ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIROMENTAL ENGINEERING

Deformation Prediction of ground near deep excavation using FEM & Hand calculation

PROJECT SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF ADDIS ABABA UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF ENGINEERING IN GEO-TECHNICAL ENGINEERING

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DECLARATION

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT

Urban development usually require construction close to adjacent structures or directly above underground infrastructure. The excavation for the new structure induces stresses and strain changes on the excavated side and displacements onto the nearby ground and the effects have to be evaluated. In our country especially in Addis Ababa Major Constructions in every direction is now a common practice. So due to these processes the evaluation or calculation of the settlement induced and the different tools of computation are high priority.

This research aims at studying the effect of deep excavations on adjacent ground by using both Numerical methods and Hand calculations methods. Finite element based software (PLAXIS) was used for the numerical analysis and three different types of hand calculation methods, by the name of Bowels, Peck and Clough & O'Rourke's methods, were used. Therefore based on the outputs from these methods it tried to compare & contrast based on the different criteria's. Also parametric study was done by varying Elastic modulus and observing its impact on three types of soils which are soft clay, stiff clay and sand. Therefore, studying the ground deformation by using the different methods and trying to see their variation on their prediction is believed to be an important step to develop the knowledge gap on this matter.

ACKNOWLEDGEMENTS

I would like to express my most sincere gratitude to my advisor Ato Ameyu Temesgen (M.Sc.) for his guidance and suggestions he provided throughout the project. My special thanks go to Ato Ayalneh W. (M.Sc.) for his time and support he provided me as well.

And I would like to thank Ethiopian road authority and Addis Ababa institution of technology for granting me this opportunity. Also my classmates who helped me achieve and complete this project; my deepest gratitude goes to you all. Finally my family who has been there in this journey supporting and motivating me in every way showing me endless compassion, I am beyond words to thank you.

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1. INTRODUCTION

1.1. BACKGROUND OF THE STUDY

The high rate of construction of, high buildings and transport facilities, from previous times in urban areas makes excavation very common. Due to the congested life style in these urban areas the excavations mostly take place near existing structures. Even though there are mostly retaining structures around deep excavations the additional stress and strain induced is difficult to prevent totally. So the damage potential on the nearby structures and ground has to be assessed and if necessary apply any preventive measures in design.

In our country especially in Addis Ababa Major Constructions in every direction has been common norm. In addition to the construction of the high rise building there is large construction of Asphalt roads and light railway project. There was large volume of excavation in the city due to the construction of especially the transport facilities. The case of the ground settlement is of large concern due to the probability of additional settlement that might be over the design limit.

Depending upon the depth of the excavation there might be excess displacement of the retaining wall and that has large impact on the adjacent ground. The soil type of Addis Ababa is mostly the difficult black cotton soil and most of the existing structures founded on this type of soil are sensitive to additional stress and displacement that comes from these excavations.

Deep excavations in urban areas require special measures due to the buildings and other engineering constructions existing nearby. They must be designed in such a way that the elements of bracing system and neighboring structures & ground meet both ultimate and serviceability limit state requirements. In the first case, there might be no major difficulties to meet these requirements whereas in the serviceability limit state, especially for the nearest structures and ground; there are some specific demands which have to be fulfilled by geotechnical engineers. On the one hand, in case of any damage caused, it is related to possible claims of the owners of neighboring buildings and ground and on the other, to the legal requirements and necessity for determination of impact zones and their environmental influence during execution and operation stages.

The environmental impact is usually related to displacements and strains caused by deep excavations and also additional stresses incurred. The most common are displacements of retaining structures and settlements of the adjacent grounds.

When roads are excavated, retaining walls are used so that the soil behind the wall does not affect the adjacent soils. Though retaining structures are provided, there might be additional stresses and settlements incurred on the nearby ground & existing structures and foundation systems. This effect of construction activities near adjacent structures on soils and the settlement of the ground might not have been given much attention as it should have been given as it can be observed in some parts of Addis Ababa. Studying the existing ground & structure and design of the new construction could be vital in knowing the detail effects and being responsible for existing structures and nearby ground.

This research aims at studying the effects of the deep excavations on adjacent ground and analyzing the settlement with both FEM using PLAXIS and some hand calculation methods. It also tries to see the effect varying elastic modulus has on the magnitude of the ground settlement.

1.2. OBJECTIVE

1.2.1. General Objectives

To study the effect of deep excavations on adjacent ground using finite element based software (PLAXIS) and Hand calculation methods.

1.2.2. Specific Objectives

To study the impact of varying elastic modulus on settlement of the ground by using finite element based software (PLAXIS).

Comparison of the deformation found using both PLAXIS and the hand calculation methods.

1.3. METHOD

The analysis of deformation to the ground was conducted by using finite element based software (PLAXIS) and Hand calculation methods. So the parameters to be included in the modeling was organized. Then using both the software & the hand calculations the deformation of the ground was analyzed and presented. The soil types chosen to be analyzed on this research are Soft clay, Stiff clay and Sand. The parametric study on deformation was conducted by varying the elastic modulus. Then these different deformation outputs were compared with each other to help us better understand their difference. Also further researches were recommended.

1.4. SCOPE

This research study the deformation on the ground near deep excavation. There are case studies to represent each of the three soil types chosen to be analyzed on this paper. Parametric study was conducted for each case study by varying the elastic modulus to calculate the different ground deformation shapes using the FE based software PLAXIS. Hand calculation methods were also used to compute the deformation.

1.5. Organization of the Thesis

The thesis is organized in the following six main chapters.

Chapter one has the introduction part, objective, method and scope of the study.

Chapter two, deals with the literature review about Numerical methods & hand calculations of deep excavations, Soil models used in the parametric study and numerical analysis of practical projects (PLAXIS FE - program), correlations for the different parameters and also some of the earth pressure theories.

Chapter three describes in detail the methodology that is used for both the Plaxis and hand calculation methods such as the input, conditions and process & output of the methods.

Chapter four describes in detail the different case studies that are covered by this paper & their analysis by using PLAXIS and also hand calculation methods.

Chapter five presents the results & discussion of the analysis in chapter three.

Chapter six deals with Conclusion based on the results and the recommendation for further research topics.

2. LITERATURE REVIEW

2.1. General

Analysis of deep excavations is usual required before going into design. Deep excavation analysis is a typical soil structure interaction problem. Soil is a nonlinear, inelastic and anisotropic material. Its behavior is normally affected by water contents. Some types of soils have characteristics of consolidation and creep. Theoretical, analysis of deep excavation involves simulations of elasto plastic behavior of soil interface behavior between soil and retaining walls and the excavation process. Some simulation theories are not fully developed, and some are too complicated to be used in practical a the present stage to sum up, a reasonable excavation analysis, at the present stage, should make use of conventional soil mechanics and simple structural mechanics, along with appropriate modifications according to field observation. [9]

The experiences with performance of deep excavation support system and the factors that are most important in controlling the performance has been summarized. These factors include the type and strength of the soil around and beneath the excavation, the excavation and supporting procedure, and workmanship. Beside the above factors, the ground water condition, the flexibility or rigidity of the components used for construction, the time taken for construction are also important factors that influence the performance of excavations.[1]

The analyses necessary for an excavation design include stability analysis and stress and deformation analyses. The aim of the stability analysis is to avoid collapse of an excavation due to the insufficiency of the strength of soils. Stress analysis is necessary for the design of structural components and deformation analysis aims at diagnosing the wall deflections and soil movements caused by excavation to protect adjacent properties.

The stress and deformation engendered by excavation may arise from either unbalanced forces or construction defects. The former are produced by the clearance of soil in the excavation site. The larger the unbalanced forces, the greater the movements of soils within the influence range of excavation. Construction defects can cause, in less serious situation, extra wall deflection, greater ground settlement and excavation bottom movement or,in serious conditons, collapses of excavations and damage to adjacent buildings and public facilties. The magnitude of stress and deformation due to construction defects cannot be predicted through theoretical simulation or emperical formulae. Such conditions can only be prevented by the improvement of construction quality.

The stress and deformation analysis methods for excavation include the simplified method and the numerical method. The latter can be further classified into the beam on elastic foundation method and the finite element method. Generally speaking, simplified methods employ the monitoring results of excavation case histories and then sort them into the stress and deformation characteristics of retaining walls and soils. The charactrestics are useful not only to help understand the actual excavation behavoir but to offer information for excavation-induced stress and deformation analyses.

As far as the wall deformation and ground surface settlement are concerned, the simplified method, which is inferred from field measurement results, represents the effect of every relevant element on deformation. Therfore, it can lead to effective predictions, without much complexity, for similar excavation projects, interms of soil conditions, construction methods, and engineering designs. Besides, some people have also conducted systematic parametric srudies using numerical methods and induced the deformation characteristics of excavation, which can be used for the prediction of wall deformation and ground settlement.

Clough and O'Rourke found that the wider the excavation, the larger the deformation of the retaining wall. As a matter of fact, for a typical excavation the wider excavation, the larger are the unbalanced forces; the larger the unbalanced forces, the greater is the wall deformation. Moreover, the factor of safety against basal heave for soft clay decreases with and their excavation depths [9]. In most of the case histories, the deformation of a retaining wall deteriorites with the increase of the excavation depth.

Theoretically,the defomation of a retaining wall will decrease with the increase of the stiffness of the retaining wall. However, the amount of decrease does not have a linear relationship with the increament of stiffness. The increase of wall thickness or wall stiffness to reduce wall deformation is certainly effective, but only to a certain extent [9]. Thus, to decrease the deformation by way of increasing the thickness of the retaining wall will not be very effective.

Shortening the vertical spacing of struts can effectively decrease the deformation of a retaining wall because the stiffness of the strut system is raised. We can see that soil in back of the retaining wall moves forward and down with the retaining wall deforming under normal conditions and ground settlement will thus be produced. Thus, the factors causing wall deformation will also produce ground settlement.

The shapes or types of the ground surface settlement engenderd by excavation can be categorized into the spandrel type and the concave type. The main factors responsible for these two types of ground surface settlements are the magnitude and shape of deformation of the retaining wall.

Peck proposed that the influence zone of settlement should be two or three times of the excavation depth. Clough and O'Rourke proposed excavation in sandy soils may induce an influence zone of settlement about twice of the excavation depth. As for stiff to very stiff clay, three times the excavation depth. Soft or medium soft clay, twice the excavation depth. In addition to the above,there are various other suggested values of the influence zone [9].

However, most of them are lacking in formal defintions of the influence zone and the excavation depth is the only parameter in estimating the influence zone. Nevertheless, numerical analyses and studies of the characteristics of ground settlement from excavation case histories, the influence zone of ground settlement doesnot relate exclusively to the excavation depth. It also relates to the excavation width, the loacation of the hard soil,etc

2.2. Constitutive soil models available in Plaxis for an excavation problem

Ideally a soil model would be able to predict the stress-strain and time dependent behavior under all types of loading. However, such models are mathematically complex and difficult to use.

Therefore, a solution to practical problems requires that some simplifying idealization is made regarding the behavior of soils. The elasto-plastic cap models have the advantage that they address the important behavior of soils, such as non-linearity, stress-path dependency, plasticity, dilatancy and compaction, etc. However, there is still a need at least to partially evaluate the response of each constitutive model to some typical stress-strain paths associated with laboratory or field conditions. [1]

A summary of the basic features, the failure criteria, the required soil parameters, range of application, etc. of the three main soil models available in PLAXIS is presented as follows.

Mohr-Coulomb Model (MCM)

It is an elastic perfect plastic model

Its basic features are

• offers a special option for the input of a stiff-ness increasing with depth

• Soil dilatancy

It has Isotropic State of stress

The required soil parameters are c´, φ `, ψ , Young's modulus E, ν

Its Range of Applications is on All types of soils

- This is the soil model used in this paper for Plaxis analysis.

Hardening Soil Model (HSM)

It is an elasto-plastic strain hardening cap model

Its basic features are

• stress dependent stiffness according to power law

• Plastic straining due to primary deviatoric loading

• Plastic straining due to primary compression

• Elastic unloading/ reloading

• Hyperbolic stress-strain relation

• Soil dilatancy

It has Isotropic State of stress

The required soil parameters are c´, φ ` , angle of dilatancy ψ , secant stiffness in standard drained triaxial test E_{50}^{ref}, unloading/reloading stiffness E_{ur}^{ref} , tangent stiffness for primary oedometer loading , E^{ref}_{oed} , power m , Poisson's ratio for unloading/reloading ν_{ur}, and K_0

Its range of Applications is on All types of soils

Soft Soil Creep Model (SSCM)

It is an elasto-plastic work hardening cap model

Its basic features are

• Stress-dependent stiffen (logarithmic compression behavior)

• Distinction between primary loading and unloading/reloading

• Secondary (time-dependent) compression

• Memory of reconsolidation stress

The required soil parameters are c´, φ `, ψ, modified compression index λ*, modified swelling index κ*,modified creep index μ*, ν_{ur}, M is a parameter which is a function of K_0

It has Isotropic State of stress

Its Range of Applications is on normally consolidated or lightly over consolidated clay or clayey soils

2.3 Correlations for different parameters

2.3.1 Poisson's Ratio

When investigating or predicting the deformation of the ground the deformation properties are mostly described by Young's modulus (E) and Poisson's ratio (v). These properties are obtained most often from the results of triaxial compression tests. The modulus is the ratio of the stress to strain and is obtained from the slope of deviator stress-axial strain curves. Poisson's ratio is the ratio of the radial strain to the axial strain.

