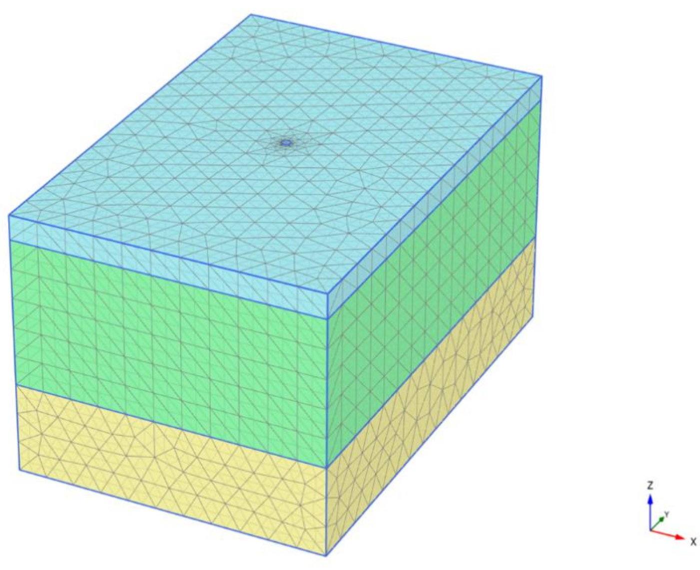


Figure 3: Mesh generated using Mohr-Coulomb Model

This is the mesh that was generated using Mohr-Coulomb model. Mesh can be generated as fine, coarse or medium. Here medium mesh is used for the Mohr-Coulomb model.

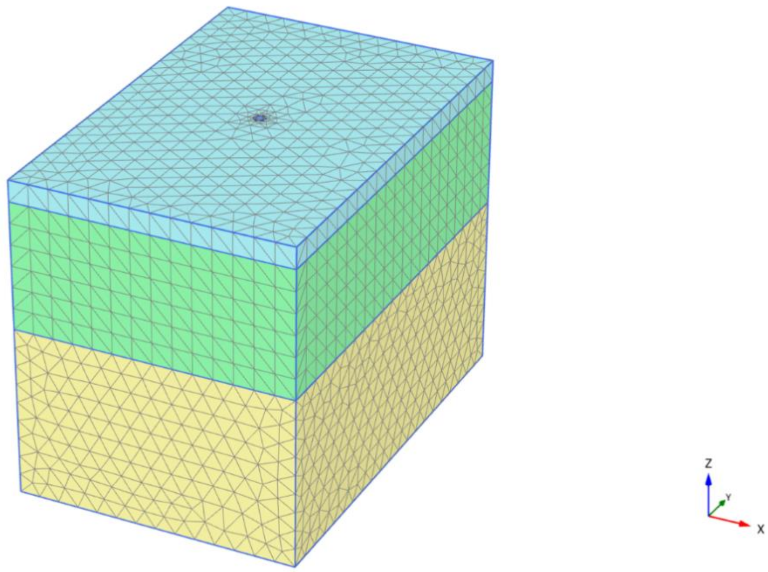


Figure 4: Mesh generated using Hardening Soil model

This mesh was generated using the Hardening Soil Model. Here medium mesh is used for the Hardening Soil Model.

4.5.4 Load Simulation

The model was then subjected to cyclic loading in the following stage of construction. The loading was set to be cyclic, with two different cycles consisting of loading and unloading phases. With the right time duration input, the incremental load started at 25% and progressed up to 100% of the maximum load in the first cycle. Following the loading phase, the unloading phase began, with the load decrementing proportionally. After the completion of the first cycle, the second cycle began, with the incremental load beginning at 25% and growing to a maximum of 200%. The loading phase was then completed, and the load was appropriately decremented.

Table 6: Loading-Unloading Considerations

Cycle	Stage	% of Design Load
1	Loading	0
		25
		50
		75
		100
	Unloading	75
		50
		25
		0

Cycle	Stage	% of Design Load
2	Loading	50
		100
		125
		150

		175
		200
	Unloading	150
		100
		50
		0

4.5.5 Calculation

The analysis was carried out when all relevant variables were entered, with the settlement for each load determined. Then the settlement comparison was performed using these values.

4.6 Bearing Capacity Determination

From The load-settlement curve which had been obtained from numerical model for our test pile BH31, the bearing capacity of pile would be calculated. The greatest load that a pile foundation can support without experiencing considerable movement or settlement is referred to as the bearing capacity of the pile foundation. It is a crucial factor in figuring out how a pile foundation should be designed. The static load test is a widely used technique for figuring out how much weight pile foundations can support. With this technique, the pile is loaded, and the subsequent movement is measured.

The readings can be used to calculate the pile's load-bearing capacity. From various reviewed paper it was noted that the researchers used various method to determine the ultimate bearing capacity of the pile foundation from load settlement curve. And from those methods of determining the bearing capacity of pile from Load-settlement curve, in this paper, 3 methods would be used - the most popular and widely used Davisson Offset limit method, Chin -konder extrapolation Method and Markiewicz’s Method. (Budi et al., 2015) used Davisson and Chin methods to determine bearing capacity of pile foundations which were interpreted from SLT results for 41 tested pile foundations where 13 pair of pile were embedded in sand layer and the rest of the 28 pair were in clay layer. (Adel & Shakir, 2022) used 15 interpreting methodologies to determine the ultimate load-carrying capacity from previously known pile load test data from different area of Nasiriyah, Southern Iraq. Then final bearing capacity with the specific settlement of each pile were obtained from the generated Load-settlement curve according to ASTM D 1143 guideline. (Adel & Shakir, 2022) also explained that among the other methodologies, Davisson offset limit method is likely to be the most well-known and widely utilized since it provides the least estimate of axial compression potential from the natural load-settlement curve without extrapolation criteria.

4.6.1 Davisson Offset Limit Method

According to Davisson (1972), the ultimate load exceeds the pile's elastic compression by 0.15-inch (ca. 4mm) plus a factor equal to the pile diameter divided by 120 which is basically indicated as offset (Adel et al., 2022). Generally, Davisson offset limit method is on the assumption of small toe movement which involves calculating the ultimate bearing capacity by identifying the intersection between the load-settlement curve and a line drawn at an offset distance from the initial tangent of the curve where OFFSET (mm) = 4 + (diameter of the pile)/120. Typically, the offset distance is between 0.2-0.4 times the diameter of the pile. And this approach enables the calculation of the safe bearing capacity of pile (Adel et al., 2022).

4.6.2 Chin-Kondner Method

Chin (1970) presented an application of Kondner's general approach to piles (1963). In this application of previous work, Chin assumes a hyperbolic relationship between load and settling. To apply the Chin-Kondner approach, the resultant value against the settlement would be plotted and each settlement would be divided by the corresponding load. After some initial volatility, the plotted data will fall on a straight line and the Chin-Kondner Extrapolation of the ultimate load would be the inverse slope of that line (Birid et al., 2017)

(Hussein, 2021) explained that as the resulting fall is smaller than that of the Davisson approach, Chin-kondner method may be much more acceptable because it achieves an acceptable maximum load. When a pile collapses, it is discovered that the resulting maximum load was not the load failure and that the settlement was low if the load was three times the real load. Hence, this analysis technique is sound. It is discovered that the generated load exceeds the test load if the pile is tested at double its operating load and does not fail. As a result, this approach is thought to be appropriate because it captures the actual circumstance and determines the maximum load when the pile succeeds or fails.

So previously discussed methods would be used to determine the ultimate bearing capacity of the tested pile foundation and justification and recommendation would be provided accordingly.

4.6.3 Mazurkiewicz Method

(Olgan et al., 2017) explained in their paper that among the graphical methods for predicting the load-bearing capacities and load-settlement behavior of piles intended to be built in weak soil layers, closest values to ultimate loads were obtained by Mazurkiewicz method.(Biridet al.,2017) presented the pile load settlement data from various project from different countries especially for India showed about 100% for all the analysis and was applicable for about 23 pile test where other methods showed 13-17% justification of the analysis. (Adel & Shakir, 2022) also explained that Mazurkiewicz's Techniques yielded the closest average failure load

As for Mazurkiewicz's method the load-settlement curve is assumed to be roughly parabolic in this approach (Abdelrahman et al., 2003). A random selection of equal pile head settling lines would made using equal intervals, and the appropriate loads would be recorded on the abscissa. Then a 45-degree line is drawn to cross the subsequent vertical line passing through the following load point for the marked loads on the load axis. These intersections roughly form a single straight line, and the point at which this line meet the load axis where the ultimate failure load is determined (Birid et al., 2017).

