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Comparative Analysis of Piles under Change in Variables using Plaxis 2D

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Abstract - The past two decades have seen a remarkable increase in the rate of construction of high-rise buildings or other civil structures which produce excessive loads, excessive settlements and differential settlements. As a solution to the settlement problem of high-rise buildings, many designers use pile foundation design by considering different number of piles, length of the pile and diameter of the piles. In this paper a pile foundation for a large multi storey building (G+14) is studied as a case study. Analysis of total settlement, pile settlement, axial force and bending moment within piles under change in variables such as diameter, spacing and length of pile using finite element method (FEM) tool Plaxis 2D is calculated. Finally, the behavior of piled w.r.t effect of diameter of piles, spacing between piles, and length of pile on total settlement, pile settlement, axial force and bending moment of pile foundation system are assessed and conclusions are made

***Key Words*:** *Pile Foundation, Finite Element Method (FEM), Plaxis 2D*

1.INTRODUCTION

To carry the excessive loads that come from the superstructures like high-rise buildings, bridges, power plants or other civil structures and to prevent excessive settlements, piled foundations have been developed and widely used in recent decades. A pile foundation is defined as a series of columns constructed or inserted into the ground to transmit loads to a lower level of subsoil. A pile is a long cylinder made up of a strong material, such as concrete. Piles are pushed into the ground to act as a steady support for structures built on top of them. Piles transfer the loads from structures to hard strata, rocks, or soil with high bearing capacity. The piles support the structure by remaining solidly placed in the soil. As pile foundations are set in the soil, they are more tolerant to erosion and scour. Piles are driven into the ground to a stable platform. This is commonly bedrock but can be other stable material. Engineers determine the number and size of the pile based on the weight and size of the building. The piles anchor the building to the bedrock insulating it from any movement of the upper-level soils. In this paper a pile foundation for a large multi storey building (G+14) is studied as a case study. Analysis of total settlement, pile settlement, axial force and bending moment within piles under change in variables such as diameter, spacing and length of pile using finite element method (FEM) tool Plaxis 2D is calculated. Finally, the behavior of piled w.r.t effect of diameter of piles, spacing between piles, and length of pile on total settlement, pile settlement, axial force and bending moment of pile foundation system are assessed.

II. PLAXIS 2D

Geotechnical applications often require advanced constitutive models for the simulation of the non-linear, time-dependent, and anisotropic behaviour of soils and rock.

Developed by Bentley Systems, PLAXIS is a user-friendly, finite element package with trusted results that are used by geotechnical engineers globally. From excavations, embankments, foundations, tunnelling, and mining to reservoir geomechanics, users can determine deformation and stability to assess the geotechnical risk. An extensive range of 2D and 3D versions are available, including finite element analysis (FEA), limit equilibrium, dynamics, and transient groundwater flow and thermal capabilities, to suit your project requirements and budget. Geometry creation tools and automated settings allow you to solve geotechnical problems efficiently and accurately with minimum training.

III. OBJECTIVES

- Interpretation of borehole data, in-situ tests, laboratory tests to derive ground model and characteristic geotechnical parameters using correlations.
- Analysis of pile foundation under presumed structural load when diameter, spacing and length of pile is varied.
- Comparative analysis of axial force, bending

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moment and shear forces along with vertical settlements within piles under change in variables such as diameter, spacing and length of pile using finite element method (FEM) tool Plaxis 2D

IV. METHODOLOGY

This section discusses in detail the study undertaken to achieve the objectives set. This also sequentially defines the process, assumptions and approach followed to find the solution for a generic piled-raft foundation. To briefly understand the flow of work in sequence a flowchart has been shown below:

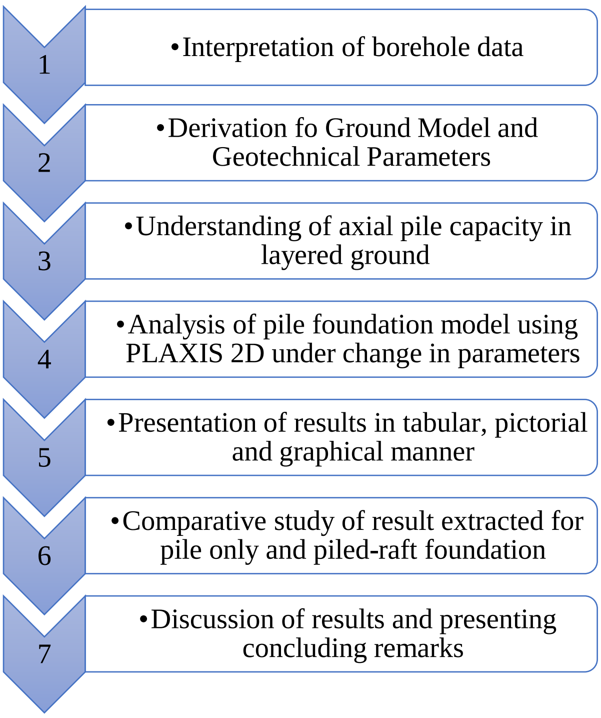


Figure 1: Flowchart for Methodology

V. INTERPRETATION OF BOREHOLE DATA

Borehole surveys use site investigation methods to extract core soil samples across a site, allowing for a picture to be built up of how the site has formed over time, and to identify any layers, features or areas which might be archaeologically significant. The boreholes (BH01, BH02, BH03 and BH04) were drilled and investigated during Sept 19-25, 2021. Visual observations reveal the following generalized information:

1. Depth of drilling of boreholes was 15 m to 25 m.
2. Layer wise strata distribution in each borehole is presented in following table:

Table 1: Borehole Data

BH No.	Description	Top(mbgl)	Bottom(mbgl)	Thickness(m)
BH01	Black Cotton Soil	0	1.5	1.5
BH01	Sand	1.5	4.5	3
BH01	Clay	4.5	7.5	3
BH01	Boulders	7.5	10.5	3
BH01	Clay	10.5	12	1.5
BH01	Sandstone	12	19.5	7.5
BH01	Basalt	19.5	25	5.5
BH02	Black Cotton Soil	0	1.5	1.5
BH02	Clay	1.5	3	1.5
BH02	Sand	3	4.5	1.5
BH02	Boulde rs	4.5	7.5	3
BH02	Clay	7.5	10.5	3
BH02	Boulde rs	10.5	12	1.5
BH02	Sandstone	12	15	3
BH03	Black Cotton Soil	0	1.5	1.5
BH03	Sand	1.5	6	4.5
BH03	Boulders	6	9	3
BH03	Clay	9	12	3
BH03	Boulders	12	13.5	1.5
BH03	Sandstone	13.5	22.5	9
BH03	Basalt	22.5	25	2.5
BH04	Black Cotton Soil	0	3	3
BH04	Clay	3	4.5	1.5
BH04	Sand	4.5	6	1.5
BH04	Clay	6	9	3

BH04	Boulders	9	10.5	1.5
BH04	Sandstone	10.5	15	4.5

VI. DERIVATION OF GROUND MODEL AND GEOTECHNICAL PARAMETERS

In the assessment of geotechnical parameters for foundation design, it is first necessary to review the geology of the site and identify any geological feature that may influence the design and performance of the foundation. A desk study is usually a first step, followed by site visits to observe the topography and any rock or soil exposures. Local experience, coupled with a detailed site investigation program, is then required. The site investigation is likely to include a comprehensive boreholes drilling (already discussed in previous section) and in-situ testing program together with a suite of laboratory tests to characterize strength and stiffness properties of the subsurface conditions. Based on the findings of the site investigation, the geotechnical model and associated design parameters are developed which are then used in foundation design process.

VII. DESIGN PARAMETERS

Many contemporary foundation systems incorporate both pile and a raft, and in such a cases the following parameters required for assessment:

1. Unit weight
2. Angle of internal friction
3. Drained cohesion
4. Undrained cohesion
5. Drained stiffness
6. Undrained stiffness
7. Drained poisson’s ratio
8. Undrained poisson’s ratio

The table below shows the derived parameters for each layer based upon the field and laboratory tests. In case of insufficient or inappropriate data, the parameters are derived using the various correlations defined by various standard codes and reference books.

Table 2: Derivation of Design Ground Parameters

	Symbol	Unit	BCS	Sand	Clay	Boulder
Unit Weight	γ_b	kN/m^3	18	19	19	19
	γ_s	kN/m^4	18	20	19	21
Internal friction Angle	ϕ'_p	degree	22	30	23	36
	ϕ'_{cv}	degree	22	30	23	34
Drained Cohesion	c'	kPa	-	0	-	0
Undrained Cohesion	c_u	kPa	25.8	-	85.5+9z	-
Drained Stiffness	E'	MPa	7.8	9	34.2z+3.6z	100
Undrained Stiffness	E_u	MPa	10.3	-	26+2.73Z	-
Plasticity Index	PI	%	37	-	34	-
SPT	N		6	9	19+2Z	>50
Undrained Poisson's Ratio	N	μ'	0.15	0.15	0.15	0.15
Drained Poisson's Ratio	N	μ_u	0.5	-	0.5	-