As with the modulus, Poisson's ratio is both nonlinear and stress-dependent. However, the range of v is relatively small compared with the range of E, and therefore less effort usually is made in evaluating V precisely. For elastic materials, Young's modulus and Poisson's ratio are interrelated uniquely with the shear modulus (G) as follows:

$$G = E/2(1+v)$$

Poisson's ratio for isotropic elastic materials, the entire range of V is from 0 to 0.5. For dilatant soils that are inelastic, V may exceed 0.5. However, it should be remembered that the behavior is no longer elastic in this case. For undrained loading of saturated cohesive soil, no volume change occurs; therefore the v_u is equal to 0.5 by definition. For drained loading, volume changes occur and the drained Poisson's ratio varies with soil type and consistency.

Soil Type	**Description**	υ^*
Clay	**Soft**	**0.35 – 0.40**
	Medium	**0.30 – 0.35**
	Stiff	**0.20 – 0.30**
Sand	**Loose**	**0.15 – 0.25**
	Medium	**0.25 – 0.30**
	Dense	**0.25 – 0.35**

Table 1 Typical Ranges of Poisson's Ratio [4]

2.3.2 Modulus of Cohesive Soils

The response of cohesive soils to loading is time dependent. For initial quick loading conditions, the response is undrained. The excess pore water pressures developed will dissipate with time leading to consolidation. For undrained loading, the modulus of cohesive soils can be described by either the Young's modulus (E_u) or the shear modulus (G).

A number of authors have given typical ranges for the undrained modulus and these ranges are summarized in the next table. Most commonly, the undrained modulus is normalized directly by the undrained shear strength from the same test to give E_u/S_u.

Consistency	Normalized Undrained Modulus , E_u/P_a
Soft	15 to 40
Medium	40 to 80
Stiff	80 to 200

Table 2 Typical Ranges of Modulus for Clay [4]

Alternatively the modified cam clay model can be used to provide an estimate of the undrained modulus ratio. Wroth, et al. suggested the following:

$$(E_u/S_u)oc /(Eu/su)_{NC} = (G/Su)oc/(G/Su)_{NC}= (1+c \ln OCR) OCR$$

Correlations with SPT, CPT and PMT Results

The PMT provides a measurement of the horizontal modulus in soils. In clays, it is assumed commonly that $E_{PMT} = E_u$. For practical use, attempts have been made to correlate $E_{PMT} = E_u$. For practical use, attempts have been made to correlate E_{PMT} with the SPT N value, it is clear that more than an order of magnitude variation is possible when using N values as the sole predictor. [10]

2.3.3 Modulus for Cohesion less soils

Cohesion less soils don't exhibit significant time dependency to loading caused by excess pore water stress dissipation and therefore the modulus under undrained loading conditions exists only briefly.

Consistency	Normalized Elastic Modulus, E_d/Pa	
	Typical	Driven Piles
loose	100 to 200	275 to 550
medium	200 to 500	550 to 700
dense	500 to 1000	700 to 1100

Table 3 Typical Values of modulus for cohesion less soils [4]

2.3.4 Soil permeability coefficient

The soil permeability is a measure indicating the capacity of the soil or rock to allow fluids to pass through it. It is often represented by the permeability coefficient (k) through the Darcy's equation:

$V=ki$

Where v is the apparent fluid velocity through the medium i is the hydraulic gradient, and K is the coefficient of permeability (hydraulic conductivity) often expressed in m/s

K depends on the relative permeability of the medium for fluid constituent (often water) and the dynamic viscosity of the fluid as follows.

K= (Gamma_w)*K/ (E_{ta})

Where Gamma_w is the unit weight of water E_{ta} is the dynamic viscosity of water K is an absolute coefficient depending on the characteristics of the medium (m^2)

Empirical relations to determine the soil permeability coefficient

For Sands, the coefficient of permeability can be estimated from the Hazen's equation:

$K= 10^{-2} D_{10}^2$

D_{10} is the effective size in mm.

2.4 Hand calculation methods

There are empirical formulas to predict ground surface settlement and the characteristics of soil movement. Many empirical formulas have been proposed but on this paper we only see the three most well-known ones.

2.4.1 Peck's method

Peck was the first to propose a method to predict excavation-induced ground surface settlement, based on field observations. He mainly employed the monitoring results of case histories in Chicago and Oslo and established the relation curves between the ground surface settlement and the distance from the wall for three types of soil which are Soft clay, Stiff clay and Sand.

Basically, the curves derived from Peck's method are envelopes. Since Peck's method is the first to derive an empirical formula to predict the ground surface settlement induced by excavation and is simple to apply, it is still used by some engineers.

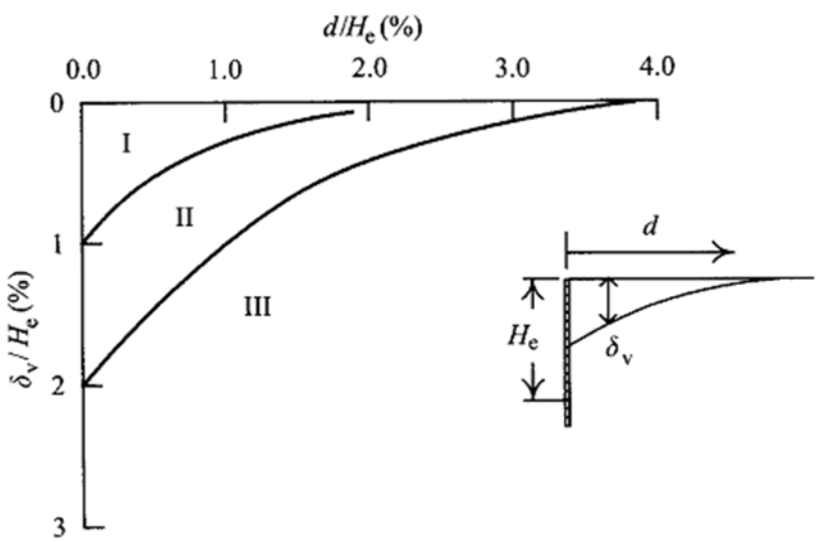


Figure 1 Peck's method for estimating ground surface settlement

2.4.2 Bowles's method

Bowels is one of the researchers who suggested a procedure to estimate excavation-induced ground surface settlements which is one of the most known empirical methods.

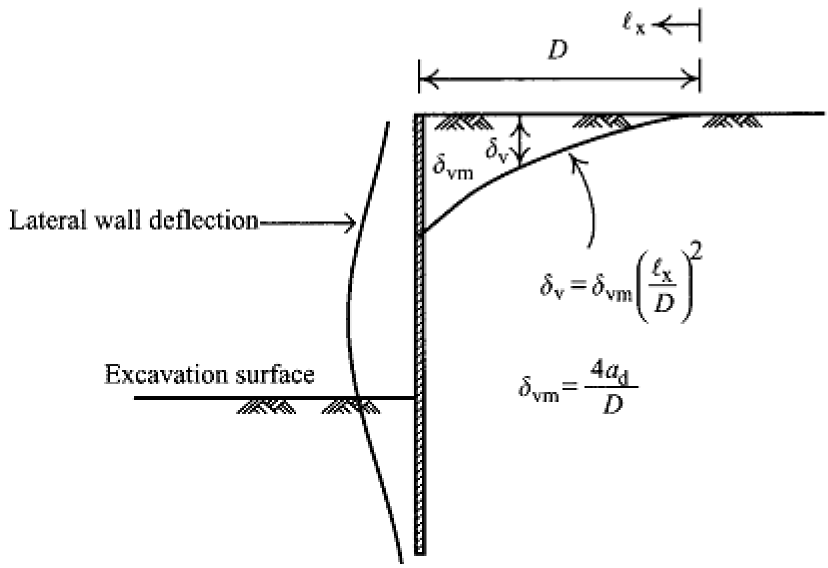


Figure 2 Bowles's method for estimating ground surface settlement

2.4.3 Clough and O'Rourke's method

Clough and O'Rourke (1990) proposed various types of envelopes of excavation induced ground surface settlements for different soils on the basis of case studies. According to their studies, excavation in sand or stiff clay will tend to produce triangular ground surface settlement. The maximum settlement will be found near the retaining wall. The envelopes of ground surface settlement are shown in Fig below whose influence ranges from $2H_e$ to 3 H_e where H_e is the final excavation depth. Excavation in soft to medium clay will produce a trapezoidal envelope of ground surface settlement. The maximum ground surface settlement occurs in the range of $0 < d/H_e < 0.75$ while $0.75 < d/H_e < 2.0$ is the transition zone where settlement decreases from the largest to almost none.

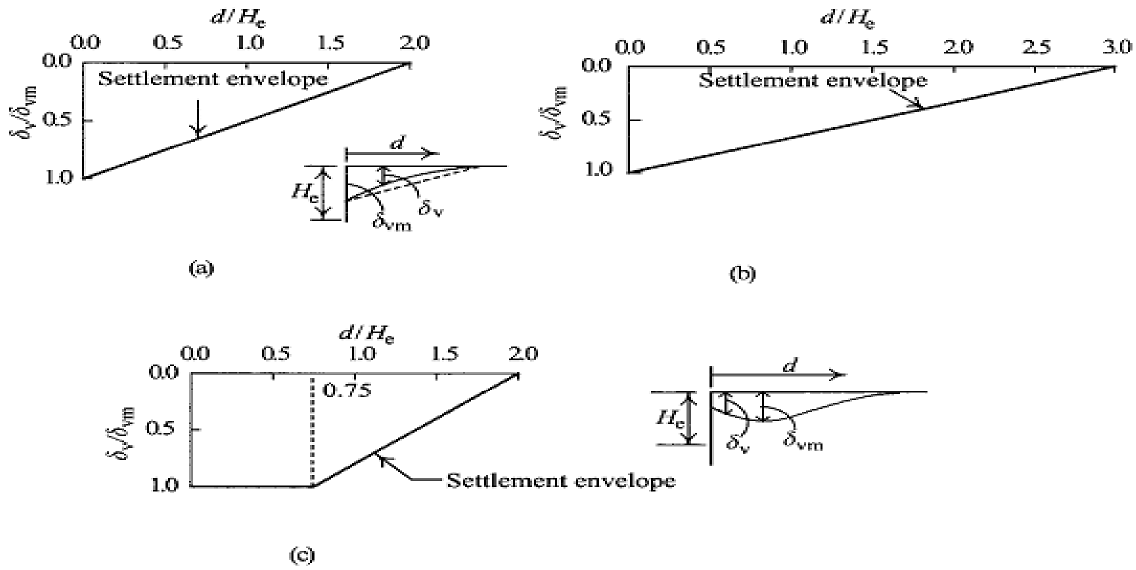


Figure 3 Clough and O'Rourke's method for estimating ground surface settlement (a) Sand, (b) Stiff to stiff clay and (c) Soft to medium soft clay

3. METHODOLOGY

3.1 General

As mentioned crudely in the introduction part of this paper the main objective of this paper is to compute the surface deformations of ground near deep excavations by using both numerical and hand calculation methods. On this paper finite element based software PLAXIS was used for the numerical method and some of the commonly used hand calculation methods are used for the analysis. In this section these analyses methods methodology is in detail discussed.

3.2 Finite element method using Plaxis software

Plaxis software is used for the modeling of different types of problems. On this paper it was used to model dry excavation using anchored pile. The anchored is pre stressed with some amount of force to resist the active pressure created by the excavation.

3.2.1 Input

The software requires the following parameters to model the problem; which are excavation width & depth, pile dimension, soil and interface properties such as material model type, unit weight, permeability, Young's modulus, Poisson's ratio, cohesion, friction angle, dilatancy angle, interface reduction factor, anchor rod & grout body parameters such as length, thickness, angle of anchor installation, spacing, modulus of elasticity and moment of inertia. For the generation of mesh it is advisable to set the Global coarseness to medium. In addition the stress concentration is expected around the grout bodies so a local refinement is proposed here. Then finally the initial conditions are generated.

3.2.2 Conditions and process

The excavation follows a staged construction process which consists of different phases. All calculation phases are defined as plastic calculation using staged construction as loading input and standard settings for all other parameters. The activities involved in each phase of the staged construction that are used for this research model can be stated as follows:

Phase 1

- Activate the wall

Phase 2

- Deactivate the upper cluster of the excavation

Phase 3

- Activate the geogrids
- Double click the upper node to node anchors and adjust the pre stress force value on the window that appears.

Phase 4

- Deactivate the second cluster of the excavation

3.2.3 Output

The outputs of the plaxis analysis are presented numerically incorporated with pictorial representation. The results of the analysis include deformation, stress, bending moment, strain, velocity and acceleration, Active & excess pore pressure.