Chapter 05

5 Results and Discussion

5.1 Comparison of total displacement in between MC & HS Model

After generating the mesh, at stage condition, the total displacements at vertical direction (u_z) were recorded for 2nd cycle of 100%, 200% loading and 100% and 0% of unloading of design load for both MC & HS model from PLAXIS 3D software. After that, the settlement results were compared in between 2 models which are shown below:

5.1.1 At 100% Loading Stage

5.1.1.1 Mc model

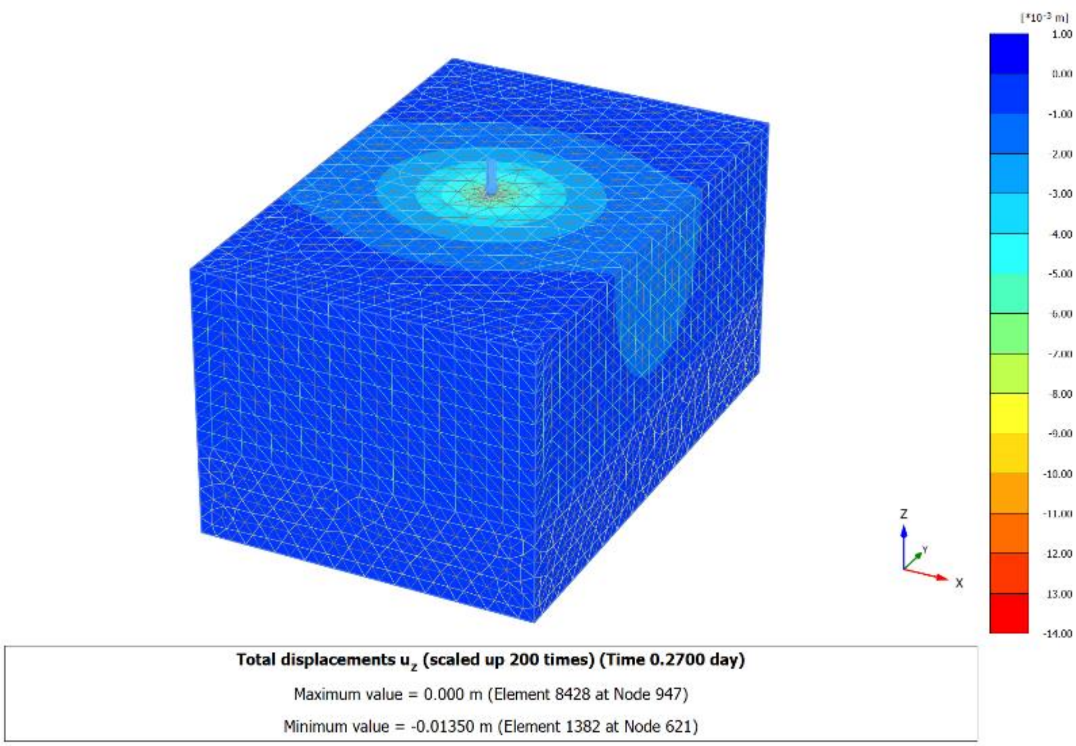


Figure 5: 100% loading stage of MC-Model

From the above figure of Mohr-Coulomb Model from Plaxis 3D output, at stage condition, for the phase of 100% loading which was 3454.73, applied to the test pile. After the application of 3454.73 KN of loading, the total displacement for the vertical direction for the pile was about 0.01350 m or 13.50 mm.

5.1.1.2 HS Model

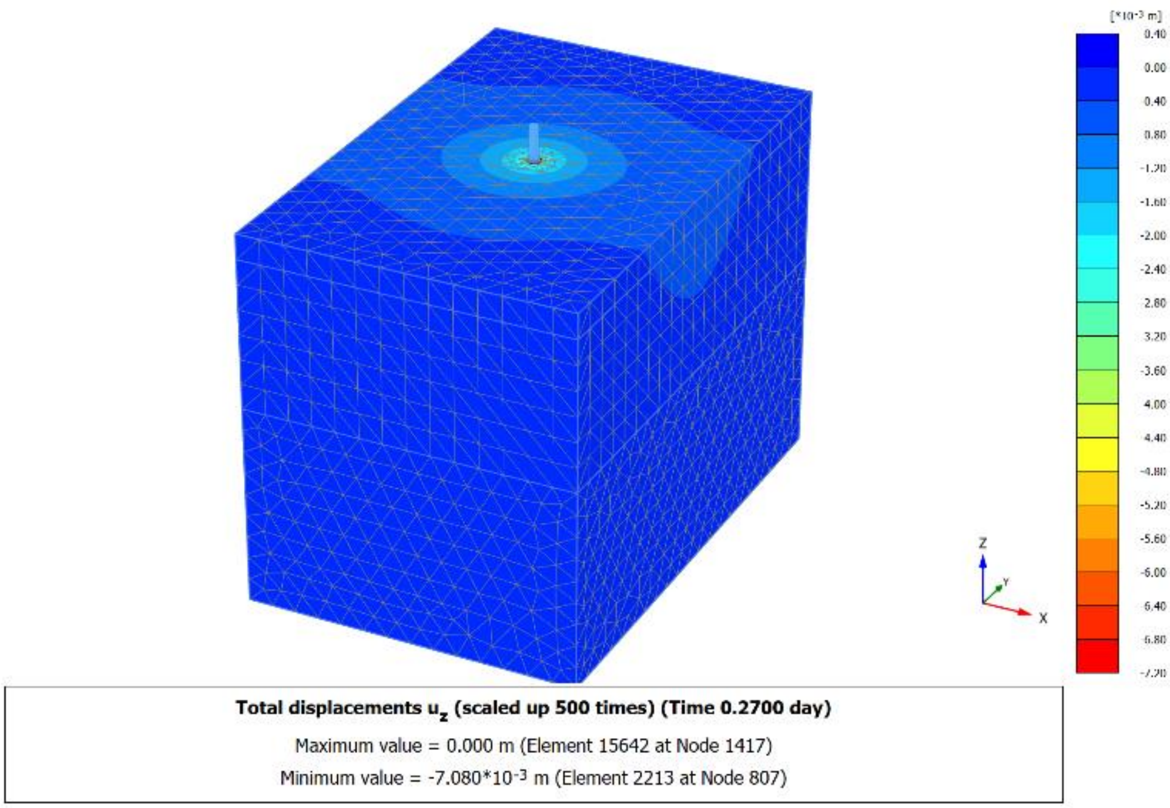


Figure 6: 100% Loading stage of HS Model

And similarly for Hardening Soil Model from Plaxis 3D output, at stage condition, for the similar phase of 100% loading which was 3454.73 KN, applied to the test pile. After the application of that 3454.73 KN of loading, the total displacement for the vertical direction for the pile was about 7.080 mm which was less than the result generated from MC-model, 13.50 mm.

