Engineering Applications
https://publish.mersin.edu.tr/index.php/enap
e-ISSN 2979-9201

The effect of changing parameters on soil settlement behavior in single pile foundation systems

Raziye Bozkurt[1*] **Atila Demiroz**[2]

[1]*RB Geotechnical Project Office, Department of Civil Engineering, Aksaray, Turkey, drraziyebozkurt@gmail.com*

[2]*Konya Technical University, Department of Civil Engineering, Konya, Turkey, ademiroz@ktun.edu.tr*

Cite this study: Bozkurt, R., Demiroz A., (2024). The effect of changing parameters on soil settlement behavior in single pile foundation systems.Engineering Applications, 3 (3), 248-259.

Keywords
Single pile systems
Settlement behavior
Pile length
Groundwater

Research Article
Received:08.11.2024
Revised: 09.11.2024
Accepted:24.12.2024
Published:30.12.2024

check for updates

Abstract

In cases where the soil properties are unfavorable depending on the building load, piles are added to the foundation system and the impacting structural load is transmitted to the deeper layers, and the load is safely carried by the soil. These foundation systems are called pile foundations. Considering the cost-related economic conditions, the difficulty of construction, correct sizing, and ensuring safety, the importance of the relevant foundation systems increases. For this reason, necessary studies should be carried out and the effect of size should be examined in different ways and methods. in this study, the amount of soil settlement that occurred in soil was examined and graphically analyzed by changing the pile length, soil groundwater level (GWL), and the amount of impacting load over the problem defined in a single pile dimensioned foundation system. Depending on the change in settlement, the effect of size in piled foundation systems was investigated. As a result of the analysis; In the case of increasing the pile length, the amount of settlement decreased, while the amount of settlement increased when the impacting load increased. Amount of settlement It is determined that it will differ depending on the soil profile if it is evaluated based on the change in groundwater level.

1. Introduction

The load from the buildings is carried by being transmitted to the solid layer of the ground through the designed foundation systems [1]. However, in all circumstances, reaching the solid soil layer may not be possible. For this reason, piled systems carry and transmit the load acting on the foundation over the structure to the solid soil layer. Pile foundation systems, which remain complex, are being researched, and the impact of size is being studied in order to identify the best possible solutions. Especially in areas with soft/loose soil and weak bearing capacity, large volume buildings necessitate the usage of piles obligatory. The situations that require the use of piles can be listed as follows.

- In case the soil bearing capacity is insufficient
- In case of high building load
- When it is necessary to reach the solid layer by passing the loose/soft soil
- In order to prevent buoyancy in water structures
- In case phereatic water level is high,
- In case of designing water structures such as bridges, where there is possibility of scour in the foundation
- In risky areas where earthquake effect is likely to occur,

- ❖ Pile systems are used in cases where liquefaction problem may occur.

According to piled systems load carrying systems; it is divided into two groups as friction pile and end pile. To make a general definition, piles are designed as friction piles if the depth of the soft/loose soil layer is large and access to the solid soil is consequently not possible. However, if it is possible to fix the piles to the solid soil at a sufficient distance, it is preferred to design them as end piles. Das (1999) grouped the usage areas of piles in the studies [2].

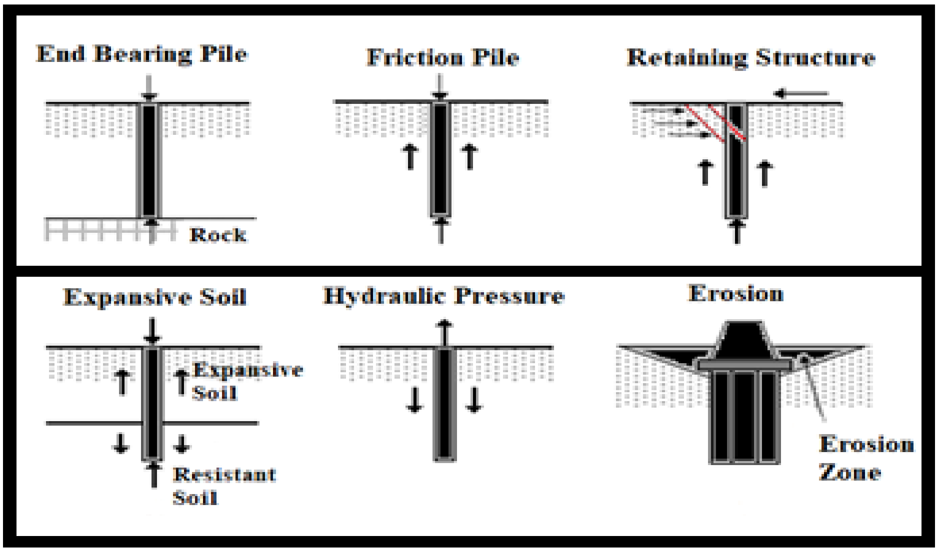

Figure 1. Classification of pile foundations according to their usage areas (Das, 1999)

Pile foundations are an area that still preserves its complexity. While calculations are mostly based on empirical formulas, their design is left to the experience of the designer. For this reason, it is thought that it would be beneficial to increase the studies conducted in this area. Regarding pile foundations; Vu (2014) examined the number and length of piles by considering the pile configuration [3]. Gürgüç (2013) investigated the places where pile foundations are used, the classification of piles, and the effects of horizontally loaded single piles and group piles on their behavior [4]. Omeman (2012) investigated the load sharing of pile foundation systems on sandy soils using PLAXIS 2D software [5]. Khoury et al. (2011) investigated the size effect of pile foundations on a sample structure [6]. Yeğit and Zorluer (2019) examined the behavior of different pile groups in the same soil conditions and found that the increase in the number of piles and pile diameter decreased the pile efficiency [7].