The vertical deformation of the ground for the different case studies is presented on the next chapter. The different outputs of the analysis for each phase can found on the annex portion of the paper and it demonstrates some of the outputs found from the software pictorially.

3.3 Hand calculation methods

There are empirical formulas to predict ground surface settlement and the characteristics of soil movement. Many empirical formulas have been proposed but on this paper we only use the three most well-known ones.

3.3.1 Peck's method

Basically, the curves derived from Peck's method are envelopes. Since Peck's method is the first to derive an empirical formula to predict the ground surface settlement induced by excavation and is simple to apply, it is still used by some engineers.

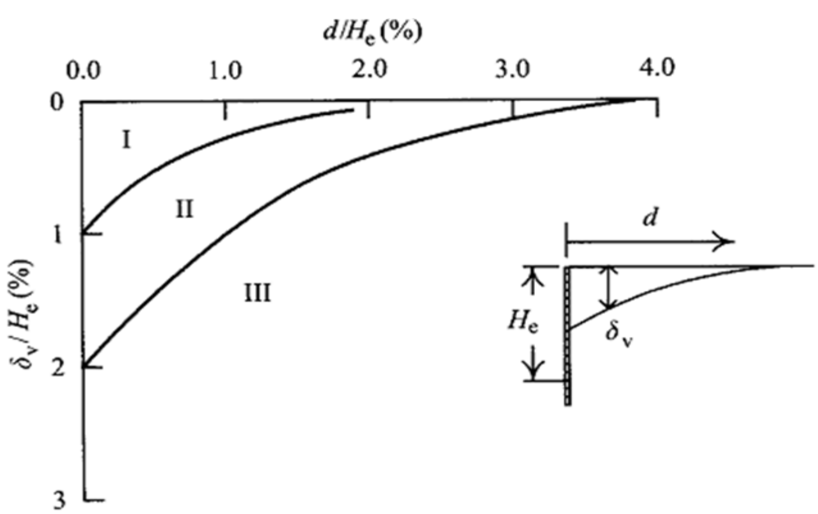


Figure 4 Peck's method for estimating ground surface settlement

The inputs needed for computing the vertical deflection of the ground surface are

He= Height of excavation

d= Distance from the wall

δv= ground surface settlement

The three ranges of zones seen on the figure above represent three different types of soils. Zone I represent sand, Zone II represent stiff clay and Zone III represent soft clay soil type.

Therefore, as the ratio of the distance from the wall to the excavation depth is given by the above fig. we can easily compute the vertical settlements for the each soil type.

3.3.2 Bowles's method

Bowels (1986) suggested a procedure to estimate excavation-induced ground surface settlements which can be described as follows:

Compute the lateral displacement of the wall using the finite element method or the beam on elastic foundation method.

1. Compute the area of the lateral wall deflection (a_d).

2. Estimate the influence range of ground surface settlement (D) following Capse's method (1966):

$$D = (H_e + H_d) \tan (45 - \phi/2)$$

Where He = the excavation depth ; Hd = B if $\phi = 0$ and Hd = 0.5 B tan(45+ϕ/2) if $\phi > 0$, where B= the excavation width and ϕ = the parameter of soil strength.

3. Suppose the maximum ground surface settlement is located at the intersection of the wall and ground surface. Estimate the maximum ground surface settlement:

$$\delta_{vm} = 4a_d/D$$

4. Suppose the ground surface settlement exhibits parabolic distribution. The settlement (δ_v) at l_x can be computed as follows:

$$\delta_v = \delta_{vm} (l_x/D)^2$$

Where l_x = distance from a point at the distance of D from the wall and δ_v = the settlement at the distance of l_x.

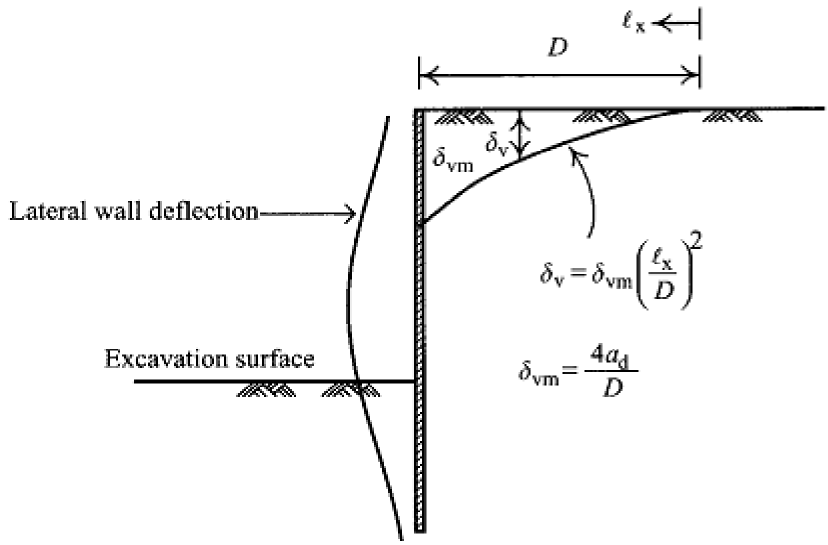


Figure 5 Bowles's method for estimating ground surface settlement

3.2.3 Clough and O'Rourke's method

Clough and O'Rourke proposed excavation in sand or stiff clay will tend to produce triangular ground surface settlement. The maximum settlement will be found near the retaining wall. The envelopes of ground surface settlement are shown in Fig below whose influence ranges from $2H_e$ to $3H_e$ where H_e is the final excavation depth. Excavation in soft to medium clay will produce a trapezoidal envelope of ground surface settlement. The maximum ground surface settlement occurs in the range of $0 < d/H_e < 0.75$ while $0.75 < d/H_e < 2.0$ is the transition zone where settlement decreases from the largest to almost none.

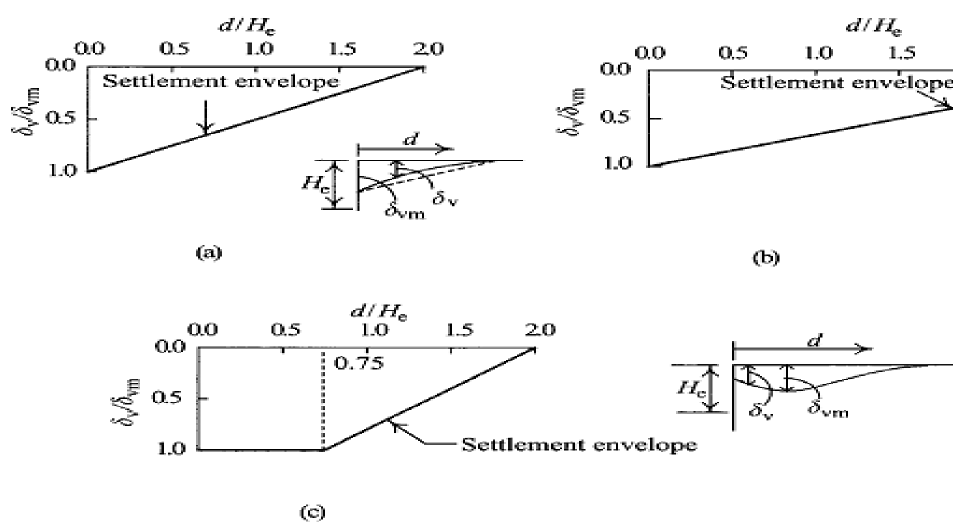


Figure 6 Clough and O'Rourke's method for estimating ground surface settlement (a) Sand, (b) Stiff to stiff clay and (c) Soft to medium soft clay

4. DATA COLLECTION AND ANALYSIS

4.1. Data Collection

The input data's needed for both the Plaxis analysis and the hand calculation methods are discussed in detail in the previous section of the paper. Different methods have been used to collect the necessary data's for these analyses.

- The pile or plate is made of C-25 concrete with a diameter of 40cm.

<u>Pile (Plate) parameters</u>

Modulus of elasticity, E = 5000 √fc   where fc = concrete strength parameter

Concrete class of C-25 has been used to model the pile with fc=25KPa

E = 800Mpa

EA = $1.008*10^5$ KN/m;   Area= ∏r^2 = 0.126m^2

EI = 1257 kNm^2/m;   Moment of inertia for circular section (I) = ∏D^2/64 = $1.257*10^{-3}m^2$

Weight of pile (W) = γv = 12.52 kN

Poisson's ratio (V) = 0.15

- The anchor rod is made of high strength steel therefore it can be considered to have modulus of elasticity equal to steel. The anchor rod has three strands each with 0.6 inch diameter and a force carrying capacity of 120kN (which value is obtained from a practical or actual design of our country)

<u>Anchor rod</u>

Modulus of elasticity, E =200GPa (steel)

EA = $7.296*10^4$ KN

Spacing in between anchors Ls = 1m

The prestress force for the anchor rod is 300kN (which is 85% of the carrying capacity of the three strands, as is used in practical design cases)

- The grout body is high stress concentration area so it's grouted with high quality cement with water which is slurry type. So it has high strength and from an expert on the field it's suggested its class is as high as C-40 concrete.

Geogrid

Modulus of elasticity, E = 5000 √fc fc= 40kpa

E = 1000MPa

Diameter= 130mm

A= ∏D^2/4= 0.0133m^2

EA= 1.33*10^4 kN/m

The parameters for the soil and interface are obtained from well known (standard) published books such as Bowels and others. These range of values obtained from those books can be found for reference on the annex section of this paper.

4.2. PLAXIS Analysis

The plaxis model used in this paper is an anchored pile type. This model type has ϕ40cm pile with a spacing of 1.0m. The width of the excavation is 30m but due to its symmetry it's modeled as only the half section. It also has an anchor rod with three strands each carrying 85% of their maximum capacity which is 300kN in total.

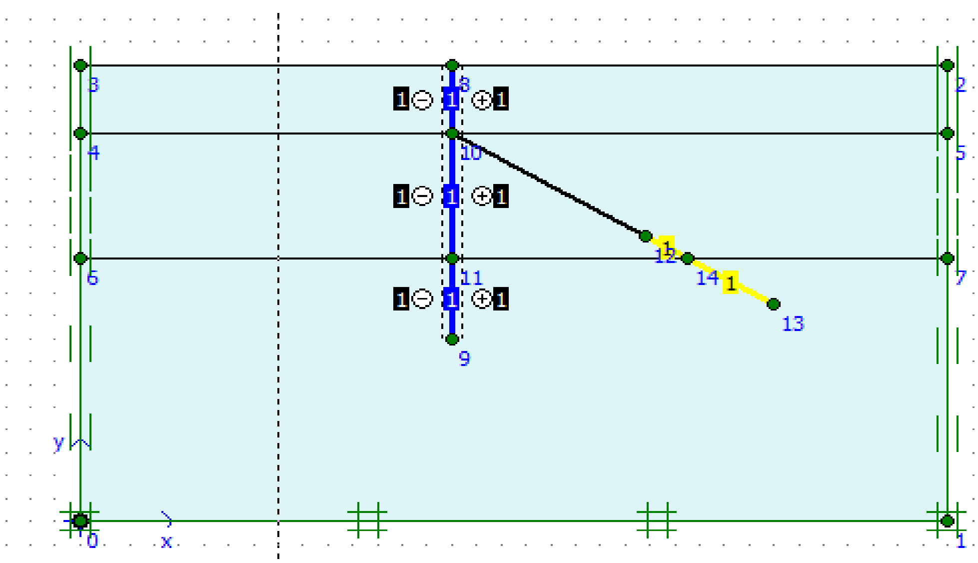


Figure 7 Soil Model

This Plaxis model is used for parametric study on Elastic modulus E by using three different types of soils. The three soil types are soft clay, stiff clay and sand. So by only varying the elastic modulus on each soil type the ground surface deformation is analyzed. For each soil type three different E are used and analyzed.