VIII. Ground Model

The design ground model in the analysis has been chosen to present a conservative ground model which safely covers worst case scenario that may occur in actual site. Generally, for soft soils higher thickness and for hard soil materials a lower bound thickness can be adopted. However, this assumption may vary based on experience and analysis requirement. The below long section refers to a pictorial description of all the geologies encountered in each borehole, The long section is evident about the presence of black cotton soil followed by a thick layer of sand overlying clay. Also, it proves some thickness of the boulder/sandstone layer.

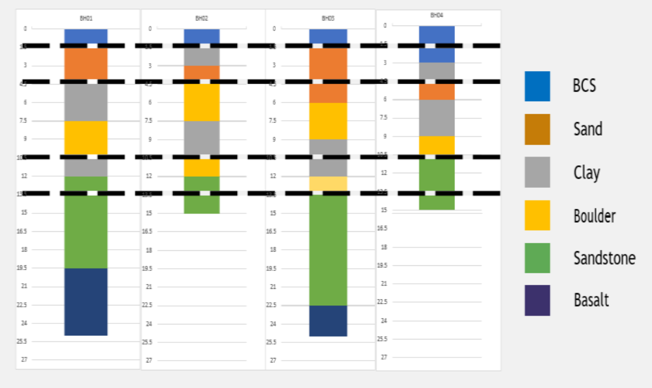


Figure 2: Ground model

IX. Plaxis Analysis

FEM analysis was undertaken using Plaxis 2D tool, PLAXIS 2D is a powerful and user-friendly finite-element (FE) software for 2D analysis of deformation and stability in geotechnical engineering and rock mechanics. PLAXIS is used worldwide by top engineering companies and institutions in the civil and geotechnical engineering industry.

X. Plaxis Input

The input provided considers the ground model, structural members, volume materials and structural loads.

1.Input for soil layers

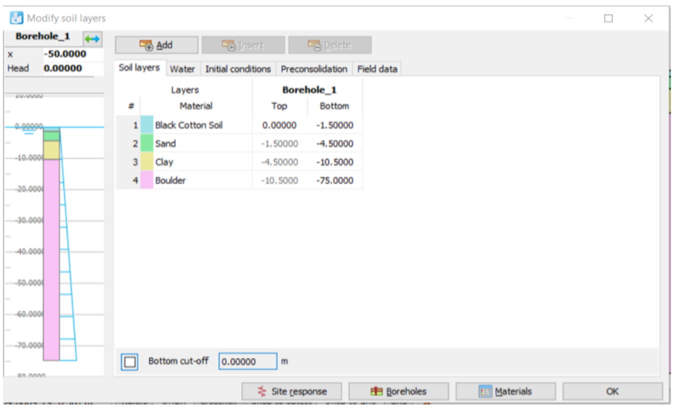


Figure 3: Plaxis 2D input for Soil layers

2. Geotechnical Parameters

The input required for the Mohr-Coloumb model is shear strength parameters (angle of internal friction, cohesion), unit weight and elastic stiffness (Young's modulus). The typical input for geotechnical parameters in PLAXIS 2D appears as below:

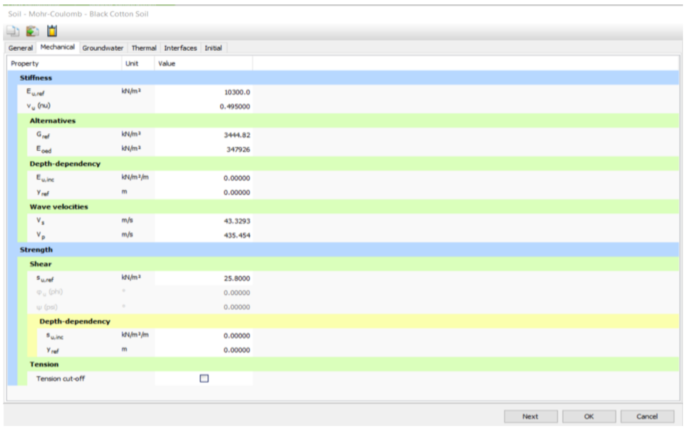


Figure 4.: Plaxis 2D input for Geotechnical Parameters

3. Pile Modelling

The tool allows the user to model pile as embedded beam which can be set up for particular diameter, material stiffness and spacing inside the plane direction. The input for piles in the analysis has been modelled with parameters as below:

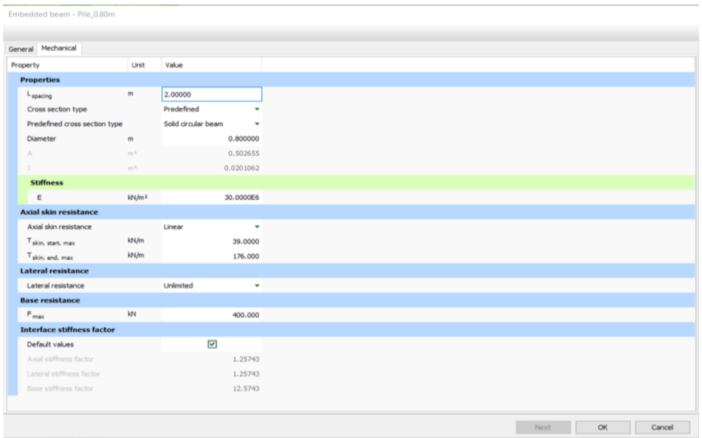


Figure 5: Plaxis 2D input for Pile Modelling

4.Set up of stages

To undertake an analysis of foundation, the stages for construction were assumed to replicate in-situ scenarios. The stages involved as initial ground condition, installation of piles, construction of pile cap or raft foundation, application of surcharge load due to the superstructure and the same input in PLAXIS 2D appears as below:

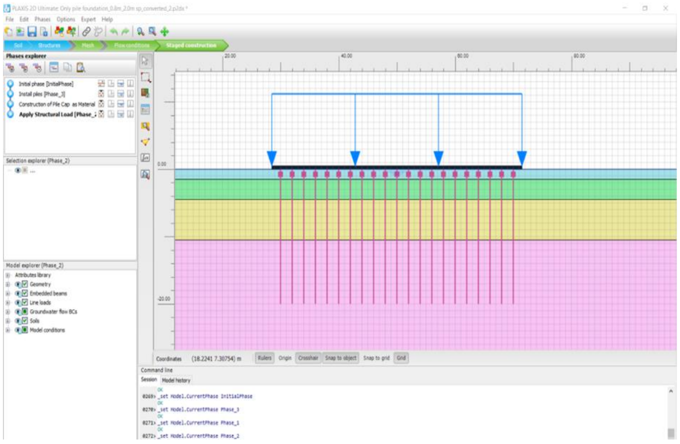


Figure 6: Plaxis 2D Construction Stages

XI. Plaxis Output

The model has been analyzed under different variables such as:

1. Total vertical settlement under pile cap

Similarly, the piles were selected to understand the total vertical displacement and differential settlement between the adjacent piles. The outputs were recorded in tabular form and the contours were represented as below:

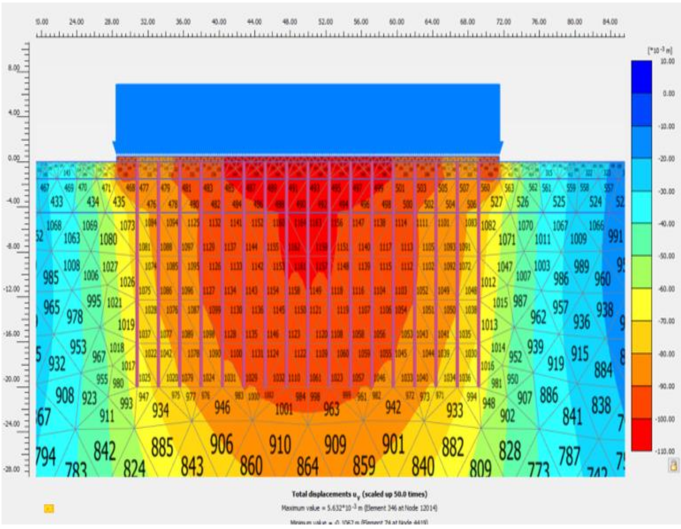


Figure 7: Settlement under pile cap

2.Pile Settlement

Similar to the vertical settlement, the pile settlement was recorded to understand the change when variables are used in different scenarios. A section was taken at the base and along the width of pile cap and results were tabulated.

