Recent Trends in Civil Engineering and Built Environment Vol. 3 No. 1 (2022) 198–208
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RTCEBE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rtcebe
e-ISSN :2773-5184

A Comparative Study on Pile Design of Residential Buildings On Soft Soil Utilizing End-Bearing Pile Vs. Friction Pile

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DOI: https://doi.org/10.30880/rtcebe.2022.03.01.022
Received 4 July 2021; Accepted 13 December 2021; Available online 15 July 2022

Abstract: Pile foundation was most commonly used for structure built on soft soil and failure such as settlement always been noticed after installation and when subjected to building load. Hence, it is important to study the effect of embedded pile length and load transfer mechanism on pile settlement due to driving force and building load. Both numerical and calculation analysis was carried out by Plaxis 2D 2019 and published formula respectively. A published simulation model was utilized as base model while parametric studies were conducted with proposed pile in different embedded length installed in clay deposit while subjected to simulated driving force and building load. The results of the research showed that pile settlement induced by driving force was found to be decreased with increment of embedded pile length while pile settlement due to static building load had found to be decreased with increment of embedded pile length until an optimum length, in which settlement of pile was increased beyond its optimum length. In this research, friction pile was found to be a better option as compared to end bearing pile. It is recommended that field research should be carried out to obtaine a more reliable result.

Keywords: Soft Soil, Pile, Settlement,

1. Introduction

Pile foundation can be divided based on its load transfer mechanism which are end-bearing pile and friction pile. Pile foundation is generally used when poor soil condition is found near the surface[1] or construction of low rise residential building over soft soil to withstand heavy column load from building to deeper soil strata. In Malaysia practices, installation method of pile foundation for construction of low rise residential building is mostly by driving hammer and commonly precast reinforced square pile is utilized. Pile set is a time increase in pile capacity process[2] and normally pile set criteria which is a maximum settlement of 25mm per last 10 blows is allow for pile to set during driving process. Modified Hiley formula[3] is used for determine pile set criteria as it include hammer falling height, effect of pile length and driving condition to pile set up. When subjected to static building load, pile

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desire settlement is about 1% of pile diameter[1] but it can always be affected by factors such as soil condition, pile material and water table level.

In Malaysia, it can be noticed that most of the coastal region is covered by soft soil deposit such as clay or peat soil and development of economic and cultural is mainly focused at coastal region. Soft soil deposit is consists of unconsolidated soil, therefore the consolidation process is found to be ongoing for this kind of soil deposit.[4] This phenomena become significant when pile is driven into clay deposit and it is noticed that excess pore pressure of soil surrounding pile increase.[5] Dissipation of pore pressure occurs as time pass and lowering of water table increase the effective stress of soil.[1] Thus, it cause extra settlement to pile due to consolidation and negative skin friction may occur. Down drag force force exerted become excessive and eventually leads to pile failure.[1] Thus, it is important for considering both geotechnical and structural capacity during pile design to avoid or reduce problem arise throughout design life.

PLAXIS 2D is a commercial finite element method (FEM) software utilized for analyzing two-dimensional problems of deformation and stability in geotechnical engineering such as analysis of pile behavior embedded in soft soil. Besides that, pile settlement due to simulated driving force and static building load can be analysed through Plaxis 2D using load settlement analysis. Hence, PLAXIS 2D can be utilised in study to evaluate the pile behavior in soft soil when subjected to simulated driving force and static building load. The main objectives of this study are to determine pile settlement when subjected to simulated pile driving force and building load & to evaluate pile set criteria and pile settlement due to column load in soft soil.

2. Materials and Methods

The methodology of this study is divided into two main parts The first part is to remodel a published case study [5]while the second part focuses on the parametric study with an attempt to determine pile settlement when subjected to simulated pile drving force and building load.