1.1. Calculation of Settlement on Piles

Pile foundations are preferred in cases where the bearing capacity is insufficient, in order to keep the amount of settlement within a certain limit. There are different methods developed for the settlement calculation of piles. These methods are empirical formulas, calculation methods based on soil-structure interaction, finite element-finite difference method and numerical methods [8].

Empirical Methods: Parameters defined in this method; pile diameter, length, Modulus of Elasticity and general section properties. The empirical method developed by considering the parameters is presented in Equation (1).

$$s_t = \frac{D_p}{100} + \frac{Q_F \cdot L_P}{A_p \cdot E_p} \tag{1}$$

S_t: Total settlement (m)
D_p: Pile diameter (m)
Q_F: Pile ultimate bearing capacity (kN)
L_P: Pile length (m)
A_p: Pile cross-sectional area (m^2)
E_p: Piles Modulus of Elasticity (kN/m^2)

Semi-Empirical Method: The types of settlement observed in a vertically loaded pile can be listed as follows. There are three types of settlement: settlement at the end of the pile, elastic settlement due to the carried load.

The settlement in the pile is equal to the sum of the three types of settlements. This equation is defined in Equation (2). In Equation (3), Equation (4), Equation (5), Equation (6), the steps to be followed to calculate the settlement amount are explained.

$$S_t = S_s + S_P + S_{Ps} \tag{2}$$

S_t: Total settlement amount in pile (m)
S_s: Elastic settlement amount (m)
S_P: Settlement amount at the end of the pile (m)
S_{Ps}: Amount of settlement due to load (m)

$$S_s = (Q_b + \alpha_s \cdot Q_s)\frac{L_p}{A_P . E_P} \tag{3}$$

S_s: Elastic settlement amount (m)
α_s: The coefficient of environmental friction along the pile
Q_b: Pile end resistance (kN)
Q_s: Piles total environmental friction (kN)
L_p: Pile length (m)
A_P: Cross-sectional area of pile (m^2)
E_P: Piles Modulus of Elasticity (kN/m^2)

The value of the environmental friction coefficient α_s along the pile differs according to the strength, as shown in Figure 2. Strength distribution; If it is parabolic (Figure 2 (a)) α_s=0.5, İf it is uniform (Figure 2 (b)) α_s=0.5, if it is triangular (Figure 2 (c)) α_s=0.67.

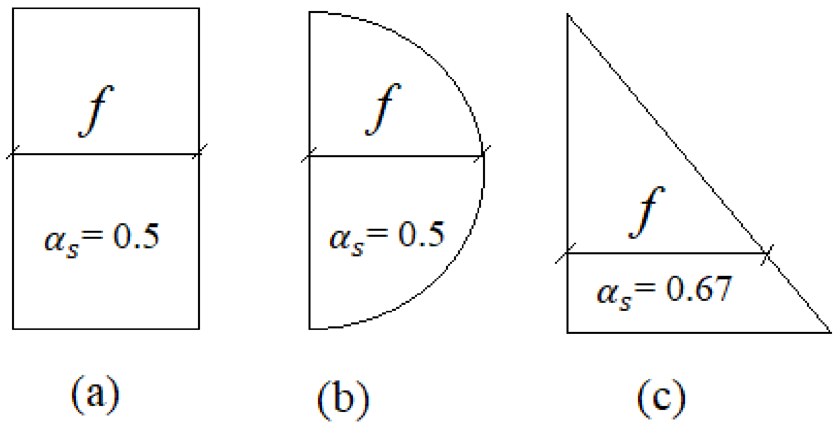

Figure 2. Different with strengths along the pile length (a) Parabolic strength distribution, (b) Uniform strength distribution, (c) Triangular strength distribution

f: Section depth under maximum moment (m)

$$S_p = \frac{C_p \cdot Q_b}{q_b \cdot D_p} \tag{4}$$

S_P: Settlement amount at the end of the pile (m)
Q_b: Pile end resistance (kN)
D_p: Pile diameter (m)
q_b: Final unit bearing capacity of pile (kN/m^2)
C_p: Empirical coefficient

The empirical coefficient C_p in Equation (4) differs according to the soil type and pile type. If the pile used is driven piles, the C_p coefficient varies between 0.02-0.05, and for bored piles between 0.03-0.12.

$$S_{ps} = \frac{C_s \cdot Q_s}{D_f \cdot q_b} \tag{5}$$

S_{Ps}: Amount of settlement due to load (m)

q_b: Final unit bearing capacity of pile (kN/m²)
D_f: Pile buried depth (m)
Q_s: Pile total environmental friction (kN)
C_s: Empirical coefficient
B: Foundation width (m)

$$C_s = \left(0{,}93 + 0{,}16\sqrt{D_f \,/\, B}\right) \cdot C_P \tag{6}$$

C_p: Empirical coefficient

2. Material and Method

In this study, firstly, the settlement behavior of the single pile and the size effect of the pile were investigated through the mathematical model. The settlement amount of the single pile was analyzed by the Mohr-Columb method and interpreted graphically. The soil profile defined in the problem can be shown as follows (Figure 3).