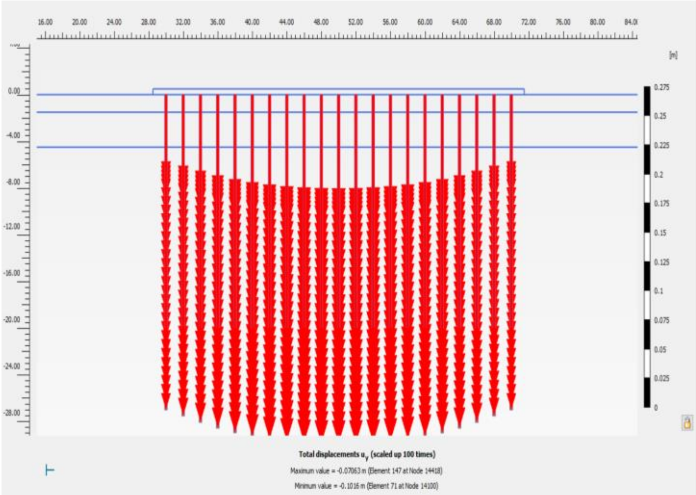


Figure 8: Pile settlement at the base of pile cap

3.Forces in embedded pile

The piles were analyzed to understand the forces induced such as axial force and bending moments when the diameter, length and spacing between the piles are varied. This also impacts the total stress over the pile cap. The forces in each pile are represented as below:

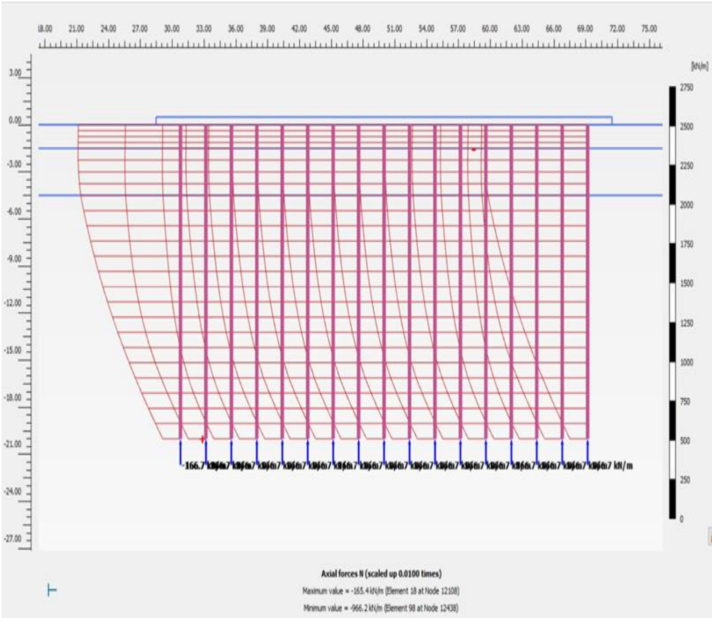


Figure 9: Axial force in piles

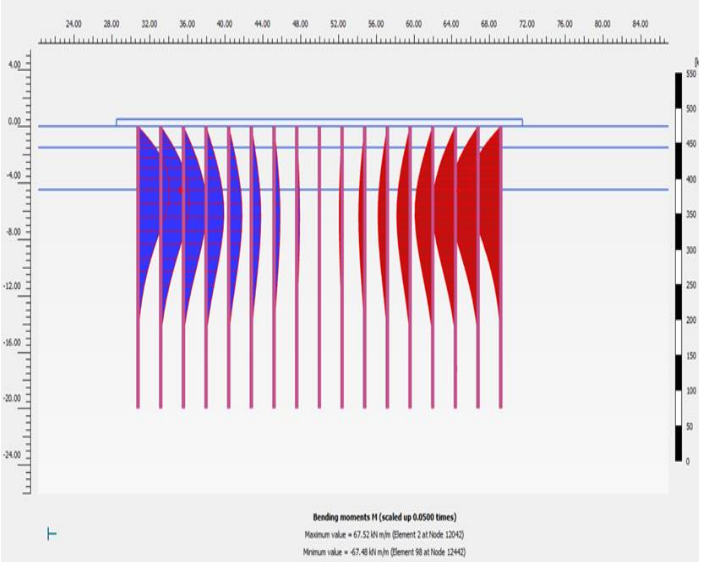


Figure 10: Bending moment in piles

XII. Analysis of pile foundation model using PLAXIS 2D under change in parameters

For analysis, the variation has been taken in the following:

1. Diameter of pile (0.8m, 1.0m and 1.2m)
2. Length of pile (15m, 17.5m and 20m)
3. Spacing between piles (2.5 and 3.0 times of diameter)

The pile cap has been modelled as volume material which rests on piles without any connection or interface.