5.1.2 At 200% Loading Stage

5.1.2.1 MC Model

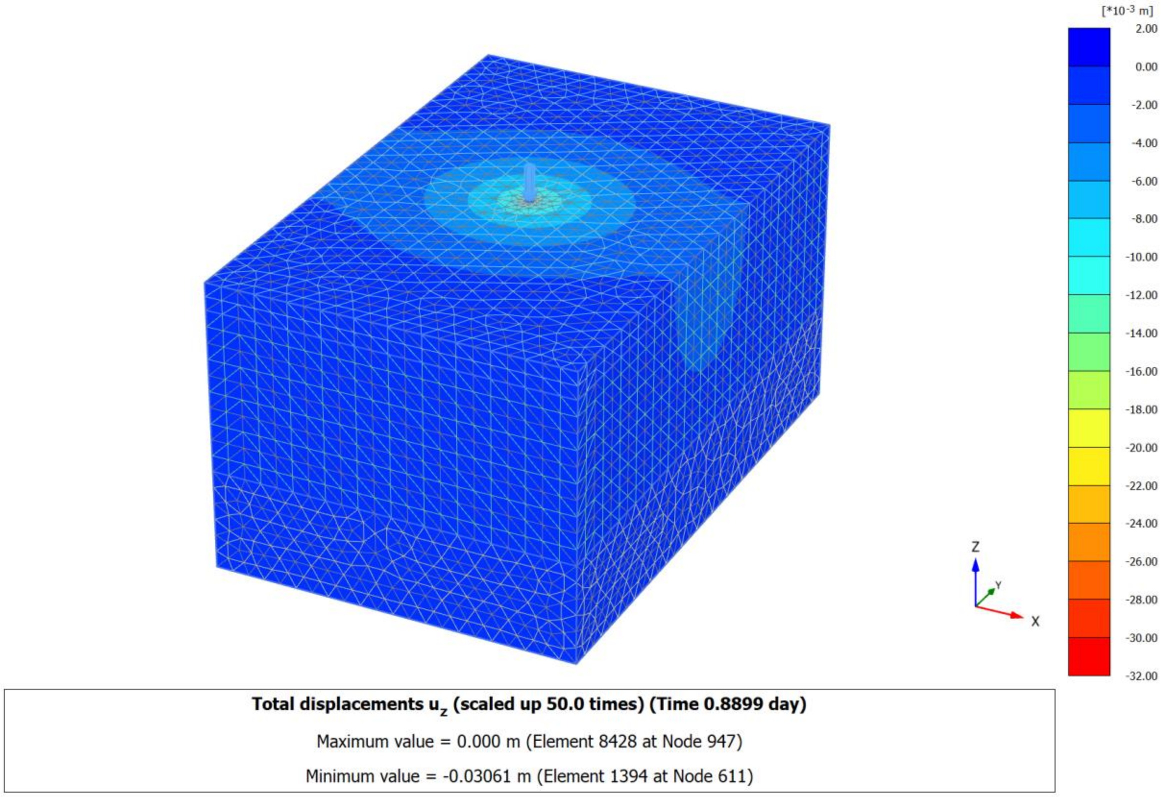


Figure 7: 200% Loading stage of MC-Model

From the above figure of Mohr-Coulomb Model from Plaxis 3D output, at stage condition, for the phase of 200% loading which was 6880.73 KN, was applied to the test pile. After the application of the 6880.73 KN of loading, the total displacement for the vertical direction for the pile was recorded which was about 0.03061 m or 30.61mm. But previously for 100% of loading for MC-Model which was about 3454.73 KN, the vertical displacement value was 13.50 mm. So, the 2 times of the 100% loading gives more than 2 times of the vertical displacement for the test pile.

5.1.2.2 HS Model

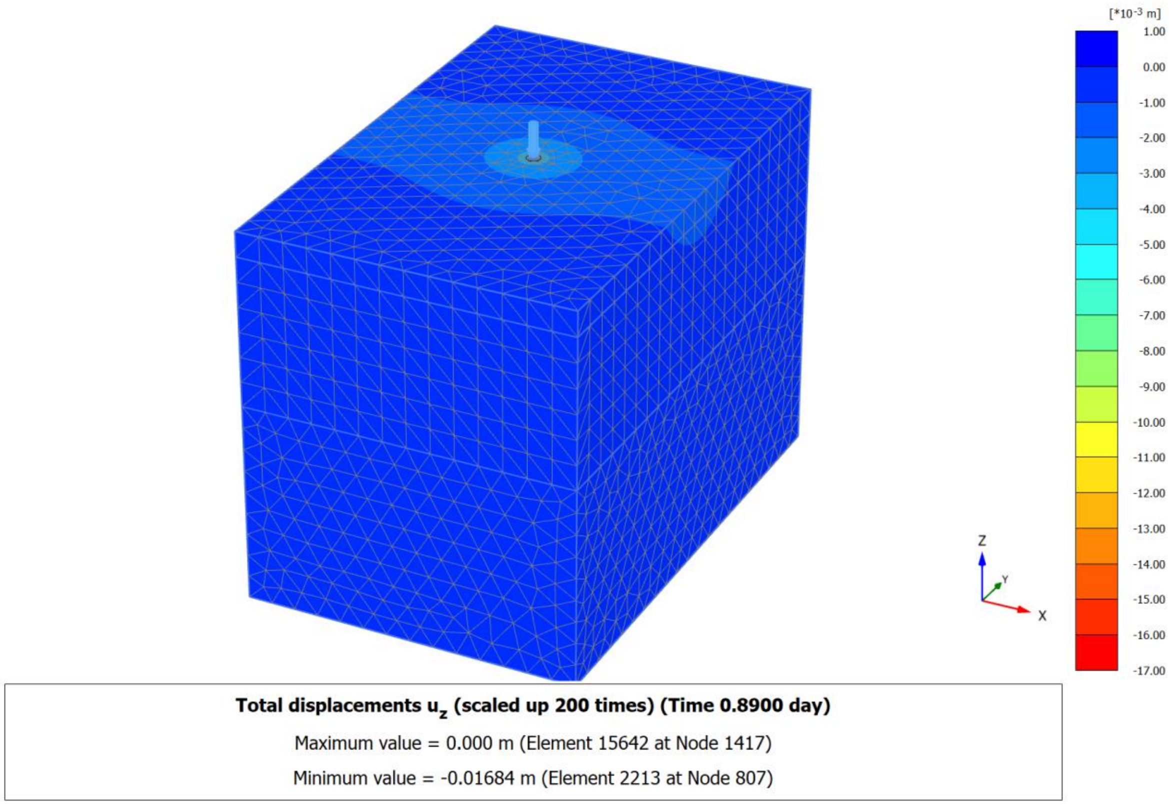


Figure 8: 200% Loading stage of HS-Model

And similarly for Hardening Soil Model from Plaxis 3D output, at stage condition, for the similar phase of 200% loading which was 6880.73 KN, was applied to the test pile. After the application of that 6880.73 KN of loading, the total displacement for the vertical direction for the pile was about 0.01684 m or 16.84mm which almost half of the value generated from MC Model. But for previously 100% loading the vertical displacement for HS-Model was 7.080mm which is half of the generated value than that of 200% loading.

5.1.3 At 100% Unloading Stage

5.1.3.1 MC Model

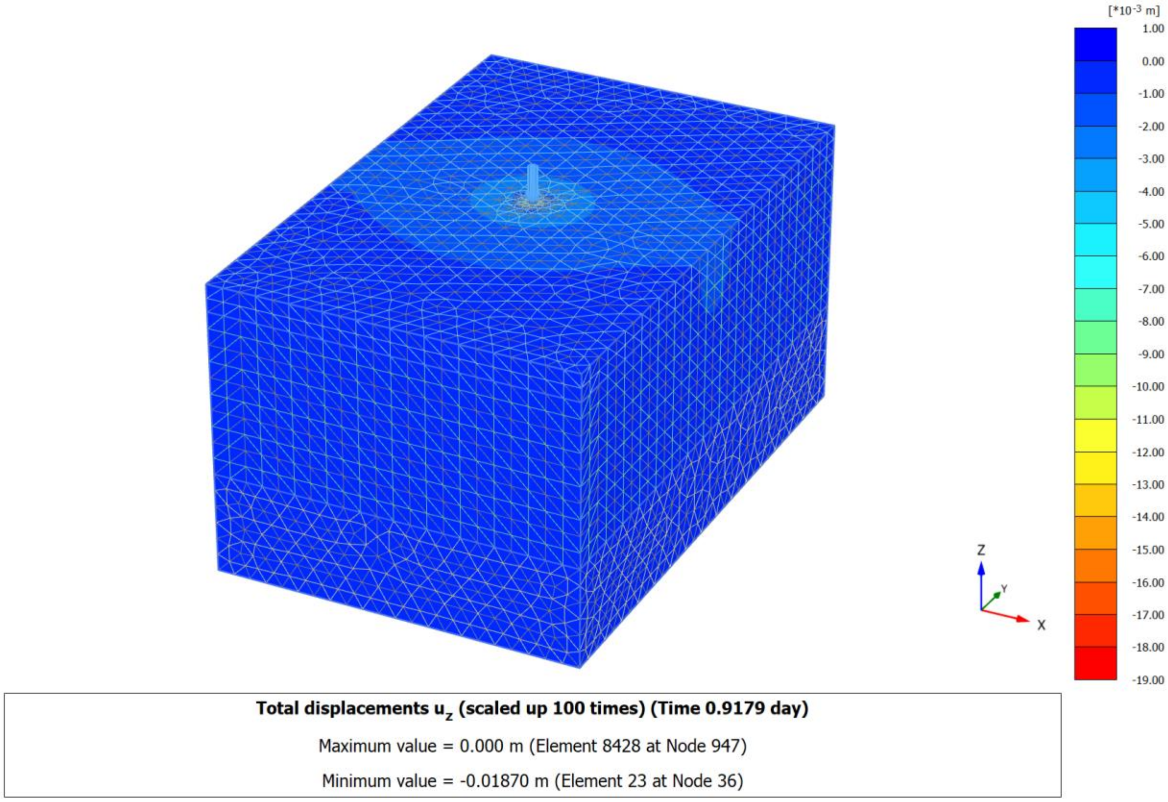


Figure 9: 100% Unloading Stage of MC-Model

From the above figure of Mohr-Coulomb Model from Plaxis 3D output, the results were recorded for unloading stage which means the applied load were gradually unloaded. So, at stage condition, for the phase of 100% unloading which was 3454.73 KN was unloaded from the test pile. After the unloading of the 3454.73 KN of load, the total displacement for the vertical direction for the pile was recorded about 0.01870 m or 18.70 mm.