Soft Clay

Case 1

Input Datas

Modulus of elasticity E_1 = 5MPa

Unsaturated unit weight γ_{unsat} = 16 kN/m^3

Saturated unit weight γ_{sat} = 18 kN/m^3

Permeability coefficient kx = ky= 0.001m/day

Poisson's ratio V= 0.25

Cohesion C= 10 kN/m^2

Angle of internal friction ϕ =20°

Dilatancy ψ = 0 (It is tendency to be more viscous or solid when affected by an outside force mostly a property of cohesion less material)

Interface reduction factor R_{int} = 0.5

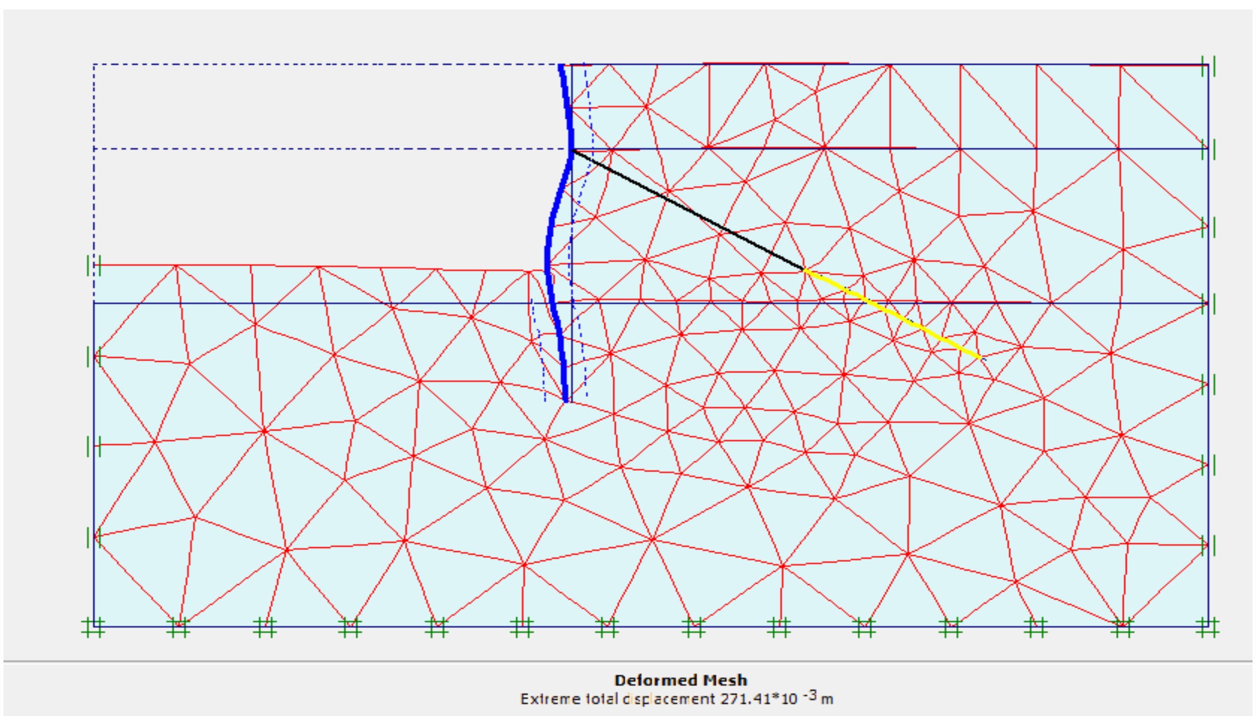


Figure 8 Plaxis model output of Ground deformation for soft clay E=5MPa

Ground Deformation

x (m)	Deformation (m)
0	0.055
0.5	0.052
1	0.049
1.5	0.046
2	0.043
2.5	0.04
3	0.037
3.5	0.034
4	0.031
4.5	0.028
5	0.025
5.5	0.022
6	0.019
6.5	0.016
7	0.013
7.5	0.01
8	0.007
8.5	0.004
9	0.001
10	0
11	0
12	0
13	0
14	0
15	0

Table 4 Ground deformation for soft clay E=5Mpa

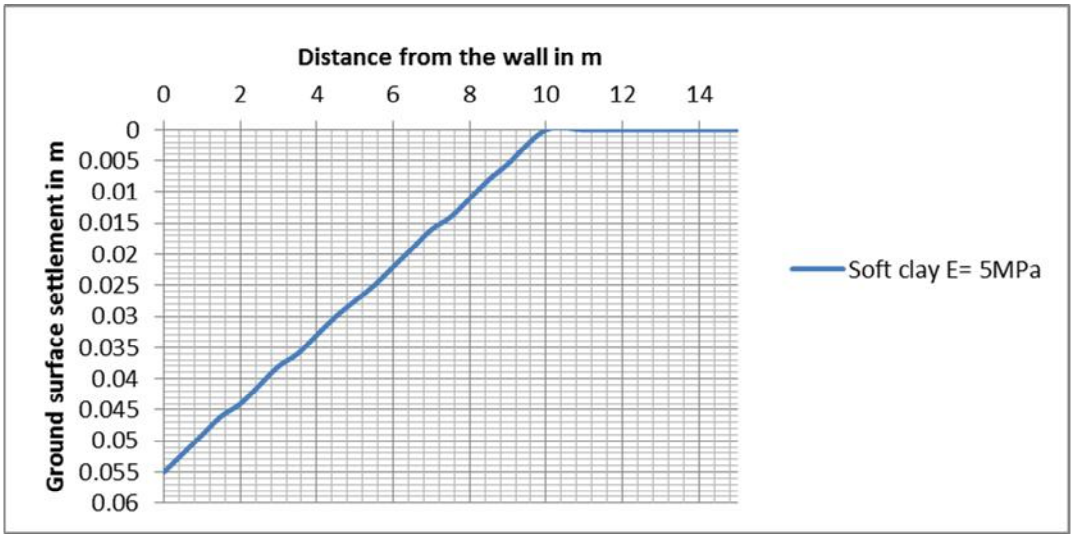


Figure 9 Ground deformation for soft clay E=5Mpa

Soft Clay

Case 2

Input Datas

Modulus of elasticity E_2 = 15MPa

Unsaturated unit weight γ_{unsat} = 16 kN/m^3

Saturated unit weight γ_{sat} = 18 kN/m^3

Permeability coefficient Kx = ky= 0.001 m/day

Poisson's ratio V= 0.25

Cohesion C= 10 kN/m^2

Angle of internal friction ϕ =20°

Dilatancy ψ = 0

Interface reduction factor R_{int} = 0.5

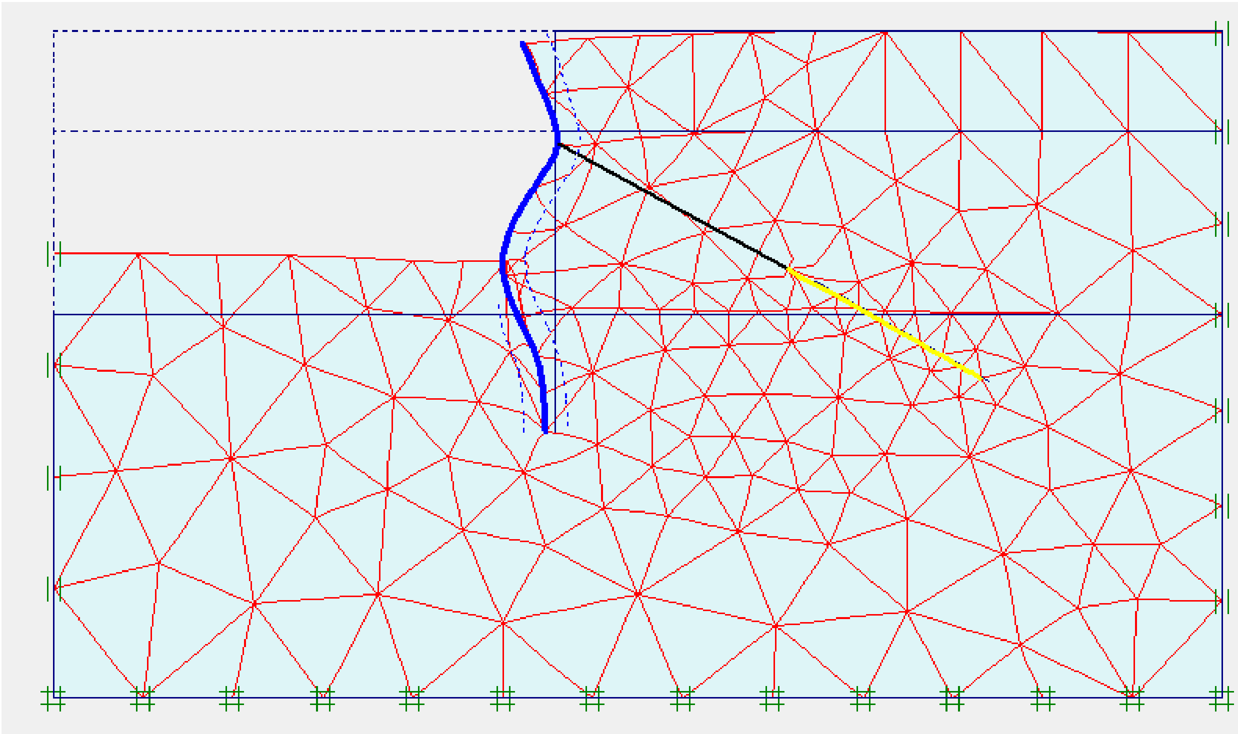


Figure 10 Plaxis model output of Ground deformation for soft clay E=15MPa

Ground Deformation	
x (m)	Deformation (m)
0	0.05
0.5	0.047
1	0.044
1.5	0.041
2	0.038
2.5	0.036
3	0.033
3.5	0.03
4	0.027
4.5	0.025
5	0.022
5.5	0.019
6	0.017
6.5	0.014
7	0.011

7.5	0.008
8	0.005
8.5	0.001
9	0
10	0
11	0
12	0
13	0
14	0
15	0

Table 5 Ground deformation for soft clay E=15Mpa

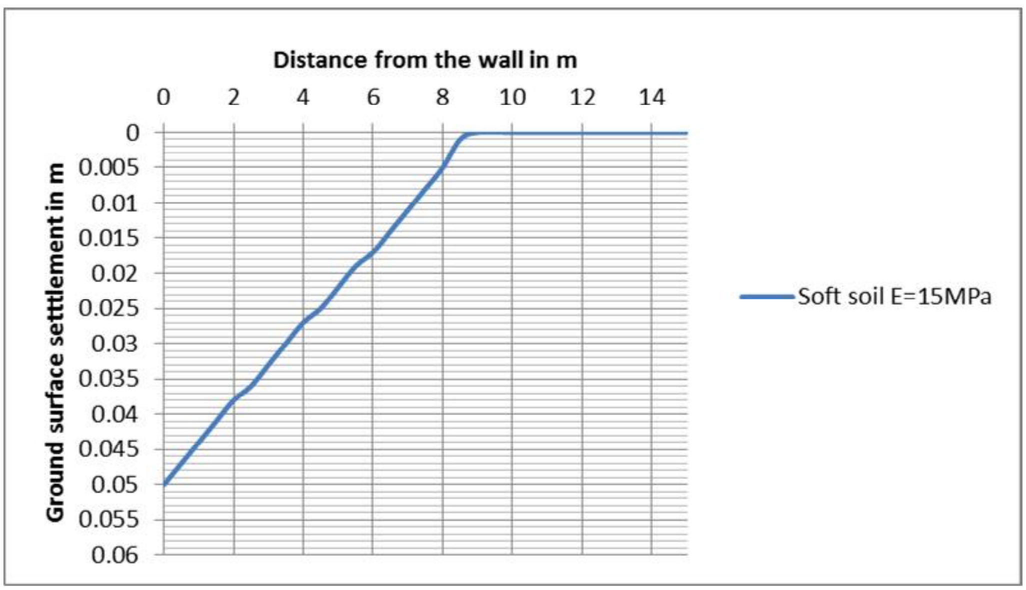


Figure 11 Ground deformation for soft soil E=15MPa

Soft Clay

Case 3

Input Datas

Modulus of elasticity E_3 = 25MPa

Unsaturated unit weight γ_{unsat} = 16 kN/m^3

Saturated unit weight γ_{sat} = 18 kN/m^3

Permeability coefficient Kx = ky = 0.001 m/day

Poisson's ratio V= 0.25

Cohesion C= 10 kN/m^2

Angle of internal friction ϕ =20°

Dilatancy ψ = 0

Interface reduction factor R_{int} = 0.5

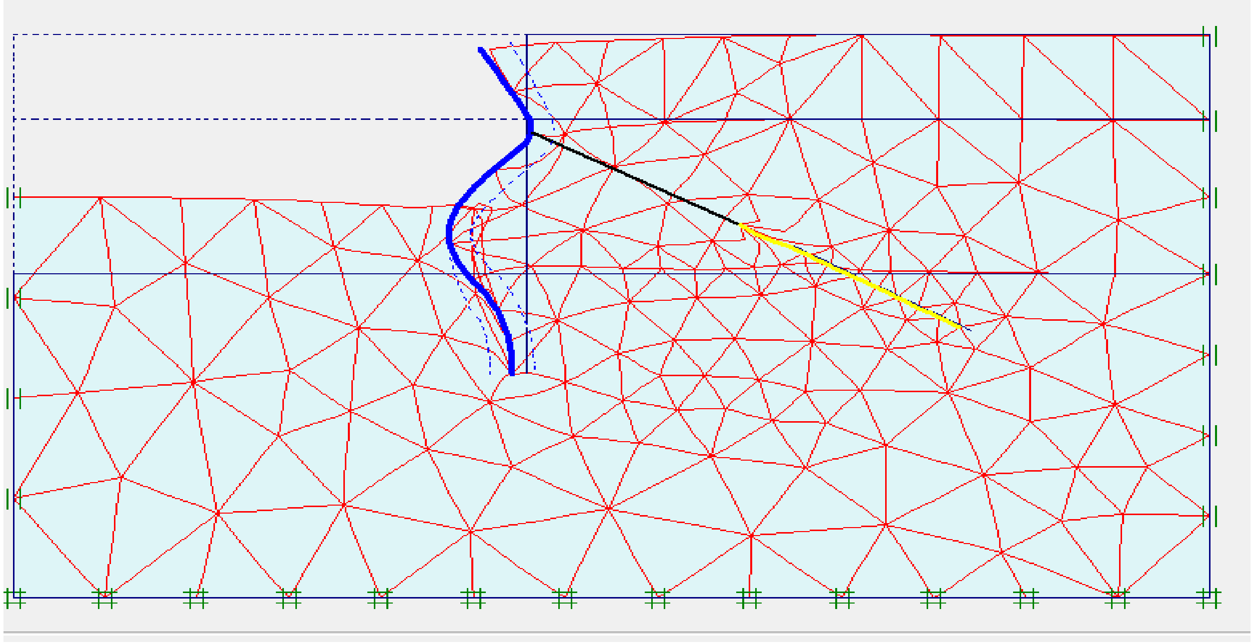


Figure 12 Plaxis model output of Ground deformation for soft clay E=25MPa

Ground Deformation

x (m)	Deformation
0	0.022
0.5	0.02
1	0.017
1.5	0.014
2	0.011
2.5	0.008
3	0.007
3.5	0.005
4	0.003
4.5	0.001
5	0.0008
5.5	0.0005
6	0.0002
6.5	0.0001
7	0
7.5	0
8	0
8.5	0
9	0
10	0
11	0
12	0
13	0
14	0
15	0