2.1 Modelling of Case Study

Model of pile driven into clay by published journal[6**]** was utilized as the base model in this study. The numerical analysis by published article[6] was modelled using PLAXIS 2D 2019 to determine the effect of the pile driving and loading to pile settlement from staged construction. Results obtained were compared to the published findings to verify the model**.**

The cross-section and soil parameters used to remodel the case study was based on published article[6]. The embedded pile length simulated in this study was 15m with full diameter of 0.4066m in soft caly layer which assumed to be 27.452m and pile as a concrete material was assumed behave linear elastic with non porous. Besides that, a static load of -1700kN/m^2 is assumed to loaded on the pile immediately after the consolidation process of 31.1 days. In Plaxis 2D, the model is defined as axisymmetric model with 15 nodes selected. Thus, only half pile diameter of 0.2033m was modelled in Plaxis 2D. The groundwater table was located at ground level. The cross-section of the pile driven into clay model simulated in PLAXIS 2D is shown in Figure 1.

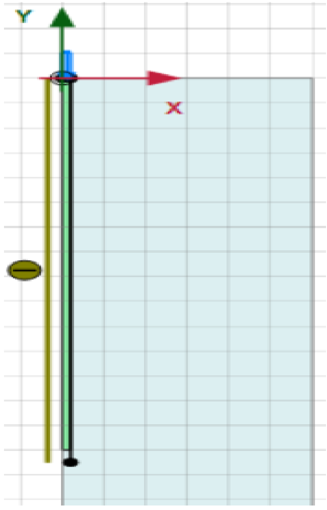

Figure 1: Pile driven into clay cross section in PLAXIS 2D

Soft clay was modelled as undrained condition Soft clay was in undrained condition because water is expected not able to discharge immediately when saturated clayey soil was loaded. The soil parameters used in this study are listed in Table 1. For calculation part, pile driving was set as dynamic analysis, consolidation analysis was set as 31.1 days to reach ultimate consolidation and static load was set as plastic analysis. Staged construction was chosen as loading type.

Table 1: Soil and Pile Properties in Plaxis 2D[6]

Soil Propepties	
Undrained Strength, C_u	23.9 kN/m^2
Modulus of Elasticity, E_s	2150 kN/m^2
Poisson ratio, V_s	0.35
Adhesion factor, α	1.0
Normal consoliation line slope, λ	0.17
Shear Modulus, G	725 kN/m^2
Pore pressure parameters in triaxial state of stress, A	1
Unit weight of soil, γ_{soil}	17.5 kN/m^3
Permeability coefficient, Kx=Ky=Kz	20x10^{-6} m/day
Pile Properties	
Modulus of Elasticity, E_p	21x10^6 kN/m^2
Poisson ratio, V_p	0.2
Unit weight of soil, γ_{pile}	24.0 kN/m^2

2.2 Parametric Study

Parametric study was carried out by first determine column load of low rise residential buildings to pile foundation. The simulation was done by using ESTEEM V10. Structural analysis of ESTEEM V10 is based on the reference of Eurocode 2 and simulation was done by using Finite Element Analysis. The The soil and pile properties were referred to published article [6]. The soil was assumed to behave undrained as stated in section 2.1. The pile and soil parameters used in the parametric study was referred to Table 2.1 as followed in published article.[6]

Square pile with diameter of 200mm with design working load 300kN was chosen in this study. Instead of using geotechnical design parameters in classifying pile, this research utilized structural design parameters which is Modified Hiley formula[3] and the criteria for classifying end bearing pile is that pile must be set or reached settlement within 25mm per last 10blows. This structural design parameters did not take in to account for soil condition for pile embedded in. In order to determine pile set criteria of pile with length varied , Modified Hilley formula[3] was utilized and pile shows end bearing behavior when pile is set within 25mm per last 10 blows If allowable of penetration was greater than 25mm per last 10 blows, then pile is considered as friction pile. The following shows the Modified Hiley formula.