5.1.3.2 HS Model

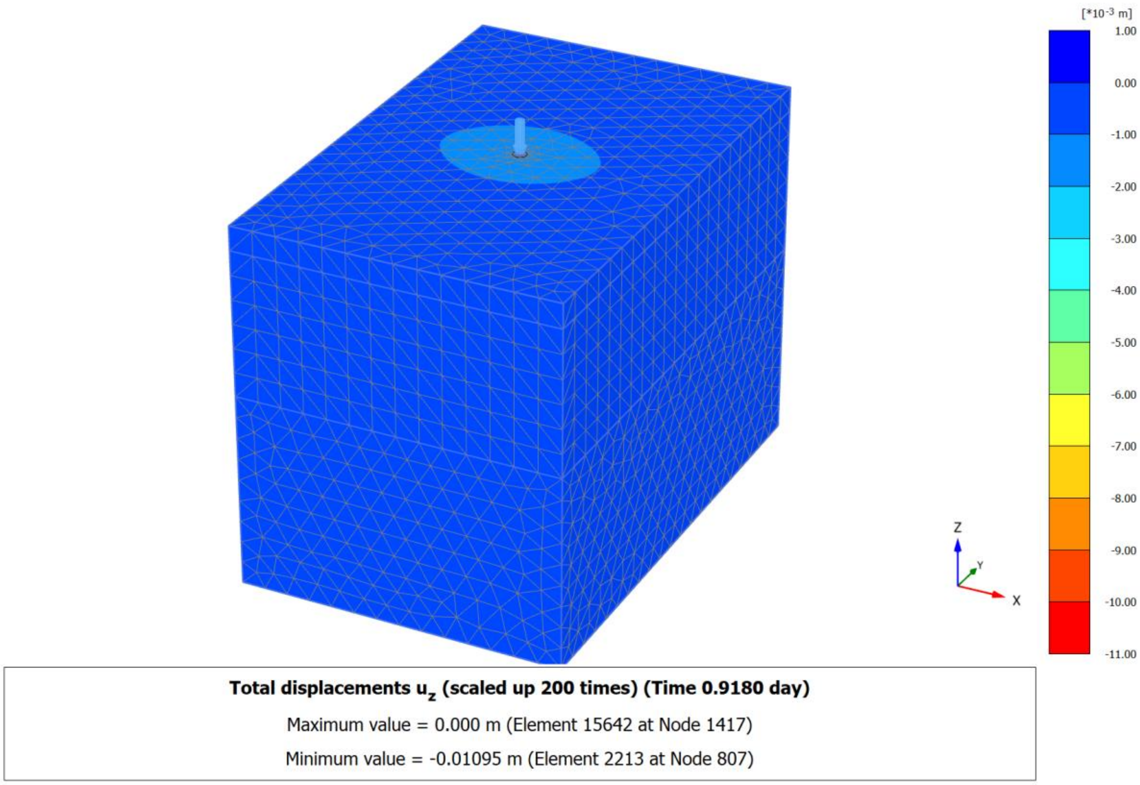


Figure 10: 100% Unloading stage of HS-Model

And similarly for Hardening Soil Model from Plaxis 3D output, at stage condition, for the similar phase of 100% unloading which was 3454.73 KN, the total displacement for the vertical direction for the pile was recorded about 0.01095 m or 10.95 mm which was more than half of the value than that of MC model, yet less than the generated result of MC-model which was 18.70 mm.

5.1.4 At 0% Unloading Stage

5.1.4.1 MC Model

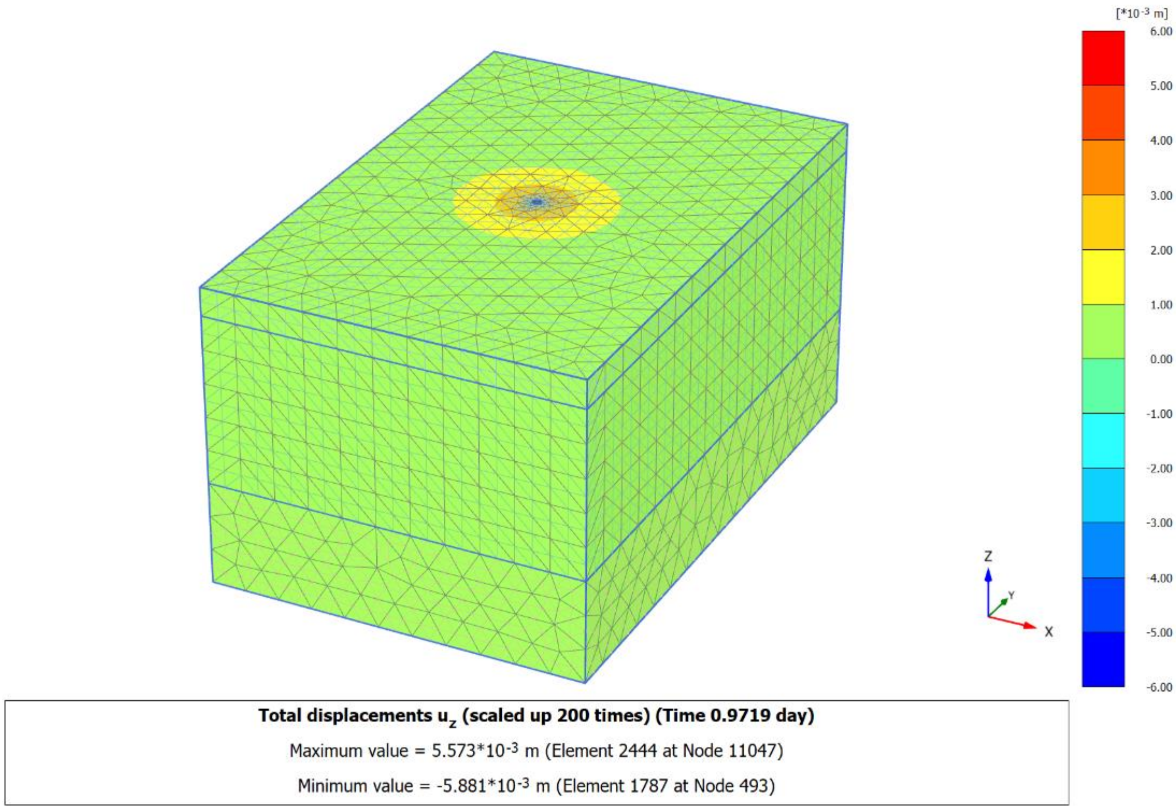


Figure 11: 0% Unloading stage of MC-Model

From the above figure of Mohr-Coulomb Model from Plaxis 3D output the results were recorded for unloading stage which means the applied load were gradually unloaded. So, at stage condition, for the phase of 0% unloading, the total displacement for the vertical direction for the pile was recorded about 5.881 mm.

5.1.4.2 HS Model

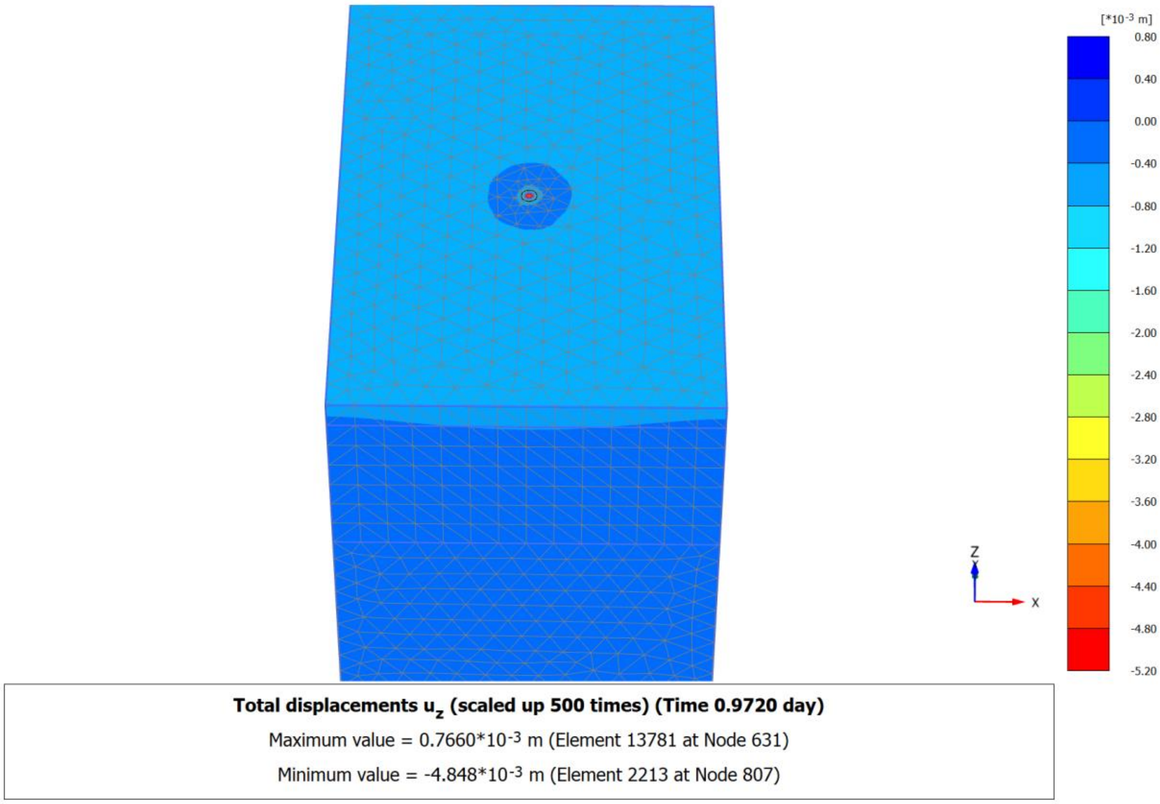


Figure 12: 0% Unloading stage of HS-Model

And similarly for Hardening Soil Model from Plaxis 3D output, at stage condition, for the similar phase of 0% unloading phase, the total displacement for the vertical direction for the pile was recorded about 4.848 mm which was less than the result generated from MC-model which was 5.881 mm.