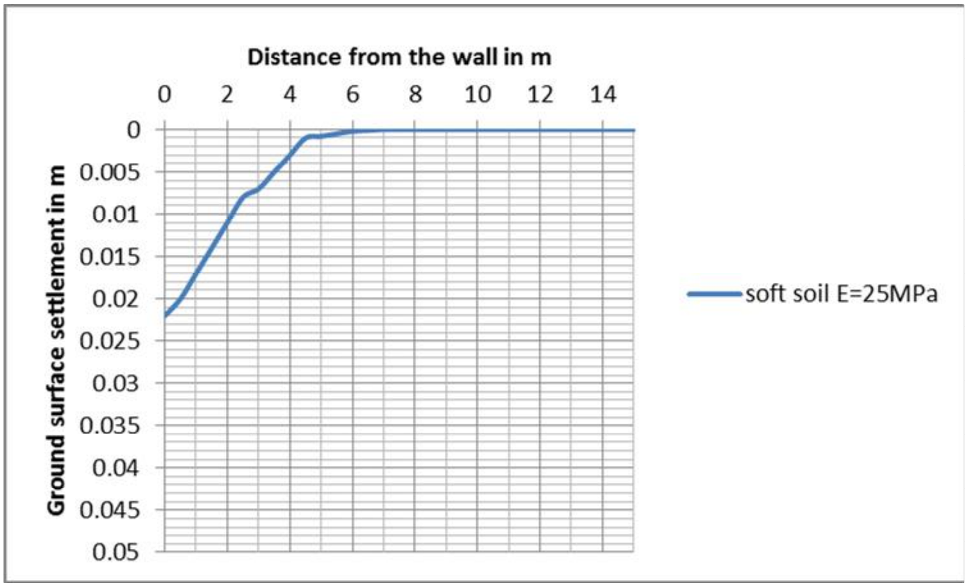


Figure 13 Ground deformation for soft soil E=25MPa

Table 6 Ground deformation for soft clay E=25Mpa

Stiff Clay

Case 1

Input Datas

Modulus of elasticity E_1 = 50MPa

Unsaturated unit weight γ_{unsat} = 17 kN/m^3

Saturated unit weight γ_{sat} = 19 kN/m^3

Permeability coefficient Kx = ky = 0.01 m/day

Poisson's ratio V= 0.20

Cohesion C= 20 kN/m^2

Angle of internal friction ϕ =30°

Dilatancy ψ = 0

Interface reduction factor R_{int} = 0.5

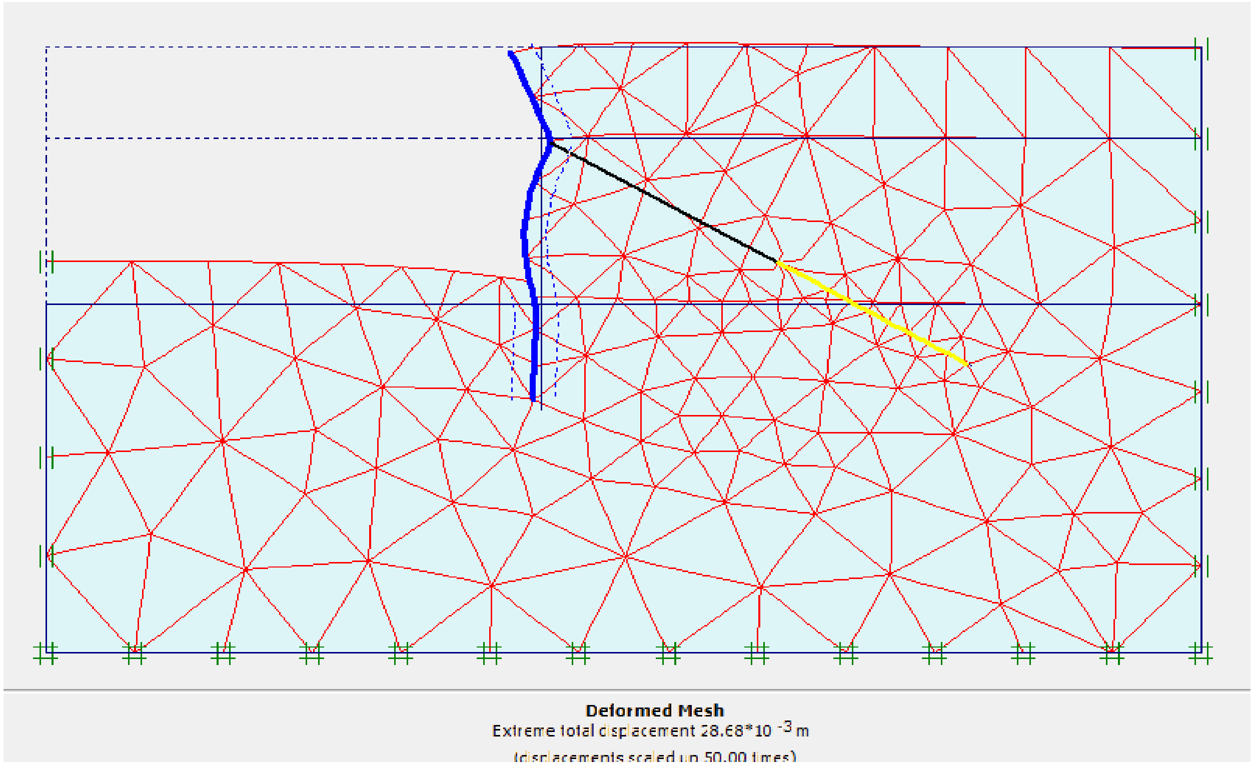


Figure 14 Plaxis model output of Ground deformation for soft clay E=50MPa

Ground Deformation

x (m)	Deformation
0	0.017
0.5	0.015
1	0.013
1.5	0.0118
2	0.0103
2.5	0.0088
3	0.0076
3.5	0.0063
4	0.0052
4.5	0.00425
5	0.0034
5.5	0.003
6	0.0019
6.5	0.0013
7	0.0008
7.5	0.0005
8	0.0002
8.5	0.0001
9	0.00005
10	0
11	0
12	0
13	0
14	0
15	0

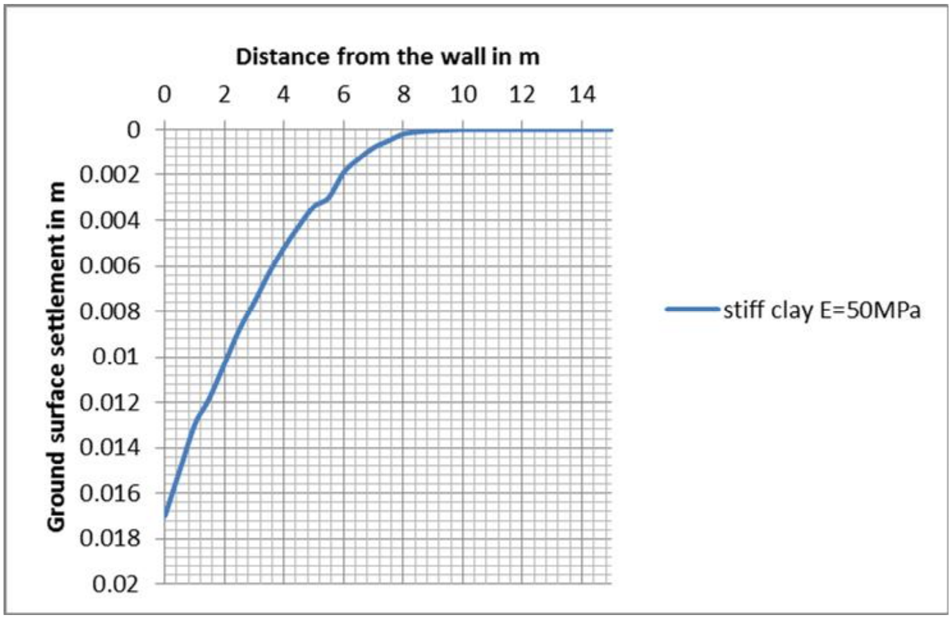


Figure 15 Ground deformation for stiff clay E=50Mpa

Table 7 Ground deformation for stiff clay E=50MPa

Stiff Clay

Case 2

Input Datas

Modulus of elasticity E_2 = 75MPa

Unsaturated unit weight γ_{unsat} = 17 kN/m^3

Saturated unit weight γ_{sat} = 19 kN/m^3

Permeability coefficient Kx = ky = 0.01 m/day

Poisson's ratio V= 0.20

Cohesion C= 20 kN/m^2

Angle of internal friction ϕ =30°

Dilatancy ψ = 0

Interface reduction factor R_{int} = 0.5

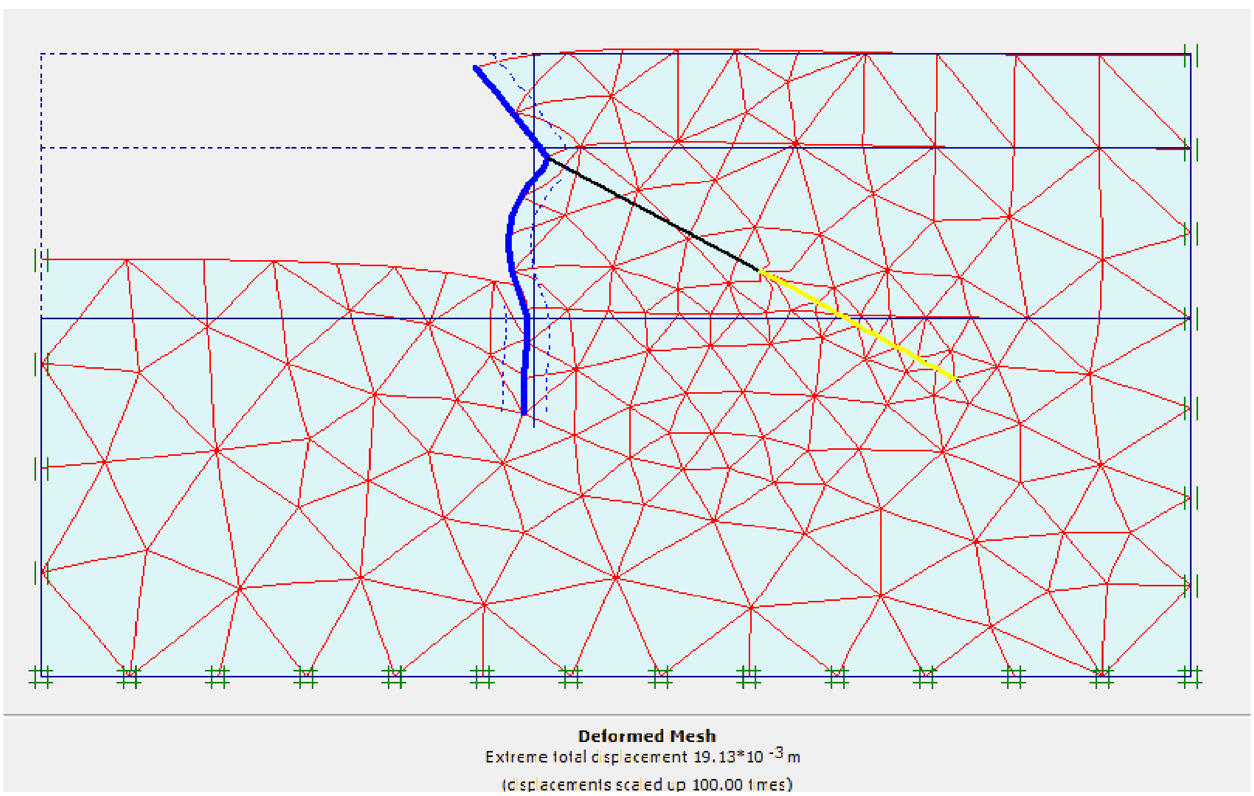


Figure 16 Plaxis model output of Ground deformation for soft clay E=75MPa

Ground Deformation

x (m)	Deformation
0	0.016
0.5	0.014
1	0.0118
1.5	0.01
2	0.009
2.5	0.0083
3	0.0071
3.5	0.0059
4	0.0049
4.5	0.004
5	0.0032
5.5	0.0024
6	0.0017
6.5	0.0012
7	0.0008
7.5	0.0004
8	0.0002
8.5	0.00009
9	0.00004
10	0
11	0
12	0
13	0
14	0
15	0