$$Q_a = WH/F(S+C) \quad (1)$$

where Q_a = allowable working load

W = weight of ram hammer

H = height of drop

F = factor of safety

S = final set penetration

C = 2.5, empirical constant for drop hammer

$$n = (W_m - w - P) / \{(w \times H x\ e) - (W_m - w - P) \times A_c\} \quad (2)$$

where Wm = settlement load

P = self-weight of pile and total weight of accessories on pile

Ac = temporary elastic compression factor

W = Weight of hammer

H = Hammer drop height

E = Efficiency of blow

$$S = 10/(n \times FOS) \quad (3)$$

n = number of blows

s = allowable penetration depth per 10 blows

FOS = factor of safety

Due to limitation in Plaxis 2D functionality, height of hammer drop is not able to simulate and euiqvalent static load[7] formula was used to convert kinetic energy of dropping hammer to simulated static repeating load on pile. The proposed method changed the impact laoding due to hammer dropping to load that can be simulated in Plaxis 2D. In a case that weight dropped from certain height, impact factor is given in in equation below.

$$n = 1 + \sqrt{}(1 + \frac{2he}{\&static})$$

where $\&static = W/k$ is the deflection due to a static force applied at the impact surface in the vertical direction. W is defined as weight of object. K is the stiffness of member equal to EA/L, where E is the modulus of elasticity, A is cross sectional area and L is embedded length of pile.

Pile settlement was determined by using Vesic's method[1] when subjected to static load. According to Vesic, pile settlement is he value of elastic shortening , settlement at pile head and along pile shaft. It is assumed that pile settlement at pile head and tip are the same.[1] . The equations can be computed as below.

$$St = Se(1) + Se(2) + Se(3) \quad (4)$$

Elastic shortening of pile due to skin friction along pile shaft varies and theoretically shown in the equation below.

$$Se(1) = (Qwp + ƹQws)/ ApEp \quad (5)$$

where,

Qwp = working load at pile tip

ƹ = skin friction distribution factor, 0.5-0.67

Qws = working load along pile shaft

Ap = area of pile tip

Ep = modulus of elasticity of pile

Settlement caused by load carrying at pile tip is computed at below.

$$Se(2) = (QwpCp)/ qpD \qquad (6)$$

where,

Qwp = working load at pile tip

Cp = based on Table 2

qp = ultimate tip resistance of pile

D = diameter of pile

Table 2 : Values of Cp [1]

Type of soil	Driven pile	Bored pile
Sand (dense to loose)	0.02–0.04	0.09–0.18
Clay (stiff to soft)	0.02–0.03	0.03–0.06
Silt (dense to loose)	0.03–0.05	0.09–0.12

Settlement caused by load carrying at pile tip is computed at below.

$$Se(3) = (QwsCs)/ qpL \qquad (7)$$

where,

Qws = working load at pile shaft

Cs = $(0.93+ 0.16\sqrt{L/D})$ Cp

qp = ultimate tip resistance of pile

L = Length of pile

For numerical analysis, the phase in stage conctruction was followed journal published[6]. Pile was modelled in axisymmetric model which only half of its diameter and obey Linear Elastic model with non porous behaviour and structure model as soil polygon.

2.3 Modelling Schemes in Parametric Study

A 6m reinforced square pile was first modeled with 200mm diameter. As pile driven into clay layer, pore pressure in soil increases and after dissipation vertical effective stress increases which will affect pile bearing capacity.[6] A dynamic line load was simulated at the pile head to model pile driving shceme. 10 cycle was set with total time of 0.2s and cycle graph plotted was shown in Figure 2.

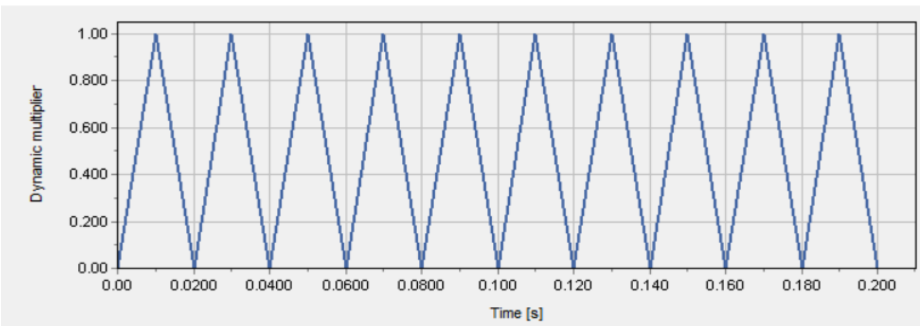

Figure 2: Cycle graph for pile driving

A graph of dynamic time versus settlement was plotted in Plaxis to determine if pile was set within last 10 blows. Modified Hiley formula[3] was used as control parameters and settlement for last 10 blows in simulation should show the same pattern as calculated result. Figure 3 shows the graph of dynamic time vs settlement. Pile reached maximum capacity when pile was set.The model was simulated with pile length varied from 6m to 42m with 3m increment for each simulation.