Table 3: Cases Considered for Design of Pile Foundation

Sub Case	Pile Cap	Pile Dia (d) in 'm'	Pile Spacing (s) in 'm'	Pile Length (L) in 'm'
1	Material	0.6	2.5d	20
2	Material	0.6	2.5d	17.5
3	Material	0.6	2.5d	15
4	Material	0.6	3d	20
5	Material	0.6	3d	17.5
6	Material	0.6	3d	15
7	Material	0.8	2.5d	20
8	Material	0.8	2.5d	17.5
9	Material	0.8	2.5d	15
10	Material	0.8	3d	20
11	Material	0.8	3d	17.5
12	Material	0.8	3d	15
13	Material	1.0	2.5d	20
14	Material	1.0	2.5d	17.5
15	Material	1.0	2.5d	15
16	Material	1.0	3d	20
17	Material	1.0	3d	17.5
18	Material	1.0	3d	15

XIII. Computation of Total settlement, Pile settlement, Maximum axial force and Maximum bending moment for different scenarios

Based on the scenarios as discussed in previous section the foundations were analyzed and the results were tabulated for settlement, total stresses, axial forces and bending moments.

Table 4: Results for pile foundation considering variables

Sub Case	Pile Cap	Pile Dia (d)	Pile Spacing (s)	Pile Length (L)	Total Settlement (uy) mm	Pile Settlement (mm)	Axial Force (kN/m)	Bending Moment (kN/m)
1	Material	0.6	2.5d	20	101.6	101.6	811.1	79.05
2	Material	0.6	2.5d	17.5	106.6	106.6	800.8	80.09
3	Material	0.6	2.5d	15	112.5	112.5	780	75.44
4	Material	0.6	3d	20	106.2	106.2	966.2	67.52
5	Material	0.6	3d	17.5	112.4	112.4	874.5	67.49
6	Material	0.6	3d	15	129.9	120.7	778.2	61.74
7	Material	0.8	2.5d	20	103.4	103.5	885.5	137.5
8	Material	0.8	2.5d	17.5	108.8	108.8	873	130.4
9	Material	0.8	2.5d	15	115.9	115.9	843.4	105.5
10	Material	0.8	3d	20	129.2	129	787.6	14.25
11	Material	0.8	3d	17.5	147	146.8	710.2	30.9
12	Material	0.8	3d	15	164.4	164.3	623.2	56.65
13	Material	1.0	2.5d	20	106.3	106.1	908.8	134.8
14	Material	1.0	2.5d	17.5	113.1	113	896.8	111.1
15	Material	1.0	2.5d	15	123.8	123.6	868.5	59.22
16	Material	1.0	3d	20	249.1	197.2	671.8	67.33
17	Material	1.0	3d	17.5	270.8	214.9	601.8	85.92
18	Material	1.0	3d	15	295.7	234.6	534.4	102.5

XIV. Comparative study of result extracted for pile foundation

To present a detailed comparative analysis, a graphical representation has been provided with results for within subcases and major cases. The below figure representation of comparative analysis plot.