Table 8 Ground deformation for stiff clay E=75MPa

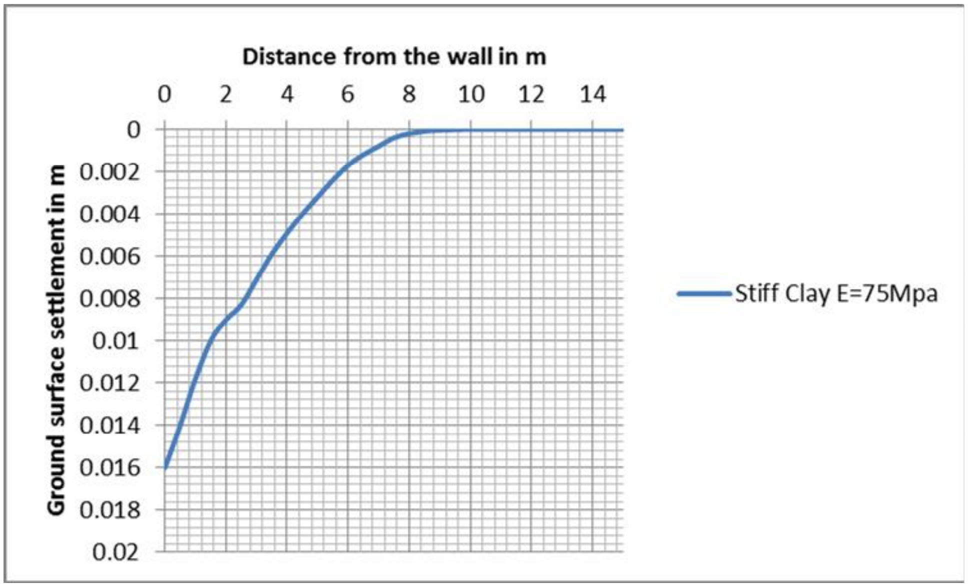


Figure 17 Ground deformation for stiff clay E=75MPa

Stiff Clay

Case 3

Input Datas

Modulus of elasticity E_3 = 100MPa

Unsaturated unit weight γ_{unsat} = 17 kN/m^3

Saturated unit weight γ_{sat} = 19 kN/m^3

Permeability coefficient Kx = ky= 0.01 m/day

Poisson's ratio V= 0.20

Cohesion C= 20 kN/m^2

Angle of internal friction ϕ =30°

Dilatancy ψ = 0

Interface reduction factor R_{int} = 0.5

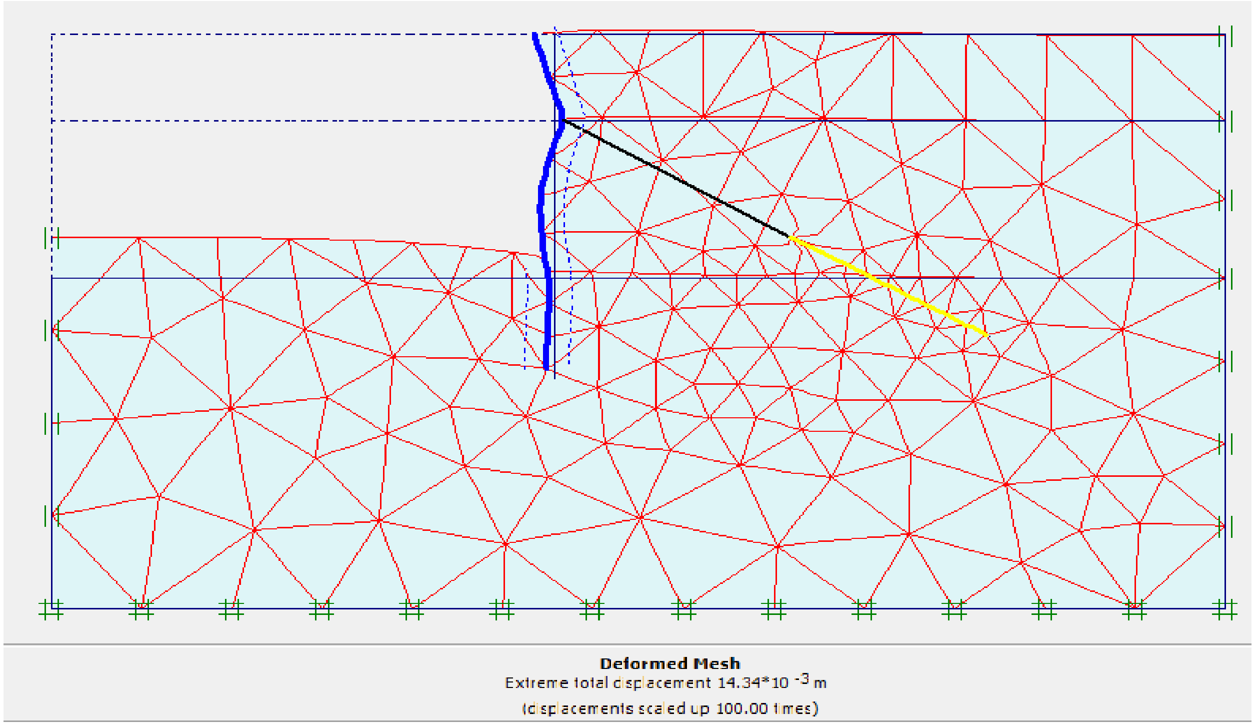


Figure 18 Plaxis model output of Ground deformation for soft clay E=100MPa

Ground Deformation

x (m)	Deformation
0	0.006
0.5	0.0053
1	0.0047
1.5	0.0041
2	0.0035
2.5	0.0029
3	0.0025
3.5	0.002
4	0.0017
4.5	0.0013
5	0.001
5.5	0.0007
6	0.00075
6.5	0.0005
7	0.00033
7.5	0.00018
8	0.0001
8.5	0
9	0
10	0
11	0
12	0
13	0
14	0
15	0

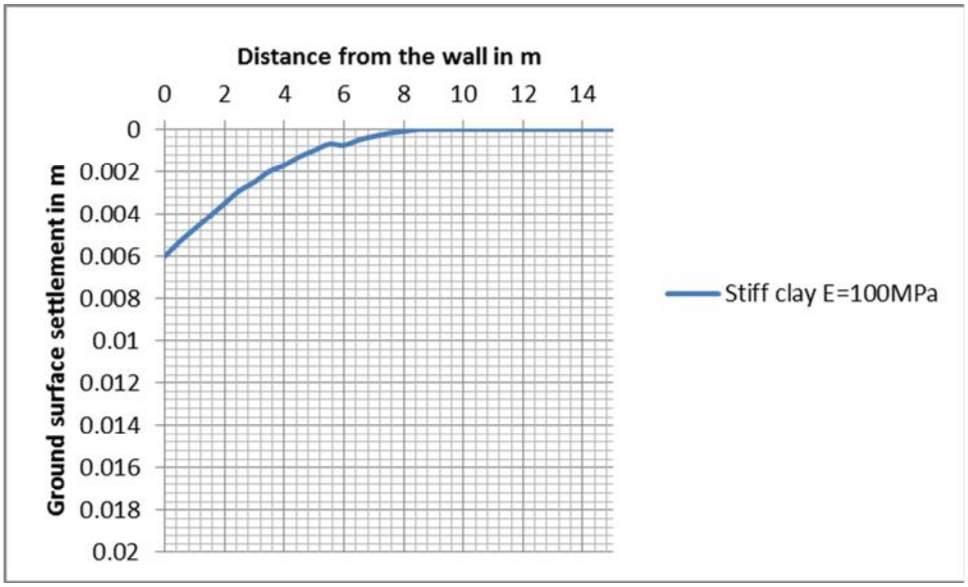


Figure 19 Ground deformation stiff clay E=100Mpa

Table 9 Ground deformation for stiff clay E=100MPa

Medium dense Sand

Case 1

Input Datas

Modulus of elasticity E_1 = 50MPa

Unsaturated unit weight γ_{unsat} = 18 kN/m^3

Saturated unit weight γ_{sat} = 20 kN/m^3

Permeability coefficient Kx = ky= 1 m/day

Poisson's ratio V= 0.30

Cohesion C= 2 kN/m^2

Angle of internal friction ϕ =35°

Dilatancy ψ = 2

Interface reduction factor R_{int} = 0.67

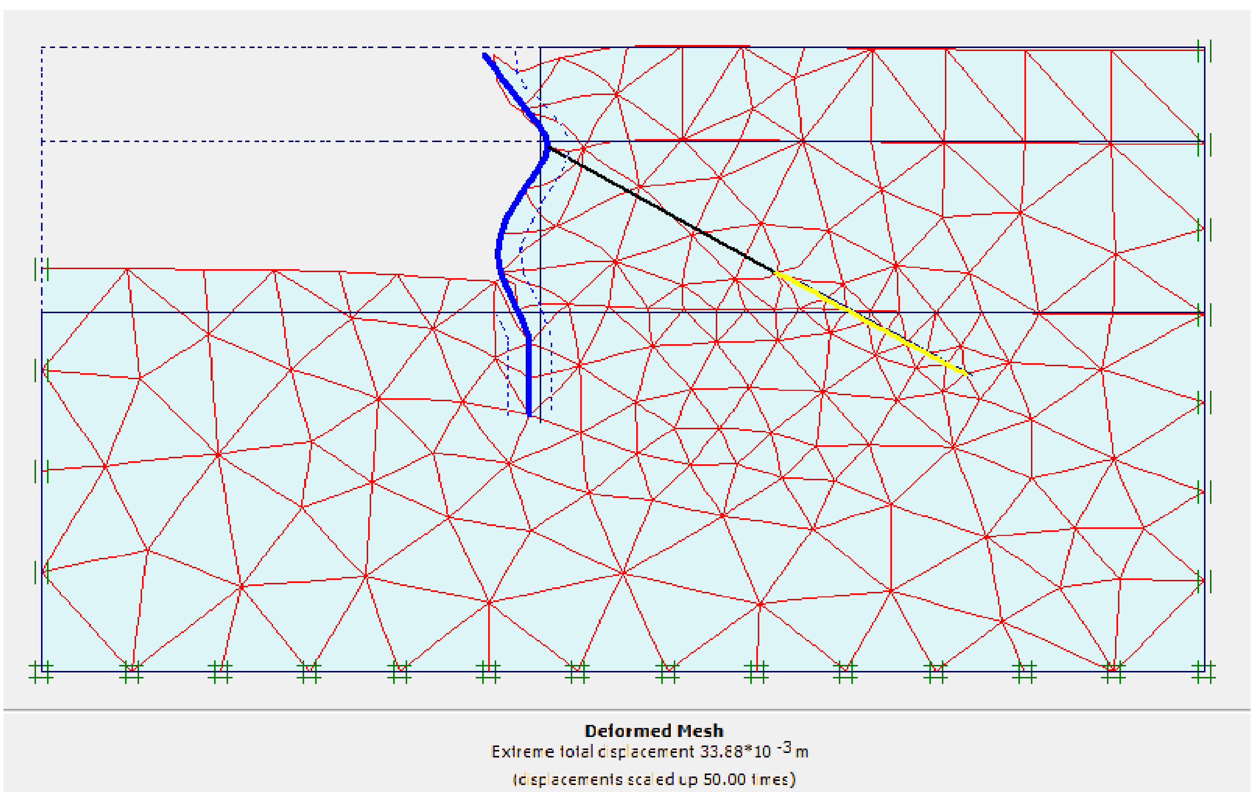


Figure 20 Plaxis model output of Ground deformation for soft clay E=50MPa

Ground Deformation

x (m)	Deformation
0	0.026
0.5	0.023
1	0.021
1.5	0.018
2	0.016
2.5	0.015
3	0.013
3.5	0.01
4	0.0094
4.5	0.0078
5	0.0065
5.5	0.0053
6	0.0042
6.5	0.0032
7	0.0023
7.5	0.0016
8	0.001
8.5	0.0006
9	0.00026
10	0.0001
11	0
12	0
13	0
14	0
15	0