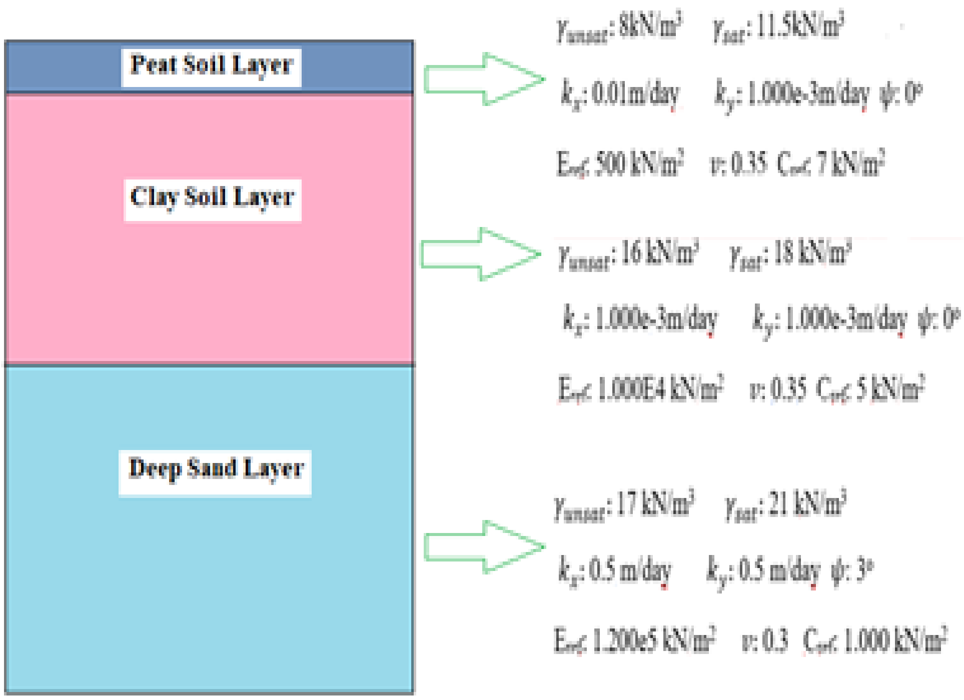

Figure 3. Soil profile of single pile design

The material properties of the single pile in the defined main problem can be expressed as follows.

Table 1. Material properties of individual piles

Axial Rigidity (kNm/m)	$8x10^6$
Bending Rigidity (kNm/m)	$1.67x10^5$
Pile Diameter (m)	0.7
Weight (kN/m/m)	3
Poisson Ratio	0.18
Unit Volume Weight of Water (kN/m³)	10
Single Load (kN/m)	400
Phreatic Water Level Coordinates	[0,24 ;50,24]

2.1. Investigation of the size effect of single pile

In geotechnical engineering, various soil models are preferred in studies with numerical analysis. These models can be listed as Hardening Soil (HS), Hardening Soil Small Strain (HS_ss) and Mohr-Coulomb (MS). Mohr-Coulomb was also used in this study. To briefly write about this method and its working principle;

Mohr-Coulomb Model: This model assumes that the soil is an elastic materail in the first part of the stress-strain curve and a perfectly plastic material in the other part. Stress states are defined by values of the soil at the time of the failure criterion. For this reason, it is appropriate to use them in preliminary analysis of designs. Analyzes are carried out quickly. This method is used in limit analysis problems, that is, in safety analysis of dams, embankments, slopes, retaining structures and bearing capacity calculations of foundation projects. According to this method, the soil is expressed with the parameters Modulus of Elasticity (E), Poisson's ratio (υ), cohesion (c), internal friction angle (ϕ), dilatation angle (ψ).

Considering the main problem defined first in this study, there different parameters were changed, respectively, and the analyzes were analyzed using PLAXIS 2D software, which works based on the finite element method, Mohr-Coulomb method, and the results were presented in tables, graphics were drawn and interpreted.

PLAXIS 2D software, which is defined as Finite Element Program, is widely used in geotechnical design. The developed software is used to examine material models and nonlinear, time-dependent soil behaviors according to soil strucutre. In this study, it was used in pile foundation systems to examine the amount of settlement that occurs when three different parameters change. In the analyses, the pile diameter was chosen as 0.7 m, with a fixed diameter. The three different parameters changed can be defined as follows.

2.2. Effect of pile length variation on settlement amount in single pile system

Considering the basic problem and taking the pile diameter of 0.7 m, the pile length was changed in the range of 14, 16, 18, 20, 22 and 24 m, analyzed and settlement amounts were calculated. Mohr-Coulomb analysis method was chosen as the solution method in the analyses.