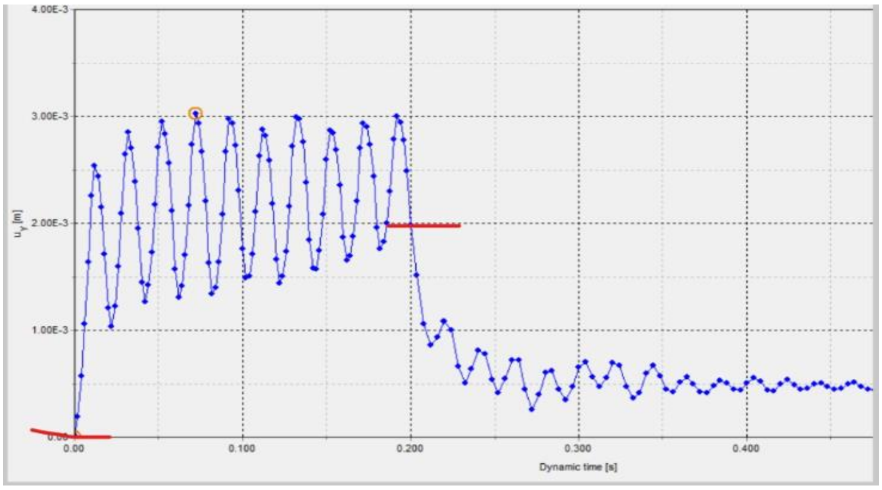

Figure 3: Dynamic time vs Settlement

The initial assumption of pile classification should be made based on manual calculation using Modified Hiley formula[3]. It is needed to set the control length in the model. If the pile settlement due to driving force is less than 25mm per last 10 blows in the specified embedded length, it was set as the control length. After end bearing or friction pile was defined, design working load was selected from ESTEEM V10 and load was multiply by FOS of 2. As single pile was simulated, pile location selected in ESTEEM V10 should obey ration of distance of adjacent pile to pile diameter greater than 5. Pile location selected in this thesis was P1/C3 shown in Figure 4.

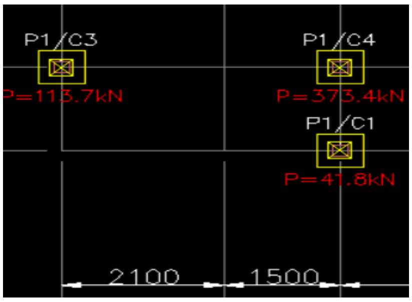

Figure 4: Pile location layout in ESTEEM V10

In order to compare end bearing pile with friction pile, settlement of friction pile during driving was more than allowable penetration calculated by Modified Hiley formula[3]. This was confirmed by plotting dynamic time versus settlement graph as Figure 3 and the settlement value was determined from the first point and to last point which was 0.2s as marked in Figure 3. The parameters used for modelling scheme is shown in Table 4. The settlement due to simulated driving force and static column load was observed through output of result.

Table 4: Modelling Scheme in Parametric Study

Modelling scheme	Design Assumption	Variable	Parameters
Modelling Scheme 1: To determine the effect of pile length and pile driving load on settlement per last 10 blows.	Geometry, pile size and soil parameters were kept as constant. Equivalent static load calculated in section 2.2 as simulated pile drving load was varied based on pile length. Undrained	Pile length	6m pile length was first modeled with increment of 3m for each simulation until 42m
Modelling Scheme 2: To determine the effect of load transfer mechanism on pile settlement	Column static load, geometry, pile size and soil parameters were kept as constant. Pile is considered as friction pile when embedded length is less than length of pile set criteria calculated using Modified Hiley formula while pile is considered as end-bearing pile when embedded length is less than length of pile set criteria calculated using Modified Hiley formula. Undrained	Pile Length	6m pile length was first modeled with increment of 3m for each simulation until 42m

3. Results and Discussion

In the remodeling of case study from published article[6], the result in term of pile settlement due to static building load in clay is presented. In parametric study, results of modelling scheme was observed in terms of settlement due to simulated drving force and static building load. The results obtained was analyzed and perform graphically. Relationship between numerical result and calculated result was discussed and equations were determined by Microsoft Excel.