Table 7: Summary table from PLAXIS 3D Output

Loading/Unloading	**Total Displacement(u_z), mm**	
	MC-Model	**HS- Model**
L100%	13.5	7.08
L200%	30.6	16.84
UL100%	18.7	10.95
UL0%	5.88	4.85

So, from the summary table it could be said that HS model has shown less displacement value than that of MC model. It is because the HS model shows much realistic settlement value than MC model as HS model consider soil as elastoplastic element where MC model, it's considered as elastic model. But these values also variate from the field load test values as in real life soil is not linearly elastic, shows plasticity while withdrawing failure loads.

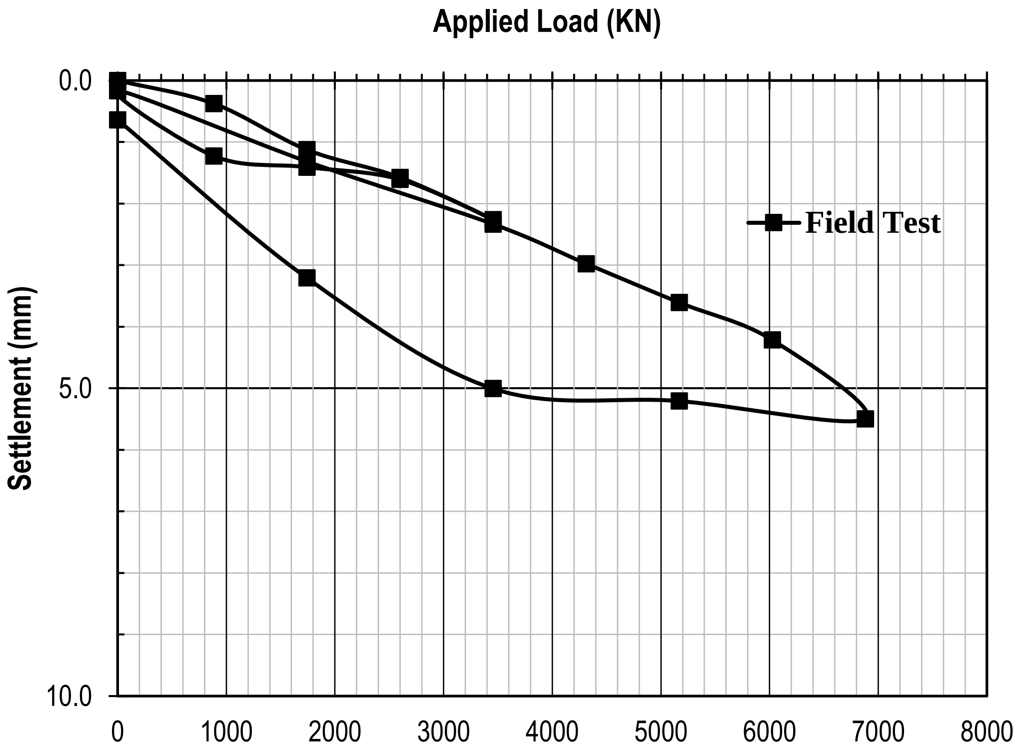
5.2 Load-settlement Curves of Pile

5.2.1 Field load test data

Table 8: Load-settlement data from field test

Cycle	Load (%)	Load, P	Settlement Top
1	0	0	0
1	25	885.23	0.375
1	50	1741.73	1.125
1	75	2598.23	1.575
1	100	3454.73	2.26
1	75	2598.23	1.607
1	50	1741.73	1.407
1	25	885.33	1.227
1	0	0	0.165
1	50	1741.73	1.315
1	100	3454.73	2.332
1	125	4311.23	2.975
2	150	5167.73	3.607
2	175	6024.23	4.215
2	200	6880.73	5.495
2	150	5167.73	5.207
2	100	3454.73	5.005
2	50	1741.73	3.207
2	0	0	0.64

A load settlement curve was generated from the field load test data.



Graph 2: Load-settlement Curve from field test

Above the curve shows the Load Settlement Curve which was generated from 2 cycle of loading and unloading of desired load to obtain the settlement against the corresponding loading from the static load test. From the graph we could see that for 1st cycle, up to the 125% of the loading was applied where unloading stage for first cycle was from 75% to 0% with the decrement of 25% of the load. And as for the second cycle of the loading, the loading stage was started at 150% of loading and then for the next steps the loading was increased 50% for each step and again decreased at the unloading stages to the 0% of load.

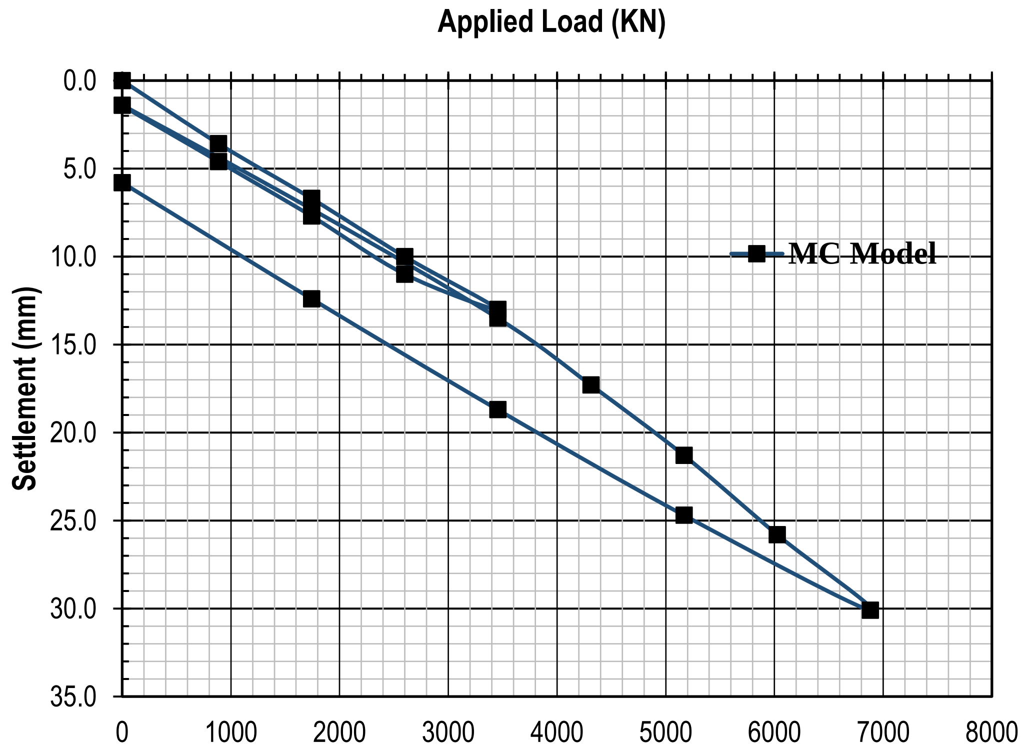
From the cycle of loading and unloading stages, the settlement values increase as the loading increased and the settlement value decreases as the unloading occurs in both cycles. The maximum settlement from the field test was for 2nd cycle of 200% loading and it was 5.495mm and the minimum settlement was for 1st cycle of 0% unloading and it was 0.165 mm.