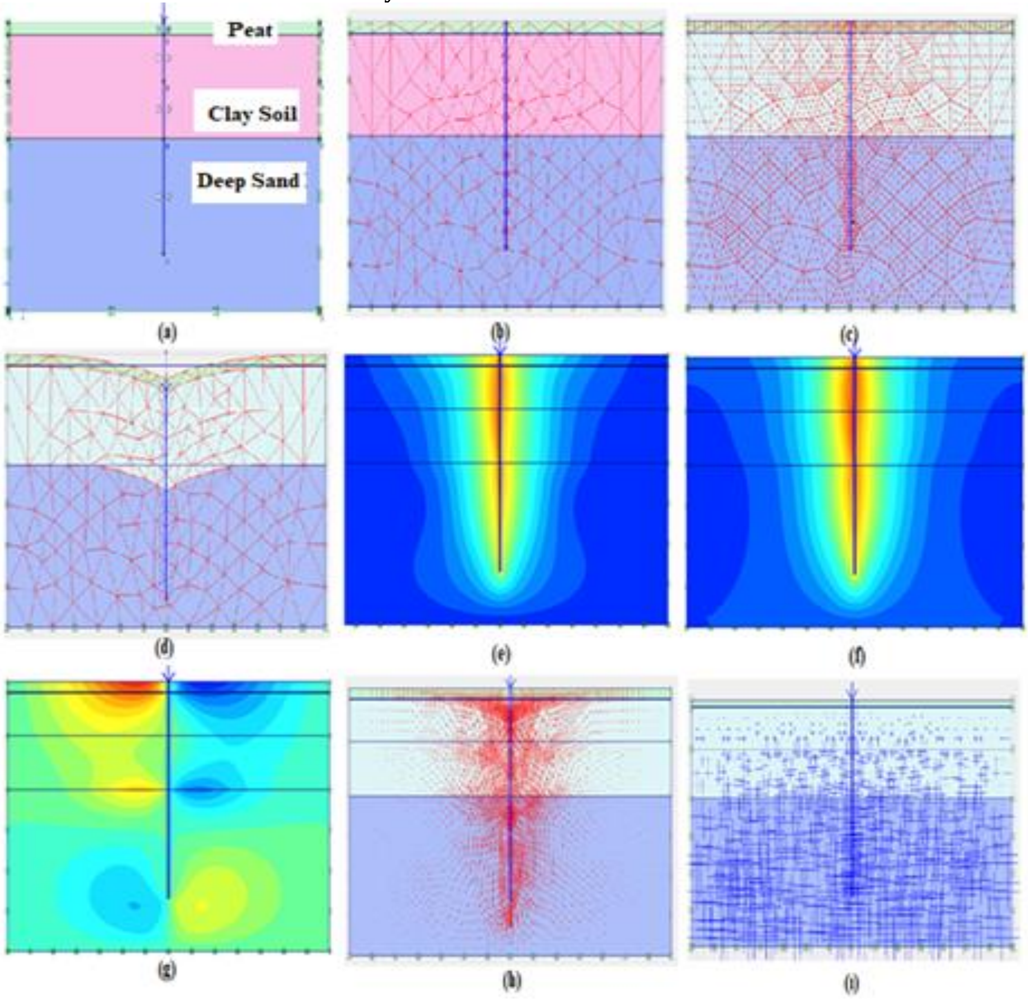

Figure 4. Single pile modeling, (a) Identification of pile and soil properties, (b) Meshing the profile, (c) Defining

Effective pressures, (d) Deformation as a result of analysis, (e) Total settlement, (f) Vertical displacement, (g) Horizontal displacement, (h) Effective stress, (ı) Pore pressure

In analysis the basic problem parameters were used in the studies in the same way, and the pile lengths were selected as 14, 16, 18, 20, 22 and 24 m based on the modeling in Fig. 2, and settlement values were obtained. The main purpose of this analysis is to determine the effect of the change in length on settlement in the single pile system. The result obtained is shown in Table 2 below.

Table 2. The effect of length variation of single pile on settlement amount

Design Number	EA (kNm²/m)	EI (kNm²/m)	D (m)	L (m)	W (kN/m/m)	γ	Total Settlement (10^{-3} m)
1	$8x10^6$	$1.67x10^5$	0.7	14	3	0.18	7.12
2	$8x10^6$	$1.67x10^5$	0.7	16	3	0.18	4.61
3	$8x10^6$	$1.67x10^5$	0.7	18	3	0.18	3.90
4	$8x10^6$	$1.67x10^5$	0.7	20	3	0.18	3.34
5	$8x10^6$	$1.67x10^5$	0.7	22	3	0.18	2.84
6	$8x10^6$	$1.67x10^5$	0.7	24	3	0.18	1.96

Pile properties and soil parametrs were analyzed using Mohr-Coulomb method in PLAXIS 2D software and the results are presented in Table 2. Obtained results were interpreted by drawing graphics. Figure 5 shows the change in maximum settlement with increasing pile length. In Figure 6, pile length-maximum total settlement is expressed with model numbers.