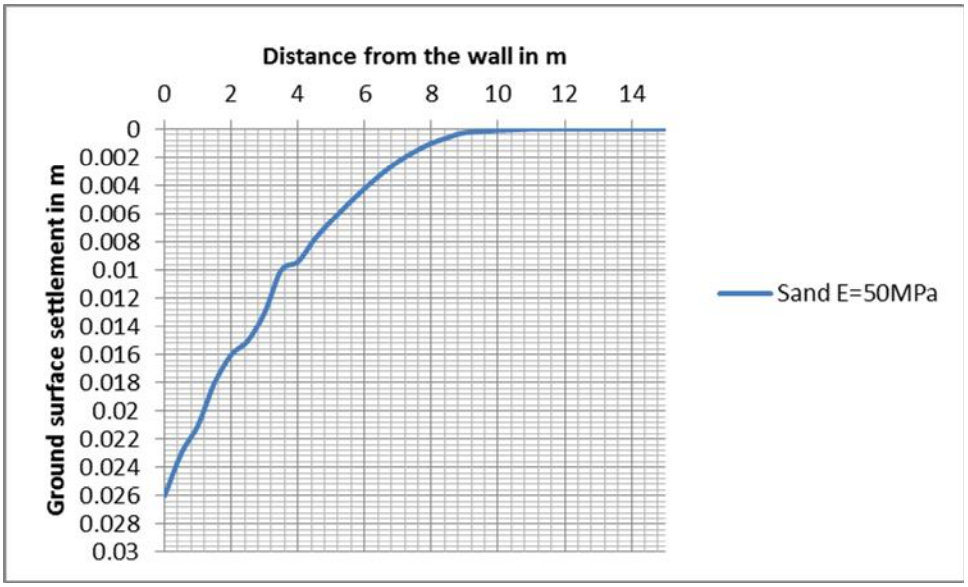


Figure 21 Ground deformation for sand E=50MPa

Table 10 Ground deformation for sand E=50MPa

Medium dense Sand

Case 2

Input Datas

Modulus of elasticity E_2 = 65MPa

Unsaturated unit weight γ_{unsat} = 18 kN/m^3

Saturated unit weight γ_{sat} = 20 kN/m^3

Permeability coefficient kx = ky= 1 m/day

Poisson's ratio V= 0.30

Cohesion C= 2 kN/m^2

Angle of internal friction ϕ =35°

Dilatancy ψ = 2

Interface reduction factor R_{int} = 0.67

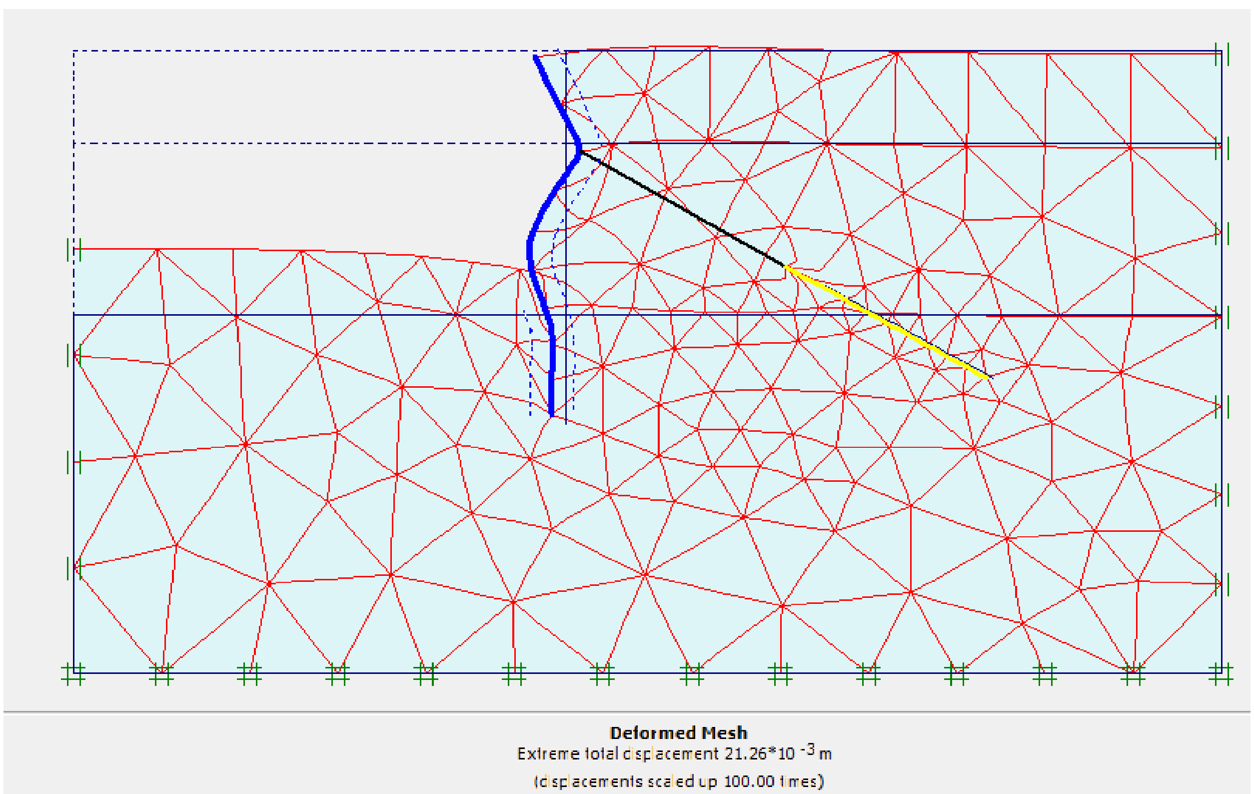


Figure 21 Plaxis model output of Ground deformation for soft clay E=65MPa

Ground Deformation

x (m)	Deformation
0	0.022
0.5	0.02
1	0.019
1.5	0.016
2	0.014
2.5	0.012
3	0.011
3.5	0.0093
4	0.0079
4.5	0.0065
5	0.0055
5.5	0.0044
6	0.0035
6.5	0.0027
7	0.0019
7.5	0.0014
8	0.0009
8.5	0.0005
9	0.0002
10	0
11	0
12	0
13	0
14	0
15	0

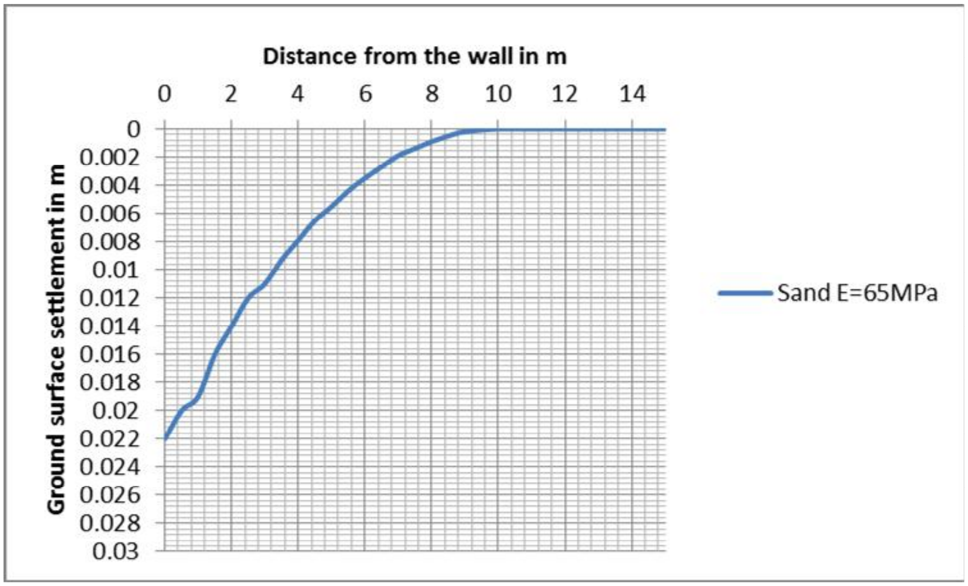


Figure 22 Ground deformation for sand E=65MPa

Table 11 Ground deformation for sand E=65Mpa

Medium dense Sand

Case 3

Input Datas

Modulus of elasticity E_3 = 81MPa

Unsaturated unit weight γ_{unsat} = 18 kN/m^3

Saturated unit weight γ_{sat} = 20 kN/m^3

Permeability coefficient kx = ky= 1 m/day

Poisson's ratio V= 0.30

Cohesion C= 2 kN/m^3

Angle of internal friction ϕ =35°

Dilatancy ψ = 2

Interface reduction factor R_{int} = 0.67

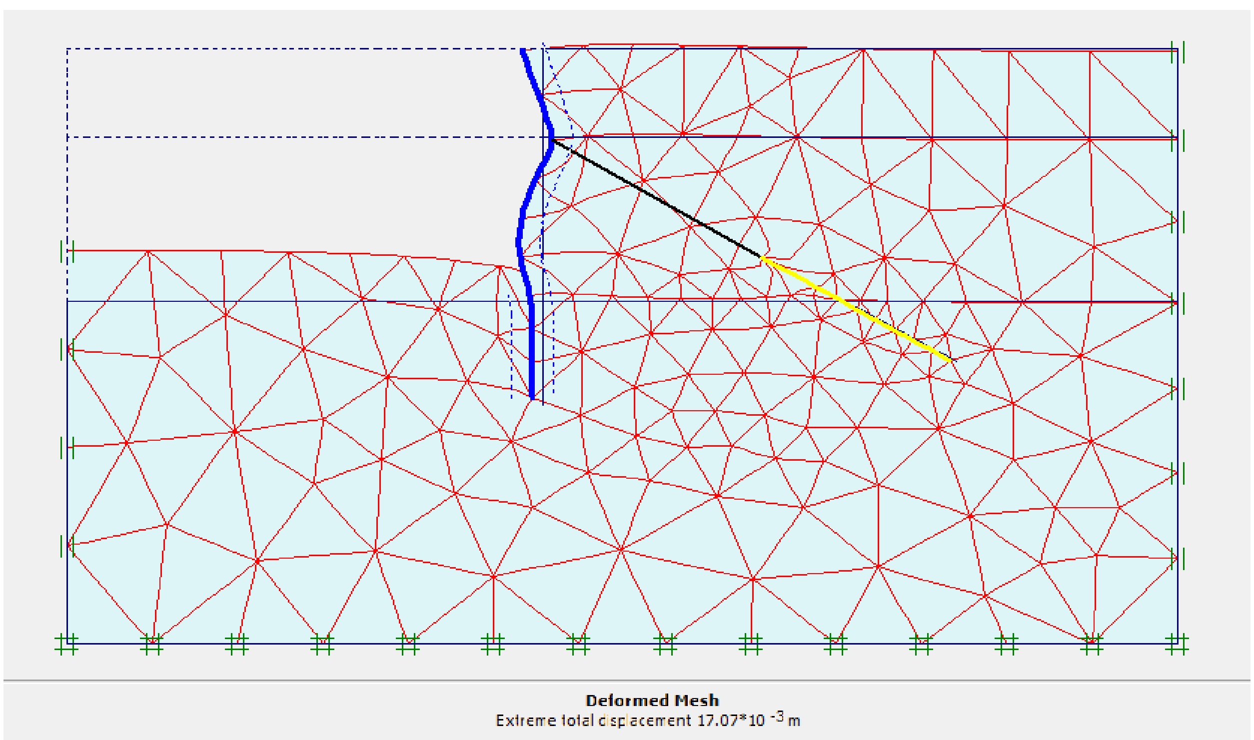


Figure 23 Plaxis model output of Ground deformation for soft clay E=81MPa

Ground Deformation

x (m)	Deformation
0	0.012
0.5	0.01
1	0.009
1.5	0.0079
2	0.0067
2.5	0.0056
3	0.0047
3.5	0.0038
4	0.003
4.5	0.0023
5	0.0017
5.5	0.0012
6	0.00075
6.5	0.00042
7	0.00019
7.5	0.00005
8	0
8.5	0
9	0
10	0
11	0
12	0
13	0
14	0
15	0

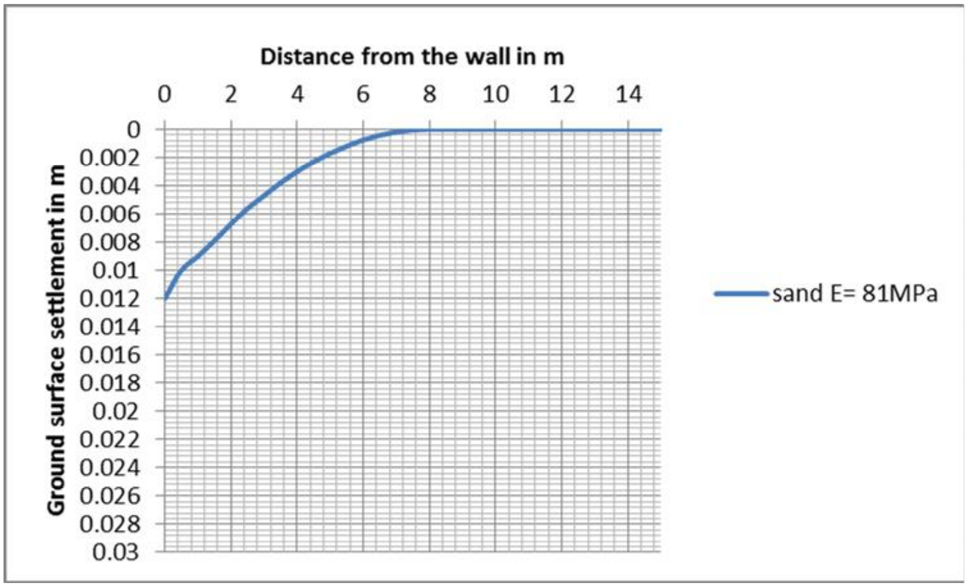


Figure 24 Ground deformation for sand E=81MPa

Table 12 Ground deformation for sand E=81MPa

4.3. Hand Calculation Methods

There are empirical formulas to predict ground surface settlement and the characteristics of soil movement. Many empirical formulas have been proposed but on this paper we only use the three most well-known ones.