5.2.2 MC Model Data

Cycle	Load (%)	Load, P	Settlement Top
1	0	0	0
1	25	885.23	3.58
1	50	1741.73	6.7
1	75	2598.23	10
1	100	3454.73	13
1	75	2598.23	11
1	50	1741.73	7.7
1	25	885.33	4.6
1	0	0	1.4
1	50	1741.73	7.3
1	100	3454.73	13.5
1	125	4311.23	17.3
2	150	5167.73	21.3
2	175	6024.23	25.8
2	200	6880.73	30.1
2	150	5167.73	24.7
2	100	3454.73	18.7
2	50	1741.73	12.4
2	0	0	5.8

Table 9: Load-settlement data from MC-Model

A load settlement curve was generated from the MC model data.



Graph 3: Load-settlement Curve from MC-Model

Above the curve shows the Load Settlement Curve which was generated from 2 cycle of loading and unloading of desired load to obtain the settlement against the corresponding loading from the Mohr-Coulomb Model. From the graph we could see that for 1st cycle, up to the 125% of the loading was applied where unloading stage for first cycle was from 75% to 0% with the decrement of 25% of the load. And as for the second cycle of the loading, the loading stage was started at 150% of loading and then for the next steps the loading was increased 50% for each step and again decreased at the unloading stages to the 0% of load.

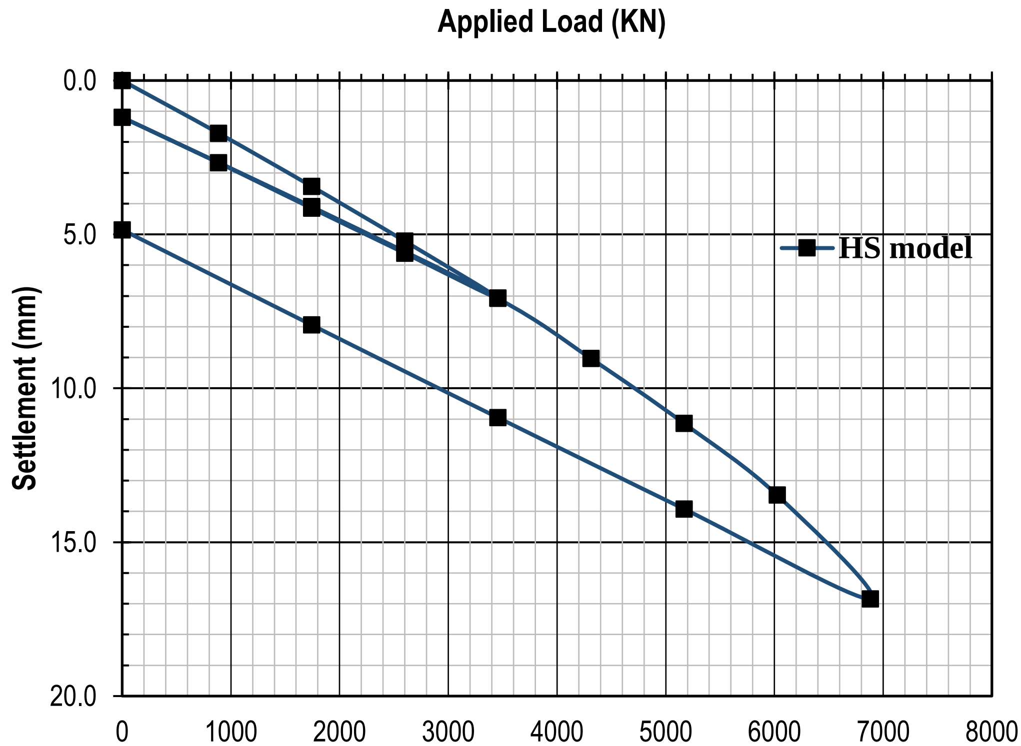
From the cycle of loading and unloading stages, the settlement values increase as the loading increased and the settlement value decreases as the unloading occurs in both cycles. The maximum settlement was for 2nd cycle of 200% loading and it was 30.1mm and the minimum settlement was for 1st cycle of 0% unloading and it was 1.4 mm.

5.2.3 HC Model Data

Table 10: Load-settlement Data from HS-Model

Cycle	Load (%)	Load, P	Settlement Top
1	0	0	0
1	25	885.23	1.71
1	50	1741.73	3.436
1	75	2598.23	5.217
1	100	3454.73	7.07
1	75	2598.23	5.608
1	50	1741.73	4.148
1	25	885.33	2.672
1	0	0	1.196
1	50	1741.73	4.098
1	100	3454.73	7.08
1	125	4311.23	9.032
2	150	5167.73	11.14
2	175	6024.23	13.47
2	200	6880.73	16.84
2	150	5167.73	13.92
2	100	3454.73	10.95
2	50	1741.73	7.94
2	0	0	4.848

A load settlement curve was generated from the HS model data.



Graph 4: Load-settlement Curve From HS-Model

Above the curve shows the Load settlement Curve which was generated from 2 cycle of loading and unloading of desired load to obtain the settlement against the corresponding loading from the HS-Model. From the graph we could see that up to the 125% of the loading was applied where unloading stage for first cycle was from 75% to 0% with the decrement of 25% of the load. And as for the second cycle of the loading, the loading stage was started at 150% of loading and then for the next steps the loading was increased 50% for each step and again decreased at the unloading stages to the 0% of load.

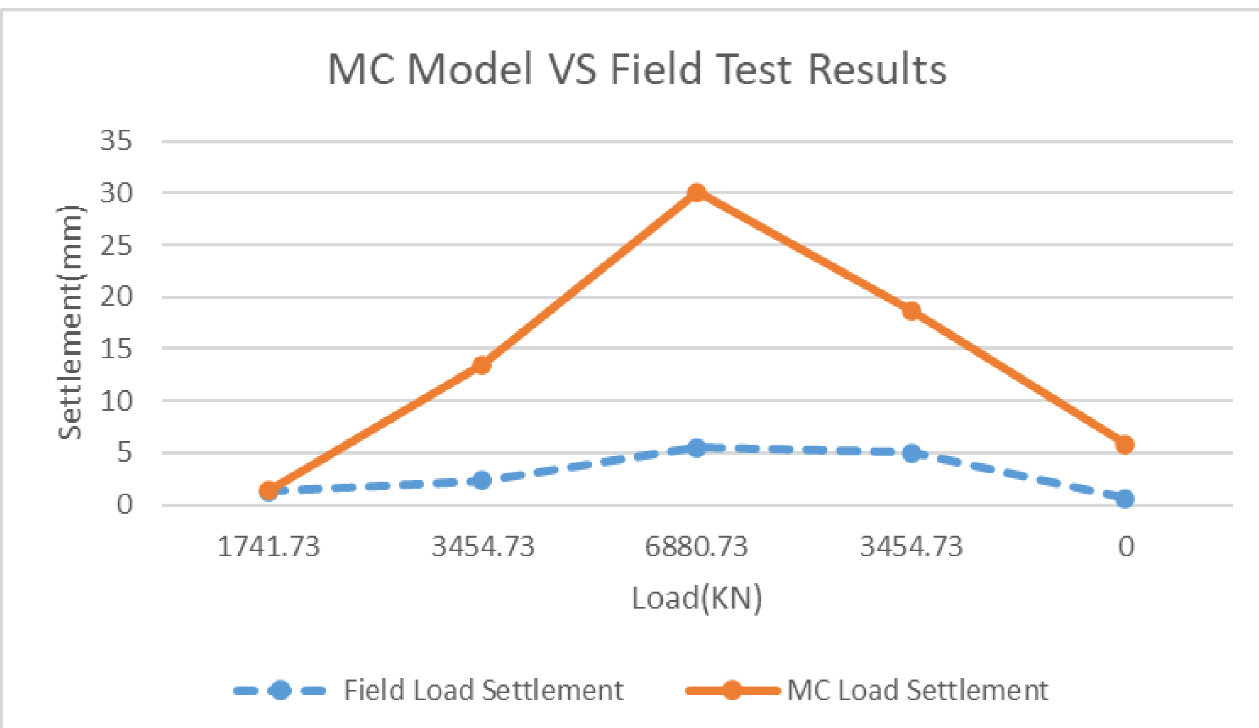
From the cycle of loading and unloading stages, the settlement values increase as the loading increased and the settlement value decreases as the unloading occurs in both cycles. The maximum settlement was for 2nd cycle of 200% loading and it was 16.84 mm and the minimum settlement was for 1st cycle of 0% unloading and it was 1.196 mm.

5.3 Comparison in Between Load-Settlement Curves

5.3.1 MC Model VS Field Load Test

Table 11: Load-settlement Data at several loading and unloading stage for MC-Model

Load (KN)	Settlement(mm)	Settlement From MC-Model(mm)
1741.73	1.315	1.4
3454.73	2.332	13.5
6880.73	5.495	30.1
3454.73	5.005	18.7
0	0.64	5.8



Graph 5: MC-Model Vs Field test Results

Above the graph, the settlement results in between Mohr- Coulomb Model and Field load test results were compared.