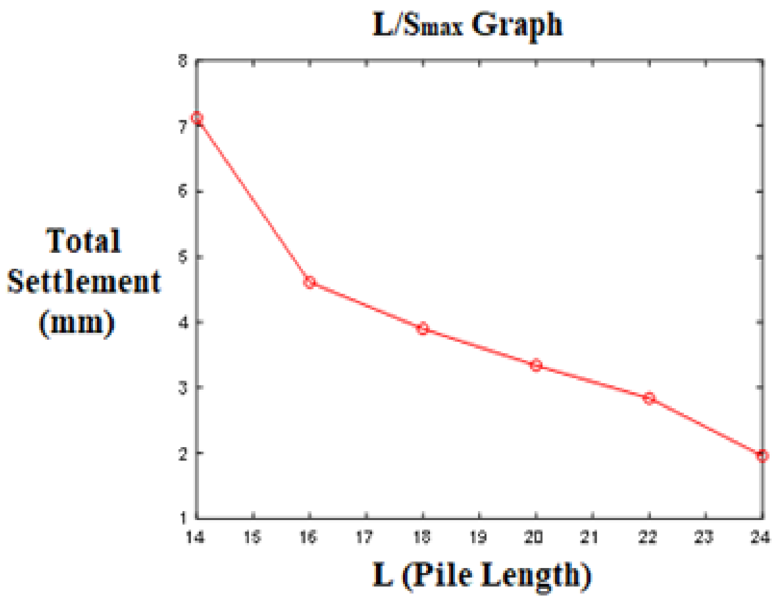

Figure 5. Pile length-total settlement graph in single systems

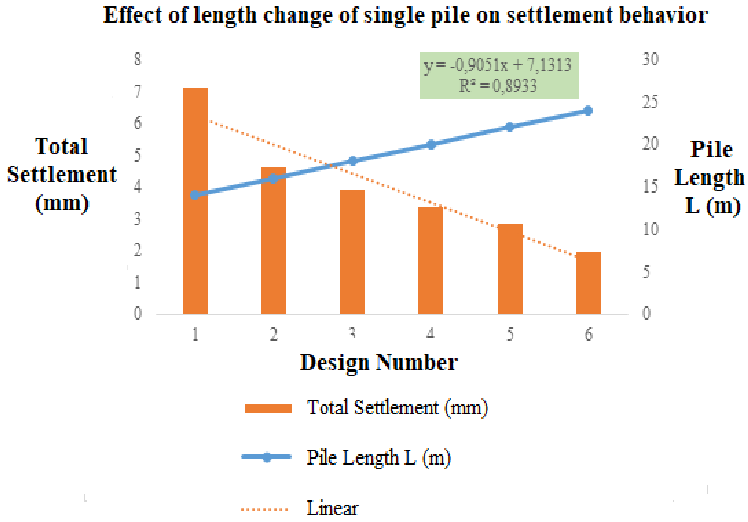

Figure 6. Effect of length variation of single pile on settlement behavior

According to Figure 6, it is seen that the amount of settlement decreases as the pile length increases. According to this result, increasing the pile length is an effective solution for reducing settlement and staying on the safe side. But at this point, economic solutions are gaining importance. It is necessary to choose the optimum size of the pile length, which meets the necessary conditions.

2.3. Effect of pile length variation on settlement amount in single pile system

Considering the basic problem created, the load acting on the pile in the single pile system was changed as 300, 400, 500, 600, 700, 800 kN and analysis were made. As a result of the analysis, as can be seen in Table 3, Figure 5 and Figure 6, the amount of settlement increased.

Table 3. In the case of an increase in the vertical load acting on the pile, the change in the settlement amount

Design Number	EA (kNm^2/m)	EI (kNm^2/m)	D (m)	L (m)	Point Vertical Load (kN)	Total Settlement (10^{-3} m)
1	$8x10^6$	$1.67x10^5$	0.7	20	300	2.57
2	$8x10^6$	$1.67x10^5$	0.7	20	400	3.34
3	$8x10^6$	$1.67x10^5$	0.7	20	500	4.12
4	$8x10^6$	$1.67x10^5$	0.7	20	600	4.93
5	$8x10^6$	$1.67x10^5$	0.7	20	700	5.80
6	$8x10^6$	$1.67x10^5$	0.7	20	800	7.00