3.1 Remodel of Case Study

The total settlement value of the pile driven into clay published by Desai [4] was 12mm. While the total settlemnt obtained in remodelling was 9.678mm. Hence, the base model of this study was verified as the difference between the published total settlement and total settlement obtained in remodelling is relatively small with difference of 20%.

3.2 Parametric Study

In parametric study, it was found that pile settlement due to driving force in both manual calculation and numerical analysis shows the same graphical pattern. Both method shows that as embedded length increase, settlement of 10 blows decreases and become constant when length reach 39m as shown in Plaxis simulation. Embedded pile length is inversely proportional to settlement due to driving force. According to calculation through Modified Hiley formula[10], minimum pile length is 18m to set the pile in range settlement of 25mm per last 10 blows and achieving a working load of 300kN. The results obtained were tabulated and plotted in Table 5,Figure 6 and Figure 7. Equation in the graph shows the relationship of driving force to pile length in both method and R^2 value near to 1 stated that the result match the statement above.

Table 5: Pile set criteria using Modified Hiley formula and Plaxis 2D simulation

Pile Length (m)	Hammer Efficiency	Settlement (mm) per last 10 blows (FOS = 2), Modified Hiley formula	Settlement per 10 blows simulated by Plaxis 2D(mm)	Remarks
6	0.35	42.00	2.0	High settlement under simulated driving force
9	0.31	36.26	1.1	
12	0.28	31.85	0.80	
15	0.25	27.48	0.70	
18	0.23	24.40	0.60	Control
21	0.2	20.09	0.57	Lower Settlement under simulated driving force
24	0.19	18.13	0.54	
27	0.18	16.54	0.50	
30	0.17	14.78	0.48	
33	0.17	14.26	0.46	
36	0.17	13.73	0.44	
39	0.17	13.20	0.40	
42	0.17	12.66	0.40	

Note: Hammer efficiency changed because of changed in pile length

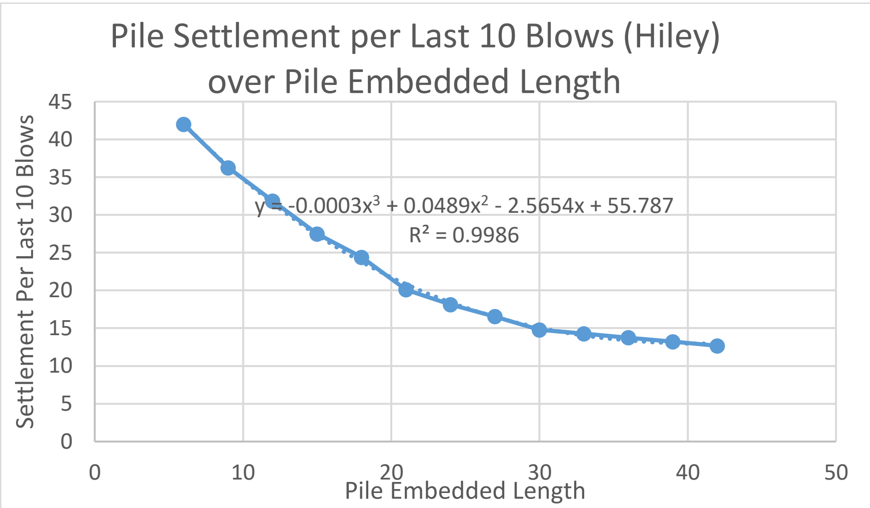

Figure 6: Graph of pile settlement per last 10 blows (Hiley) over pile embedded length