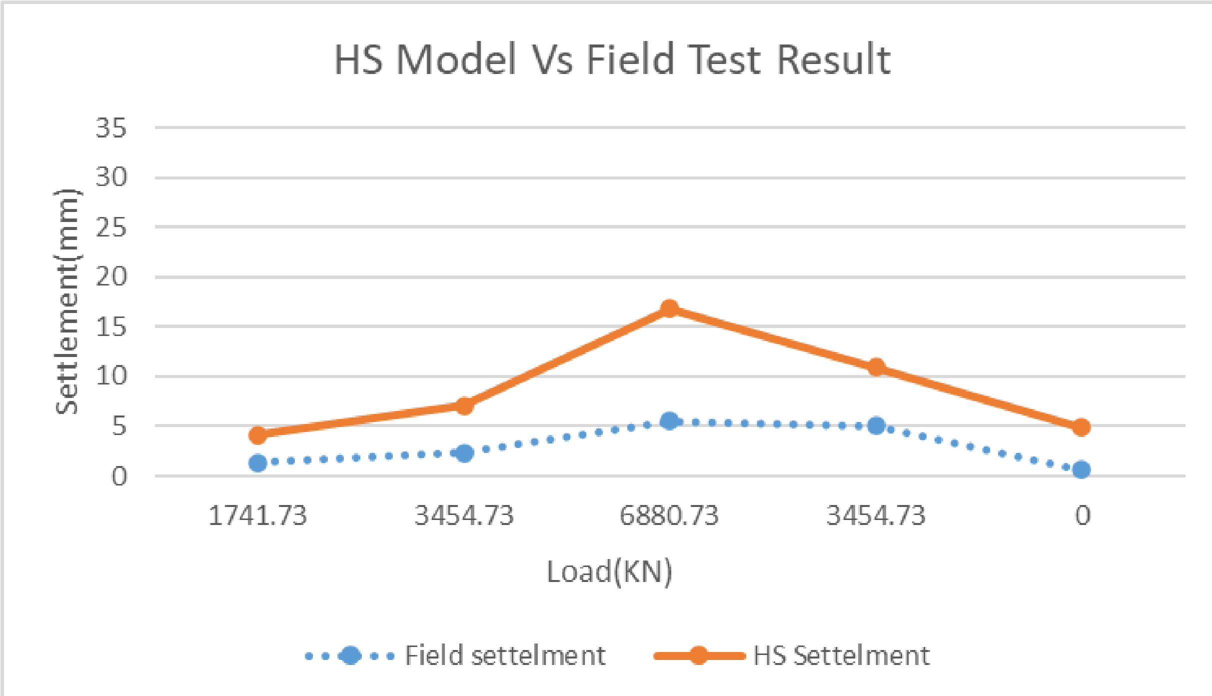
From the above curve, we could see that at the 50% loading, about 1741.73 KN of load the settlement value from field result were 1.315mm where from MC-model the settlement Value was 1.4 mm which didn't deviated much. At 100% loading of 3454.73 KN of load the settlement result from the field test was 2.332 but as for the MC-Model it was 13.5 mm which was more than 6 times of the field test result. Similarly for 200% loading of 6880.73 KN of load, the settlement value from the field test was 5.495 mm where from MC-Model it was 30.1 mm which was the highest settlement value among both Field test and Mc -Model even it was more than 12 times of the settlement value for 200% loading for field test.

Similarly at 100% unloading of 3454.73KN, the settlement value from the field test was 5.005mm where from the MC-model the value was 18.7 mm which is more than 3 times of the field load test value. And finally for the 0% unloading, the settlement results from both field load test and MC -Model were 0.64 mm and 5.8 mm respectively.

5.3.2 HS Model VS Field Load Test

Table 12: Load-settlement Data at several loading and unloading stage for HS-Model

Load (KN)	settlement(mm)	Settlement from HS Model(mm)
1741.73	**1.315**	**4.098**
3454.73	**2.332**	**7.08**
6880.73	**5.495**	**16.84**
3454.73	**5.005**	**10.95**
0	**0.64**	**4.848**



Graph 6: HS-Model Vs Field test Results

Above the graph, the settlement results in between Hardening Soil Model and Field load test results were compared.

From the above curve, we could see that at the 50% loading, about 1741.73 KN of load, the settlement value from field result were 1.315mm where from HS-model the settlement Value was 4.098mm which deviated about 3mm. At 100% loading of 3454.73 KN of load, the settlement result from the field test was 2.332 but as for the HS-Model, it was 7.08 mm which was more than 3 times of the field test result. Similarly for 200% loading of 6880.73 KN of load, the settlement value from the field test was 5.495 mm where from HS-Model, it was 16.84 mm which was the almost half of the value than MC-Model settlement value and even almost 3 times more than the field test result.

Similarly at 100% unloading of 3454.73KN, the settlement value from the field test was 5.005mm where from the HS-model the value was 10.95 mm which is about 2 times of the field load test value but is about 8 mm less than the MC-model value. And finally for the 0% unloading, the settlement results from both field load test and HS -Model were 0.64 mm and 4.848 mm respectively.

So, Comparing the settlement results at 50%,100%,200% loading and 100% ,0% unloading stage, HS-Model settlement value showed less deviated results than that of MC-Model from field load test results.

5.4 Bearing Capacity Prediction

5.4.1 From Field Load Test

For test pile TP5.4, the Bearing Capacity from

Davisson method

- Ultimate Carrying Capacity: Out of Range
- Allowable carrying capacity; half of max net shaft load:3440

Tarzaghi:

- Ultimate Carrying Capacity, at 10% of Pile width: Out of Range
- Allowable Carrying Capacity, Half of above:3440 KN

Is2911 part-4

- Load corresponding to a settlement of 12 mm: out of Range

Allowable Carrying Capacity, Two third of Above: 4586KN

5.4.2 From Graphical Methods

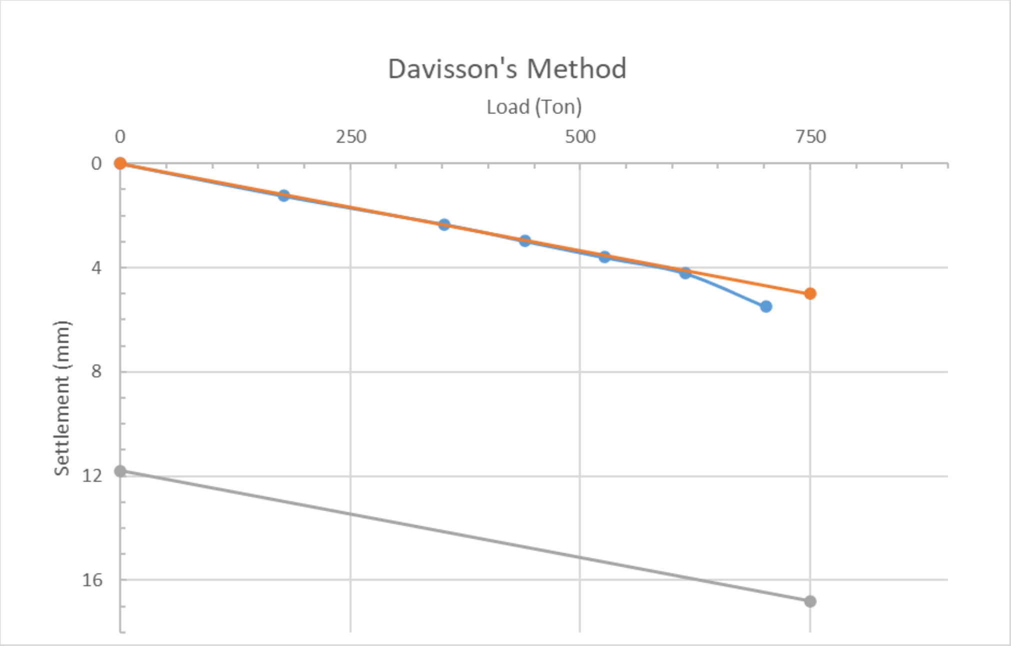
In our study, we have considered 3 graphical methods to predict the ultimate bearing capacity of pile from field test's load settlement data.