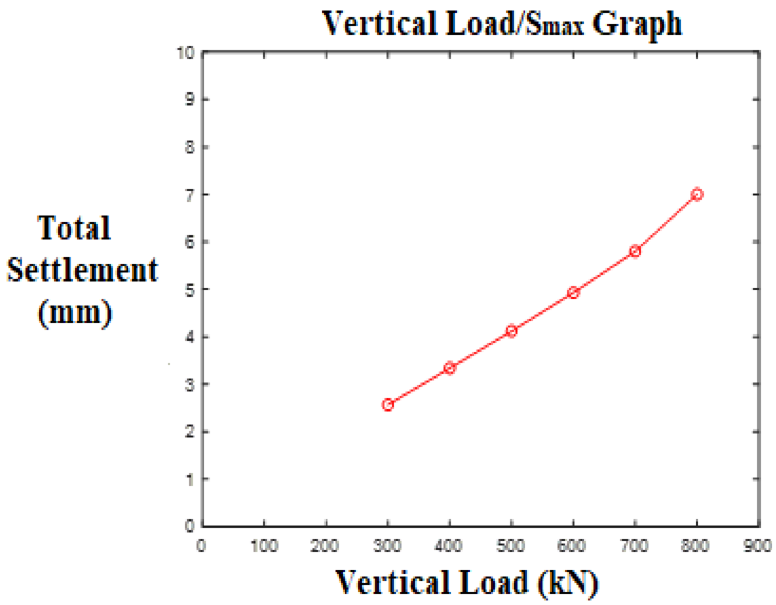

Figure 7. Vertical load-total settlement graph in single pile systems

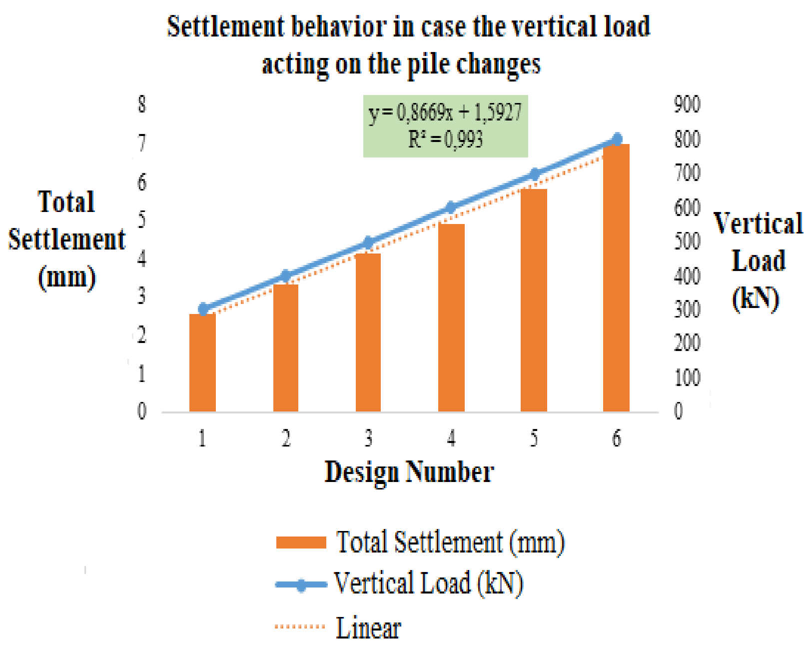

Figure 8. Settlement behavior when the vertical load acting on the pile changes

As can be seen from Figure 7and Figure 8, the amount of settlement increased as the acting load increased. According to the modeling result, since this is a change in the expected direction, it shows that the operations, modeling and problem data are working correctly.

2.4. Effect of ground water level on settlement amount in single pile system

In geotechnical engineering, many problems occur due to water flow in the soil. While it does not pose a problem in normal stable conditions, climate changes cause serious differences in phreatic water level. This situation causes a difference in possible expectations on the soil. When the ground water level changes, the soil behavior also changes proportionally.

Changes in soil behavior affect the safety of the building and can cause great damage. In addition, the amount of leaking water, the flow rate and the pressures due to the swelling that will form on the soil as a result of this flow affect the soil negatively. The resulting water stresses adversely affect the foundation structure by creating problems of stability and volumetric deformation. It has been observed by studies that the ground water level can reduce the soil bearing capacity obtained as a result of the analyzes by up to 30% [9]. It is also known that ground water level is one of the important parameters especially in foundation design.

In this study, analyses were made considering 4 different situations in order to investigate the effect of ground water level on single pile foundations. In the main problem, which is also used in other analyses, ground water level was chosen at the [0,24] coordinate. In order to examine the effect of ground water level, coordinates were changed as [0,18], [0,6] and [0,0], respectively analyzed and settlement amounts were calculated. In the [0,24] coordinate, the ground water level is located on the upper part of the clay soil, in the second case [0,18] coordinates, in the clay soil, (third case) [0,6] coordinate, close to the bottom of the pile. In the fourth case, the ground water level is not in the [0,0] coordinate and the geometric model of the soil profile.

In Figure 9, there are no changing ground water level coordinates on the soil profile. As seen in Figure 9, it is seen that it has no effect on the clay soil at the first level, in the clay soil at the second level, in the sand at the third level and on the soil profile at the fourth level. With the analyzes made at Level 4, it was desired to examine the amount of settlement that occurs on the soil when the ground water does not affect the soil at all.