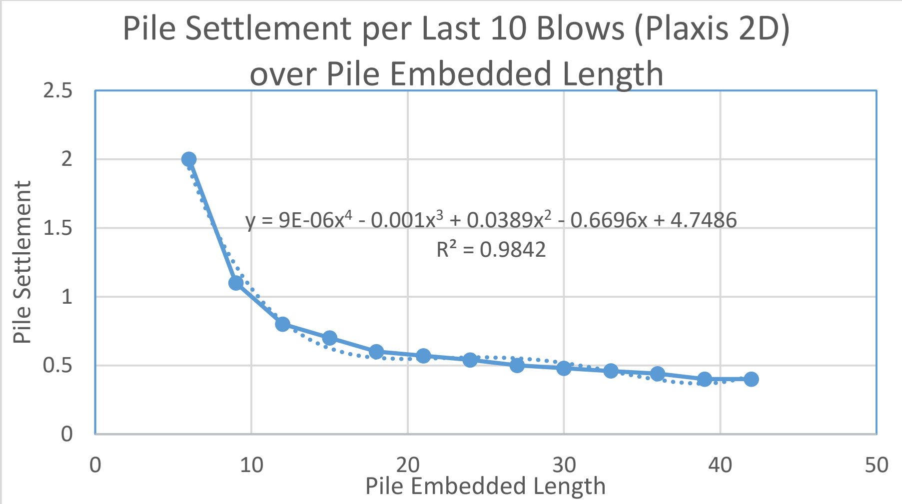

Figure 7: Graph of pile settlement per last 10 blows (Plaxis 2D) over pile embedded length

In term of pile settlement due to static building load, it was show that pile settlement decreases as embedded length increases. Theoritically, pile settlement decreases when pile capacity increases. However, when embedded pile length reaches its optimum length which is 18m,it shows extra settlement with increment of pile length. It was probably due to high self weight of pile and negative skin friction. Down dragging force due to negative skin friction in which settlement of surrounding soil become higher than settlement of pile and excessive down drag force exerted along pile shaft.[1]

This phenomena may occur due to increase of pore pressure during pile driving. As dissipation of pore pressure when time passes, lowering of water table leads to increase of soil vertical effective pressure.[1] Thus, consolidation occur and excessive down drag force exert on pile shaft. It is normally occur when pile embedded in soft soil.

However, pile capapcity calculated proved that pile with 12m and 15m length provide enough allowable pile capapcity to withstand column load ,113kN from building even pile was not set as required length calculated through Modified Hiley formula[3] which is 18m. The results obtained through both methods were perform in graphical method to show relationship of both method.

According to the result, it can be noticed that there were a big differences in between numerical and calculated result. In term of settlement due to driving force, Modified Hiley formula[3] did not take into account of soil condition while simulation in Plaxis 2D modelled the real soil-pile condition in the model. Thus, Modified Hiley formula predicted a higher settlement due to drving force. In other hand, settlement due to static column load, it showed the same concern as it can be noticed that formula proposed by Vesic[1] did not take into account of soil condition. However, both numerical and calculated shows same pattern in estimating settlement due to drving force and static column load. Since the model underestimate the pile settlement thus it is suggested to multiple with an increment factor to minimize the difference between both method.

Table 6: Pile self weight, allowable working load and settlement due to static building load

Length(m)	Pile allowable working load (kN), FOS=2	Vesic's Method (mm)	Plaxis 2D (mm)	Self weight (kN)
6	61.66	15.93	0.4230	6
9	90.34	13.95	0.2089	9
12	119.02	13.08	0.1922	12
15	147.70	12.68	0.1850	15
18	176.38	12.52	0.1837	18
21	205.06	12.50	0.1839	21

24	233.74	12.58	0.1839	24
27	262.42	12.72	0.1887	27
30	291.10	12.91	0.1910	30
33	319.78	13.13	0.1933	33
36	348.46	13.37	0.1948	36
39	377.14	13.64	0.1959	39
42	405.82	13.93	0.1976	42