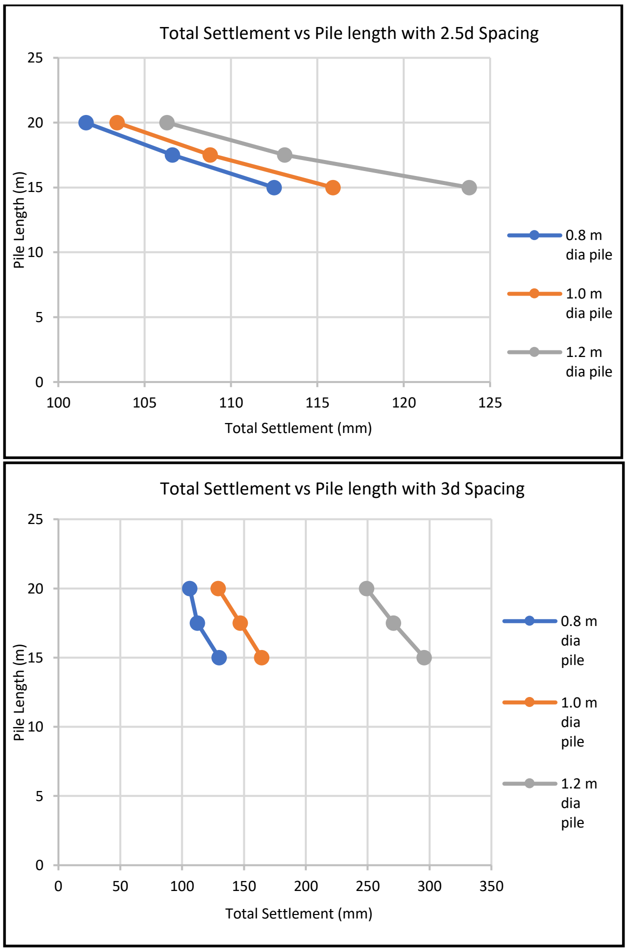
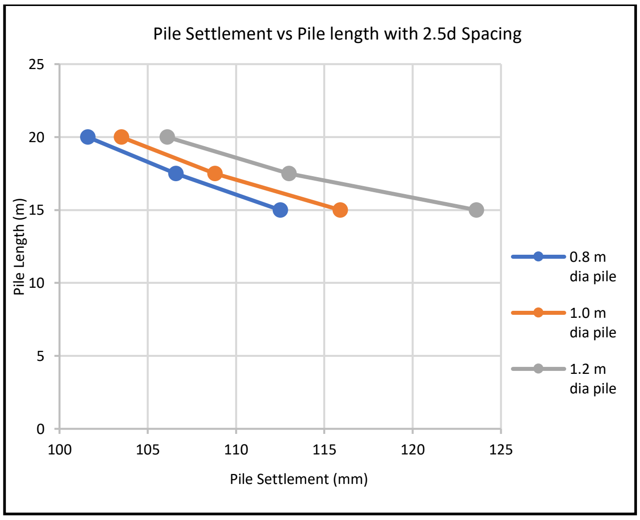


Figure 11: Graph for Total Settlement Vs Pile Length by keeping pile spacing constant



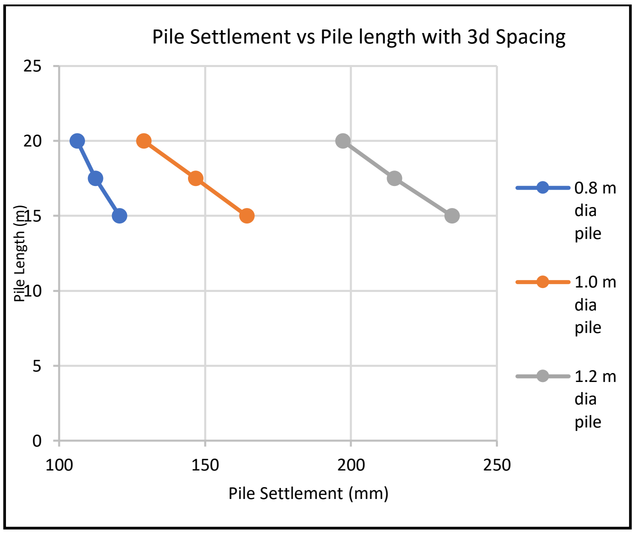
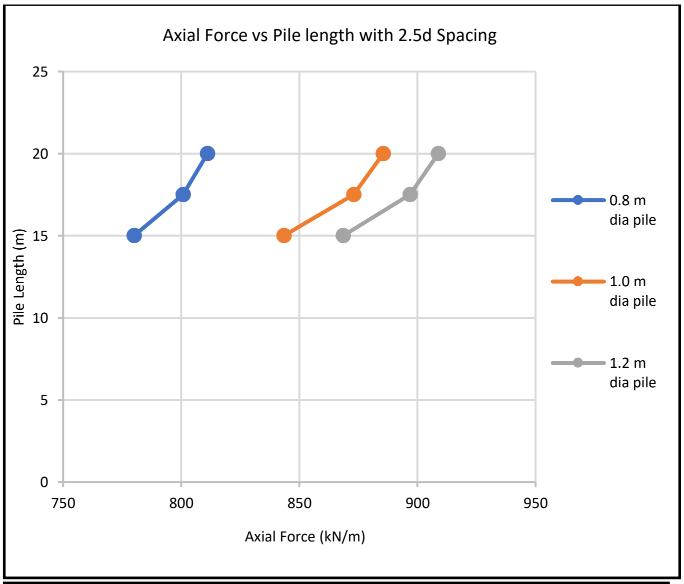


Figure 12: Graph for Pile Settlement Vs Pile Length by keeping pile spacing constant