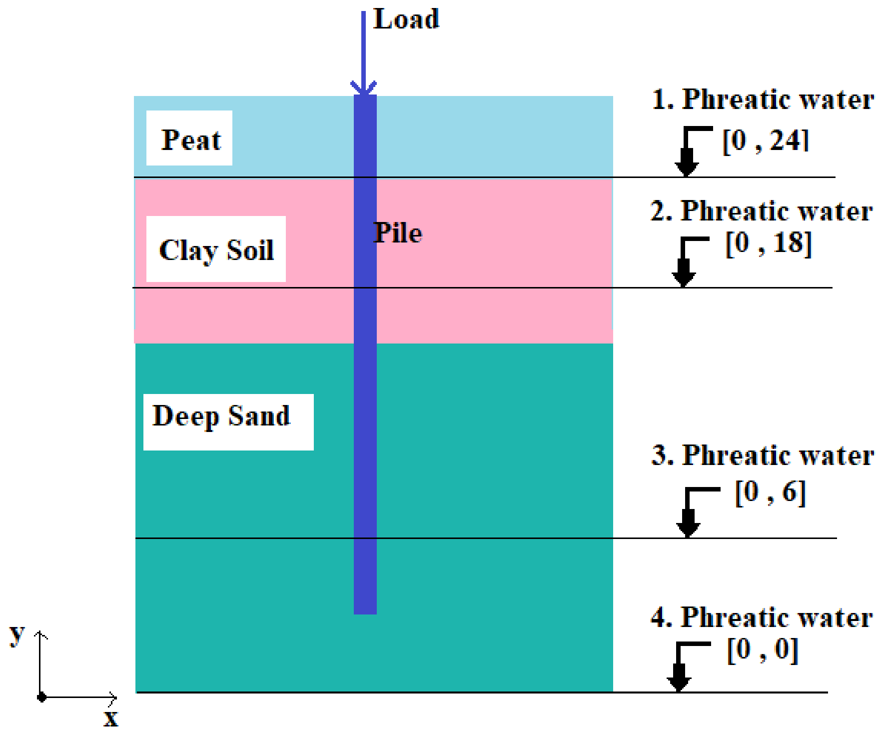

Figure 9. Changing coordinates of the ground water level

Considering the main problem for each different ground water level, the analysis were analyzed with the PLAXIS 2D software and settlement amounts were calculated as seen in Table 4.

Table 4. In the case of ground water level changes, the amount of settlements formed

Design Number	EA (kNm^2/m)	EI (kNm^2/m)	D (m)	L (m)	Ground Water Level Coordinate	Total Settlement (10^{-3} m)
1	$8x10^6$	$1.67x10^5$	0.7	20	[0,24]	2.57
2	$8x10^6$	$1.67x10^5$	0.7	20	[0,18]	3.34
3	$8x10^6$	$1.67x10^5$	0.7	20	[0,6]	4.12
4	$8x10^6$	$1.67x10^5$	0.7	20	[0,0]	4.93

Each case was analyzed separately and the analysis results obtained were graphically described in Figure 10 and Figure 11.

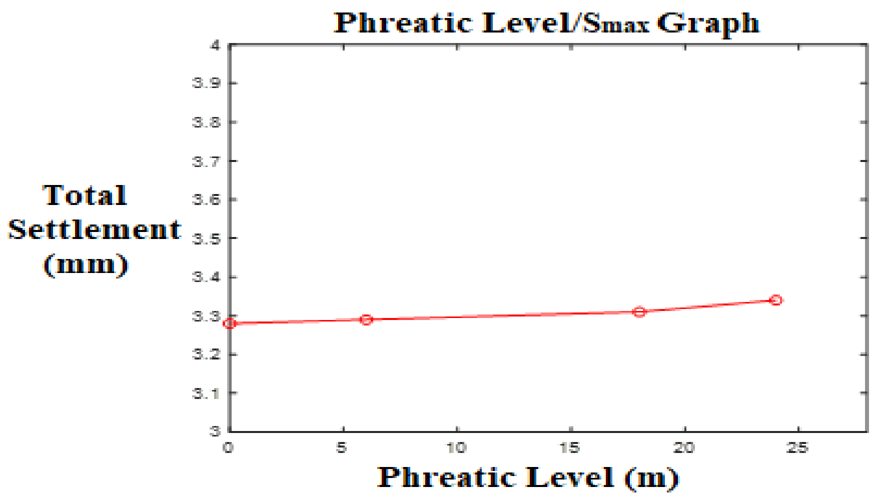

Figure 10. In a single pile system, phreatic level-settlement graph

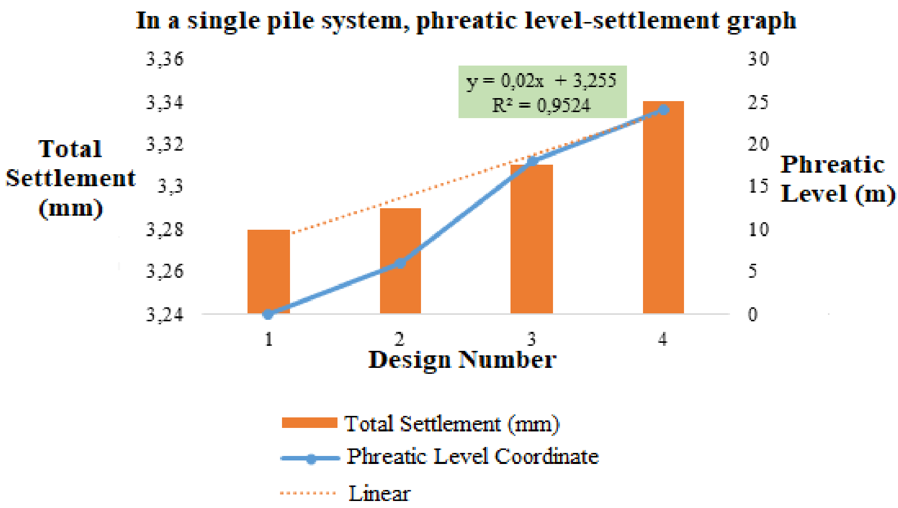

Figure 11. In a single pile system, the amount of settlement occurs in the phreatic water level change

As can be seen from Table 4, Figure 10 and Figure 11, no significant differences were observed in the soil profile and settlement amounts of the problem in the event of a change in ground water level. However, it is not correct to generalize these results. Because the ground water level can be an important and effective parameter in different soil, pile and load conditions.