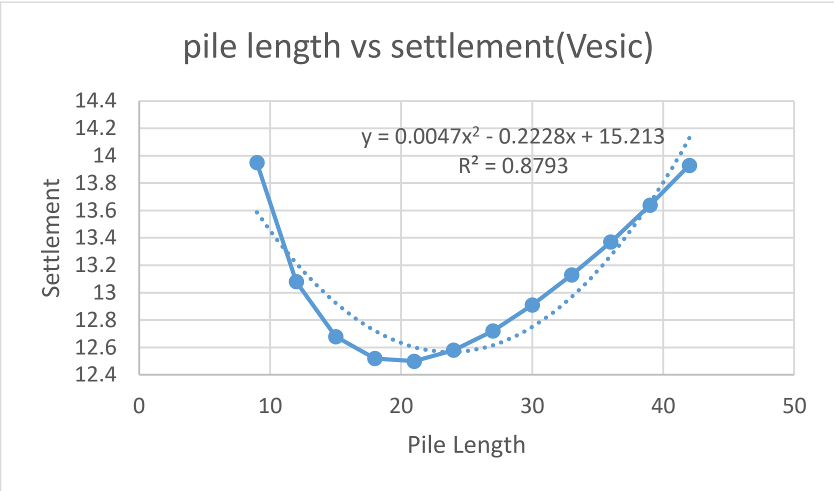

Figure 8: Graph of pile length vs. settlement (Vesic)

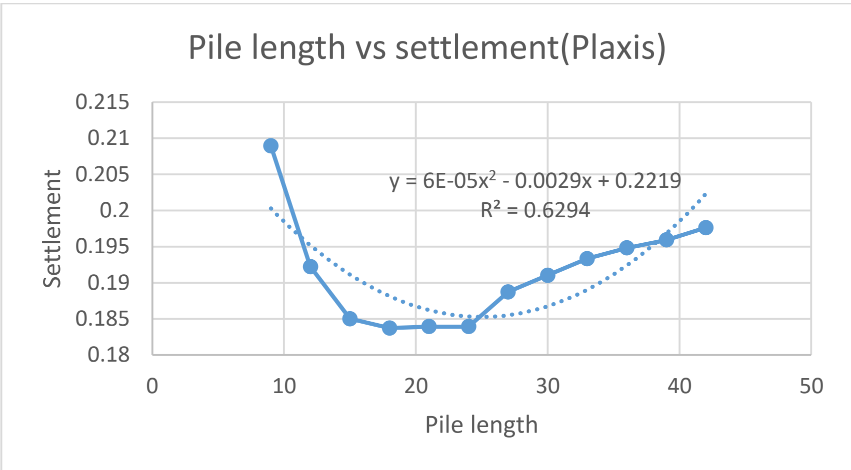

Figure 9: Graph of pile length vs. settlement (Plaxis 2D)

5. Conclusion and Recommendations

Through this research, it can be concluded that pile set criteria which is structural design parameters is a govern factor used to define whether pile shows end bearing behavior or frictional behavior. Theoretically and analytically proved that increases of pile length bring benefits in aspect of pile capacity and pile set values. However, in pile settlement analysis using both numerical and calculated method shows that increase in pile length cause extra settlement when embedded length exceed 24m. Negative skin friction may develop along pile shaft and down drag force exert on pile shaft. Pile with greater embedded length will likely to occur slender in soft soil as movement of soft soil due to surcharge may develop lateral force and it increases risk of pile lateral deformation which eventually leads to failure.[8] In aspect of safety, friction pile in this research provide sufficient capacity to sustain heavy building column load although it did not reach the pile set criteria and shorter pile length is less likely to occur slender. The findings are served as a guide for the geotechnical engineer to make an appropriate decision on the pile design over soft soil to avoid or reduce problem arises through pile design life. Few recommendations were proposed to improve validity and repeatability of the findings such as field work is suggested to be done, use a different structure model like embedded beam row in Plaxis 2D simulation and revision of Modified Hiley formula should be made. Last but not the least, increment or coefficient factor should be developed to minimize difference between numerical and calculated result.

Acknowledgement

The authors would like to thank the Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia for its support.

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