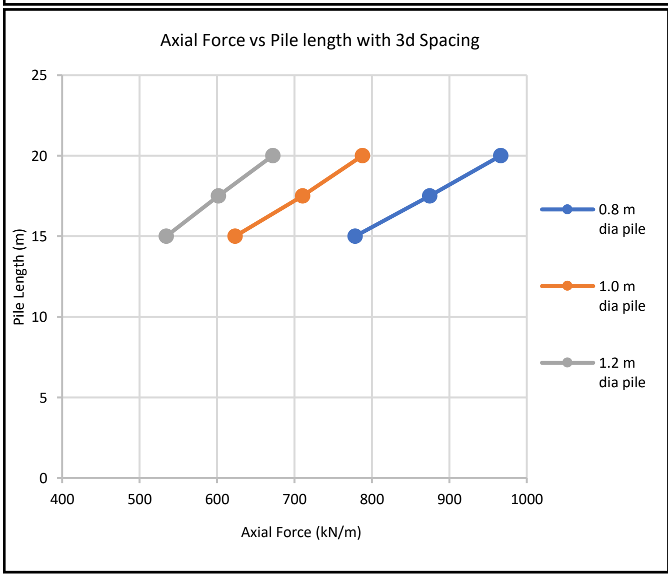
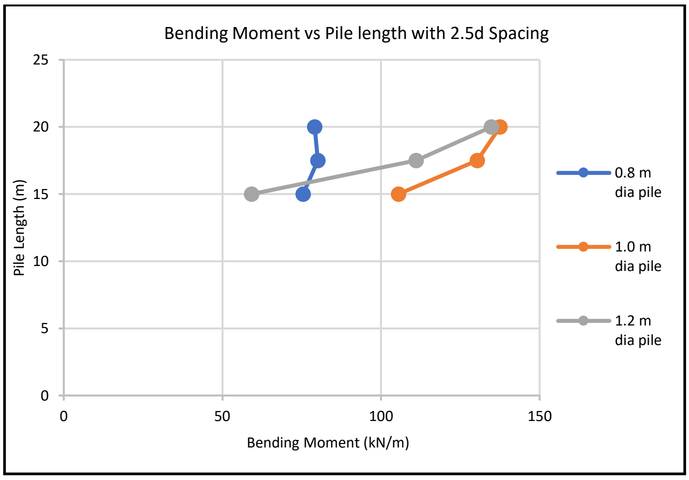


Figure 13: Graph for Axial Force Vs Pile Length by keeping pile spacing constant



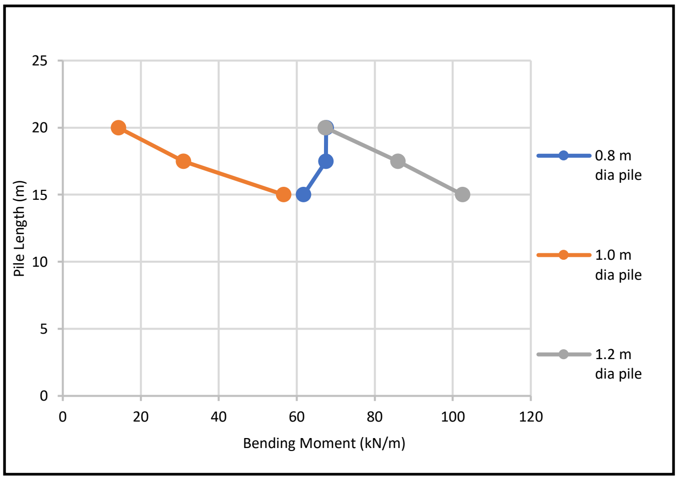


Figure 14: Graph for Bending Moment Vs Pile Length by keeping pile spacing constant

XV. Conclusion

1. From figure 11, It can be seen that the increase in the length of pile reduces the settlement and variation is linear. Also, with increase in diameter the total settlement also increases. For 2.5d spacing the total settlement is less as compare to 3d spacing. So, it is observed that to reduce total settlement in pile, it is beneficial to adopt 2.5d spacing with 15m length and 0.8m diameter.
2. From figure 12, It can be seen that the increase in the length of pile reduces the pile settlement and variation is linear. Also, with increase in diameter the pile settlement also increases. For 2.5d spacing pile settlement is less as compare to 3d spacing. So, it is observed that to reduce pile settlement in pile, it is beneficial to adopt 2.5d spacing with 15m length and 0.8m diameter.
3. From figure 13, It can be seen that the total axial load carried increases with increase the length of the pile. However, the variation is non-linear. Also, with increase in diameter the total settlement also increases.
4. From figure 14, It can be seen that the bending moment increases with increase the length of the pile for 2.5d spacing and decreases for 3d spacing, However the variation is non-linear. Also, with increase in diameter the bending moment also increases.

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