Three different situations examined in the engineering problem created with a single pile foundation system are defined graphically in Figure 12 by taking into account the settlement behavior.

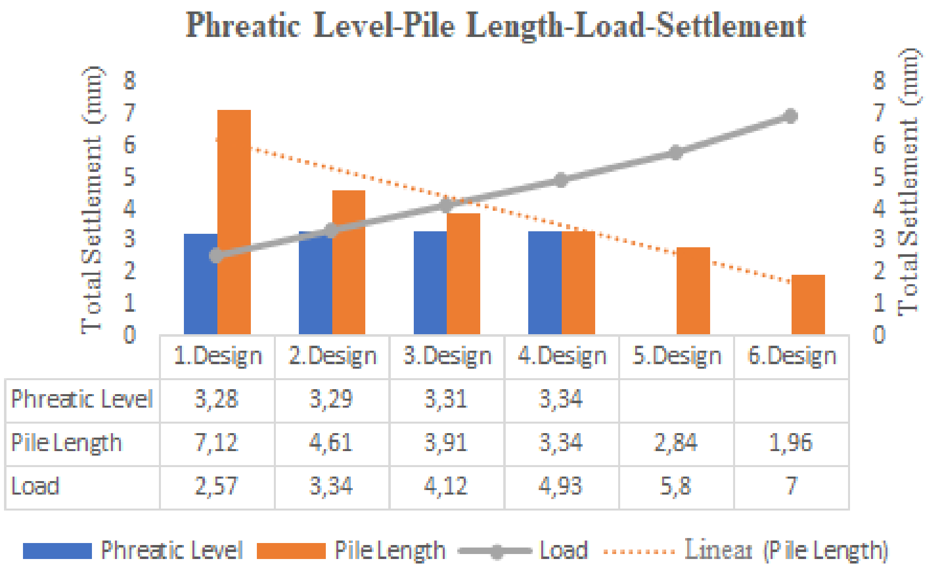

Figure 12. Settlement behavior in different designs and situations

3. Results

Within the scope of this study, the settlement behavior of single pile foundation systems after the effect of load was investigated. In the event that three different parameters affecting the individual pile change, the increase or decrease in the settlement amounts is presented and interpreted graphically. A common foundation problem has been defined and the effect of this problem on the pile system has been examined by changing the parameters. By keeping the pile diameter constant, the change in the amount of settlement was investigated by changing the length of the pile in the first stage, the load amount in the second stage, and the phreatic level in third stage.

The main purpose of the study is to present an idea to the designer in pile foundation systems, which are still complex and difficult, based on the experience of the designer and the empirical formulas developed.

- In the first case, as the pile length increases, the amount of settlement decreases, and the observed drop is approximately 52%.

- In the second case, the amount of load acting has been increased, resulting in a 22% increase in the amount of settelment.

- In the third case, the change in the ground water level was investigated and the ground level was changed at 4 different levels. As a result of the analysis in this soil profile, the change in ground water level did not result in any significant increases or decreases in the settlement amount. However, in this case, generalizations cannot be made about the ground water level. Because, differences can be observed in different soil profiles and ground water levels. For this reason, the effect of ground water level on settlement amount in individual pile systems should be evaluated separately for each soil profile.

If it is necessary to evaluate the results in general; While designing pile foundations, increasing the pile length decreased the settlement, while increasing the load increased the settlement. It can be said that the ground water level is an issue that should be evaluated according to the soil profile.

Funding

This research received no external funding.

Conflicts of interest

The authors declare no conflicts of interest.

References

1. Birand, A., 2007. Pile foundations, 2nd Edition, *Teknik Publishing House,* Ankara.
2. Das, B., 1999. Principles of foundation engineering, Pws-Kent Pub., California, *Ground Engineering*, 6, 30-42.
3. Vu, A., 2014. 3D finite element analysison behaviour of piled raft foundations, 4th International Conference on Civil Engineering, Architecture and Building Materials, China, 580-583.
4. Gürgüç, S., 2013. An investigation on pile groups with horizontal loads in two directions, Master Thesis, İstanbul Technical University, Institute of Science and Technology, İstanbul, Türkiye.
5. Omeman, Z. M., 2012. Load sharing of piled-raft foundations in sand subjected to vertical loads. Doctoral Thesis. Concordia University. The Department of Building. Civil and Environmental Engineering, Canada.
6. Khoury, M., Alzamora, A., and Ciancia, A., 2011. A piled-raft foundation fort he tallest building in Brooklyn. *Geo-Frontiers*. 3818-3827.
7. Yeğit, M., ve Zorluer, İ., 2019. Performance of different pile groups in the same soil conditions, Afyon Kocatepe University Journal of Science and Engineering, 410-418 p.
8. Ünal, C., 2019. Analysis of single piles with finite elements method and comparison with analytical methods, Master Thesis, Pamukkale University, Institute of Science and Technology, Denizli, Mayıs, Turkey.
9. Önalp, A., Sert, S., 2006. Geotechnical Information-3, Building Foundations, Birsen Publishing House, İstanbul, 375, p.