These methods are:

1. Davisson Offset limit Method
2. Chin-Kondner Extrapolation Method
3. Mazurkiewicz's Method

5.4.2.1 Davisson Offset limit Method

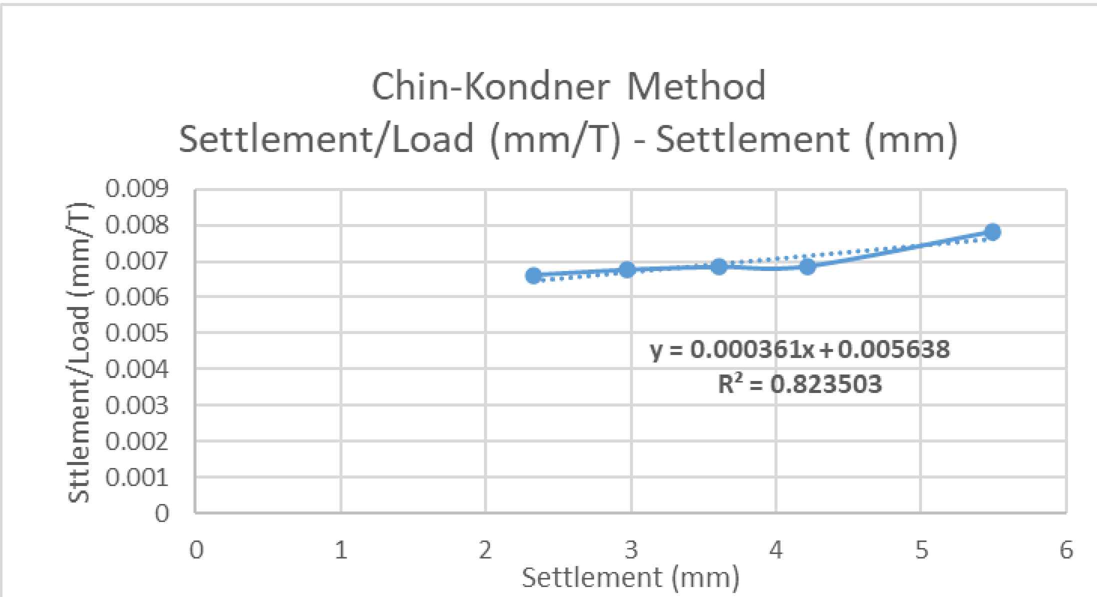
As per Davisson method the ultimate bearing capacity is value of the intercept point in between the load-settlement curve and a line drawn at an offset distance from the initial tangent of the curve where OFFSET (mm) = 4 + (diameter of the pile)/120. But this method is applicable for pile under failure loading, so for our case the result is shown as out of range.



Graph 7: Davisson Offset Limit Method

5.4.2.2 Chin-Kondner Extrapolation Method

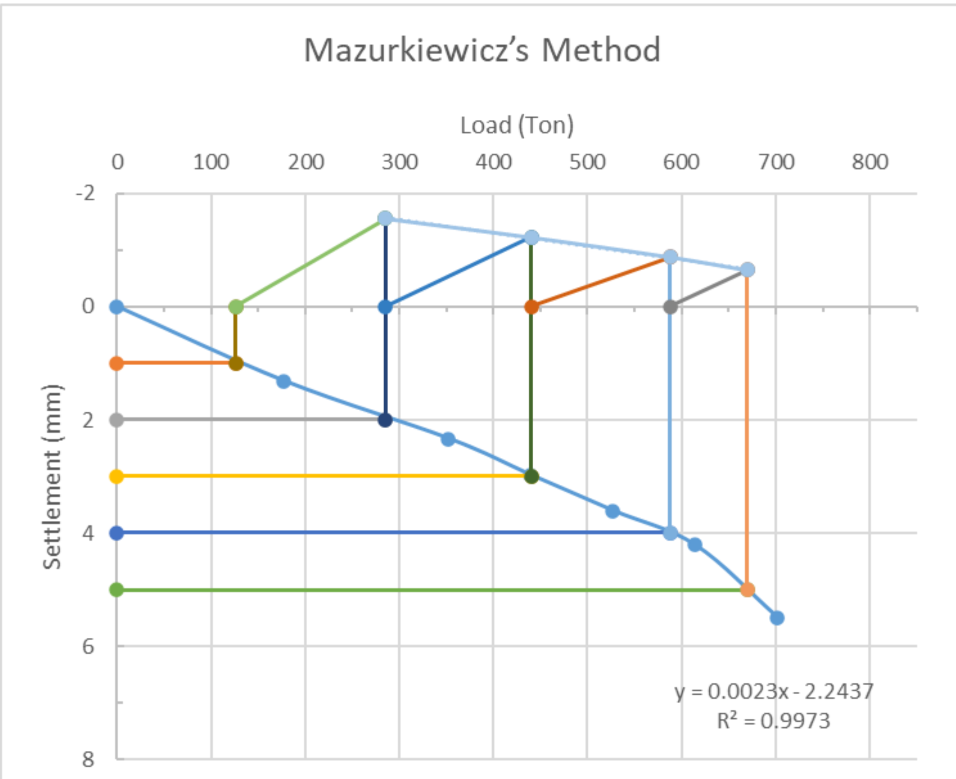
As per chin method, the value of bearing capacity is the inverse slope of the straight line which is generated from the Settlement/load Vs Settlement graph. And for this case the value of Q_U is 2770 KN/m^2.



Graph 8: Chin-Kondner Extrapolation Method

5.4.2.3 Mazurkiewicz's Method

As for this graphical method, for the equal interval of the settlement value, 45^o angled straight line is drawn from each corresponding load value. And the y intercept of a straight line which intersect the all-previously drawn lines, is the ultimate bearing capacity of the pile. And for our case, this value is Q_u= 975.52 KN/m^2.



Graph 9: Mazurkiewicz's Method

Chapter 06

6 Conclusion and Recommendations

6.1 Introduction

This chapter summarizes the key findings of our study and makes practical recommendations based on the results. As part of our research, we considered various aspects related to the research question, obtained valuable insights and contributed to the existing body of knowledge. This final chapter provides an overview of the main findings, addresses research limitations, and outlines possible scopes for future research. In this way, we aim to provide a comprehensive understanding of the research and encourage further research in this area.

6.2 Key Findings

Our work employs Plaxis software to simulate the load-settlement behavior of the soil without doing in-situ load testing. This discovery helps in the search for more affordable alternatives to traditional methods. The realistic simulation of soil behavior during the loading and unloading stages is facilitated by Plaxis software, which also offers useful insights into soil reactivity in a range of circumstances.

For Our study, selection of soil models is a crucial component. We observed that the results from the hardening soil model are more accurate than those from the Mohr-Coulomb soil model. This shows that by capturing subtle distinctions and deviations in soil activity, the hardening soil model accurately depicts the actual soil conditions.

In addition, our research examines the usefulness of modelling load settlement behavior. We show that examining the load settlement characteristics acquired from simulations helps figuring out how much weight pile foundations can support. For engineers and professionals involved in the design and construction of piling foundations, this information is helpful since it promotes better decision-making and improves structural performance. We also look at different approaches to figuring out pile bearing capacity. Our findings show that the Mazurkiewicz approach consistently produces lower bearing capacity values than Chin method and for the Davisson's offset limit method, which is only accurate when the pile is loaded till failure. These results emphasize the significance of precise pile load capacity estimation and method selection to provide reliable and secure structural systems.

In conclusion, this research provides useful information for geotechnical engineers by demonstrating the Plaxis software's capabilities in modelling soil load settlement behavior. Our study has advanced knowledge in this area by identifying the benefits of soil models, comprehending simulation bearing capacity estimation, and analyzing various approaches for figuring out the bearing capacity of piles.

6.3 Recommendations

The simulation accuracy of the soil models were tested by comparing laboratory test results with simulation results. Performing laboratory tests will provide more accurate results for the simulation of soil models. While simulation software like Plaxis offers convenience and cost-effectiveness, it may not fully capture the complexity and variations of soil behavior with absolute accuracy. Hence, performing laboratory tests provides a means to enhance the accuracy of soil modeling simulations. Additionally, advanced soil models can incorporate additional parameters and account for complex soil behavior characteristics, leading to more accurate predictions. Utilizing these advanced soil models allows for improved accuracy when simulating the settlement behavior of loads, thereby providing valuable insights into the soil's response under various loading conditions. In summary, combining laboratory testing with advanced soil models presents a comprehensive approach to simulating soil behavior, facilitating efficient and reliable geotechnical analysis while enhancing understanding of soil behavior and contributing to more precise engineering design.

6.4 Future Scopes

To draw definitive conclusions regarding changes in settlement behavior concerning soil type, it is advisable to conduct load test simulations utilizing Plaxis-3D across diverse soil profiles at multiple locations. Expanding the scope of the study to encompass various soil types and geological conditions allows for a more comprehensive comprehension of settlement behavior. This approach enables the assessment of how distinct soil properties, including grain size, composition, and compaction, influence the response to subsidence. By incorporating data from multiple locations, the study can account for regional discrepancies and offer a broader perspective on patterns of settlement behavior. Ultimately, undertaking extensive investigations through Plaxis 3D simulations will contribute to a more robust and dependable characterization of load settlement behavior associated with different soil types.

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