4.3.1 Peck's method

Peck (1969b) was the first to propose a method to predict excavation-induced ground surface settlement, based on field observations. He mainly employed the monitoring results of case histories in Chicago and Oslo and established the relation curves between the ground surface settlement and the distance from the wall for three types of soil which are Soft clay, Stiff clay and Sand.

Basically, the curves derived from Peck's method are envelopes. Since Peck's method is the first to derive an empirical formula to predict the ground surface settlement induced by excavation and is simple to apply, it is still used by some engineers.

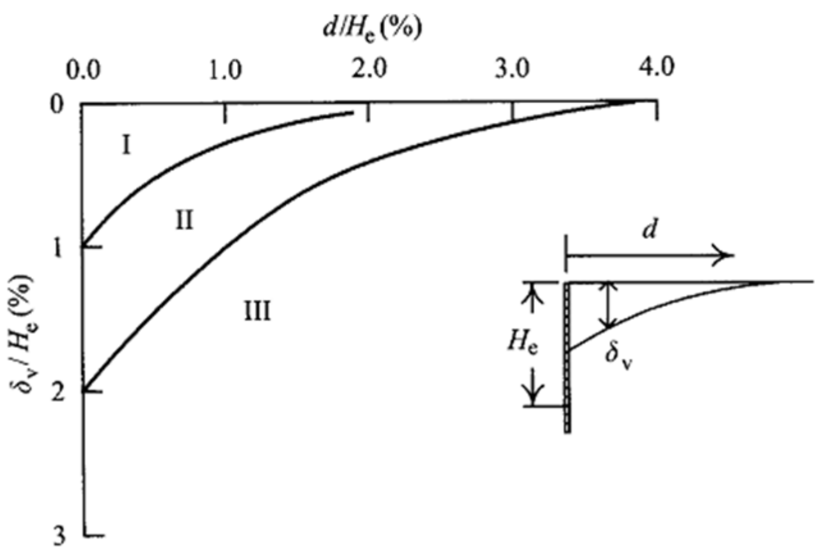


Figure 25 Peck's method for estimating ground surface settlement

Case 1 For Stiff clay Settlement envelope

He 8.5 m

d (cm)	d/He	δv/He
0	0	1
4.25	0.5	0.75
8.5	1	0.5
12.75	1.5	0.25
17	2	0

Table 13 Peck's method for stiff clay settlement envelope

Case 2 For Sand Settlement envelope

He 8.5 m

d (cm)	d/He	δv/He
0	0	2
8.5	1	1.5
17	2	1
25.5	3	0.5
34	4	0

Table 14 Peck's method for sand settlement envelope

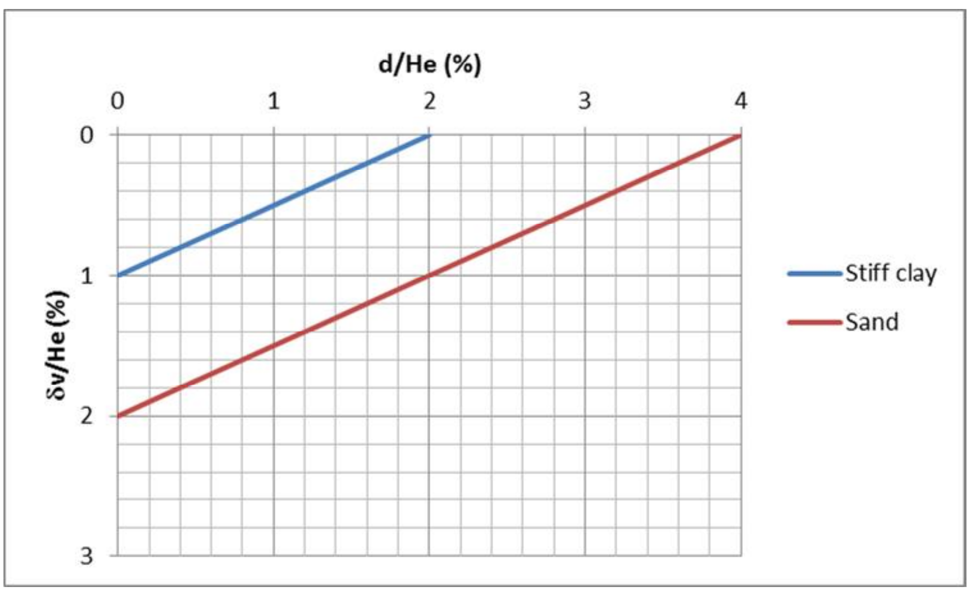


Figure 26 Peck's method for estimation of ground surface settlement

4.3.2 Bowles's method

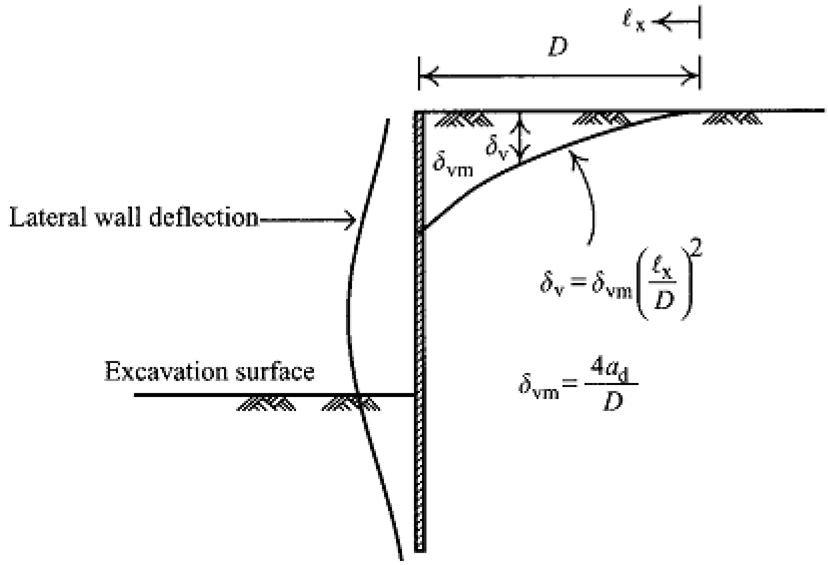


Figure 27 Bowles's method for estimating ground surface settlement

Case 1 Soft clay

Calculation of the area of the lateral wall deflection (ad) from Plaxis software results

ad = 0.27 m2

Estimate the influence range of ground surface settlement (D) ff Capse's method

D= He+Hd tan (45-f/2)

D 18.65 m

Where Height of excavation He = 8.5 m

Width of excavation Hd = 21.42m

Angle of internal friction f = 20°

Estimate the maximum ground surface settlement dvm

dvm= 4ad/D

Dvm = 0.082 m

Ground surface settlement at any point is given by dv = dvm (lX/D) ^{2}

lx	lx/D	$(lx/D)^2$	δv
0	1.00	1.00	0.058
2	0.89	0.80	0.046
4	0.79	0.62	0.036
6	0.68	0.46	0.027
8	0.57	0.33	0.019
10	0.46	0.22	0.012
12	0.36	0.13	0.007
14	0.25	0.06	0.004
16	0.14	0.02	0.001
18.65	0.00	0.00	0.000

Table 15 Bowles's method for soft clay soil settlement envelope

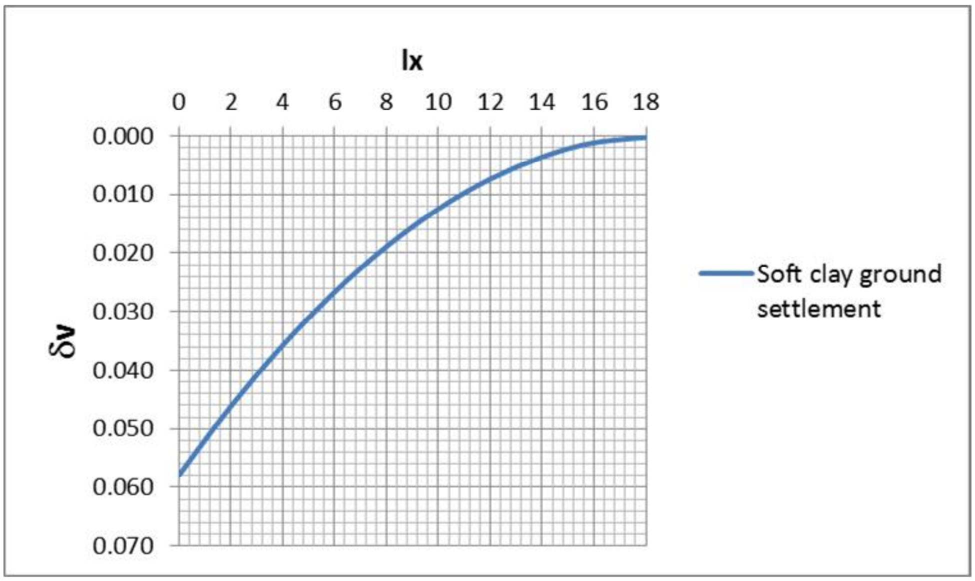


Figure 28 Bowles's method estimation of ground surface settlement for soft clay

Case 2 Stiff clay

Calculation of the area of the lateral wall deflection from Plaxis software results

ad= 0.13 m2

Estimate the influence range of ground surface settlement (D) ff Capse's method

D= $He + H_d \tan(45 - f/2)$

D = 22.60 m

Where He = 8.5 m

Hd = 0.5Btan(45+f/2)= 25.98m

f = 20°

Estimate the maximum ground surface settlement dvm

dvm= 4ad/D

dvm = 0.023 m

dv= dvm (lX/D)2

lx	lx/D	$(lx/D)^2$	δv
0	0.92	0.85	0.020
2	0.83	0.69	0.016
4	0.74	0.55	0.013
6	0.66	0.43	0.010
8	0.57	0.32	0.007
10	0.48	0.23	0.005
12	0.39	0.15	0.003
14	0.30	0.09	0.002
16	0.21	0.05	0.001
18	0.12	0.02	0.000
20.81	0.00	0.00	0.000

Table 16 Bowles's method for stiff clay settlement envelope

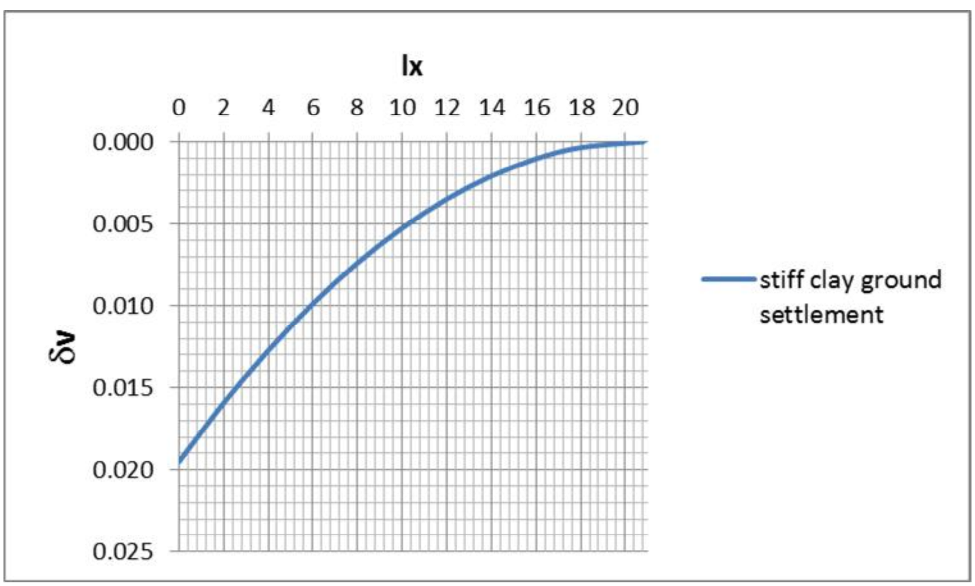


Figure 29 Bowels' method estimation of ground surface settlement for stiff clay

Case 3 sand

Calculation of the area of the lateral wall deflection from Plaxis software results

ad= 0.17 m2

Estimate the influence range of ground surface settlement (D) ff Capse's method

D= He+Hd tan (45-f/2)

D= 23.40 m

Where He = 8.5 m

Hd = 0.5Btan(45+f/2)= 28.81 m

f 20°

Estimate the maximum ground surface settlement dvm

dvm= 4ad/D

dvm 0.029 m

dv= dvm (lX/D)2

lx	lx/D	$(lx/D)^2$	δv
0	0.95	0.90	0.026
2	0.86	0.74	0.022
4	0.78	0.60	0.017
6	0.69	0.48	0.014
8	0.60	0.37	0.011
10	0.52	0.27	0.008
12	0.43	0.19	0.005
14	0.35	0.12	0.004
16	0.26	0.07	0.002
18	0.18	0.03	0.001
22.15	0.00	0.00	0.000

Table 17 Bowles's method for Sand settlement envelope

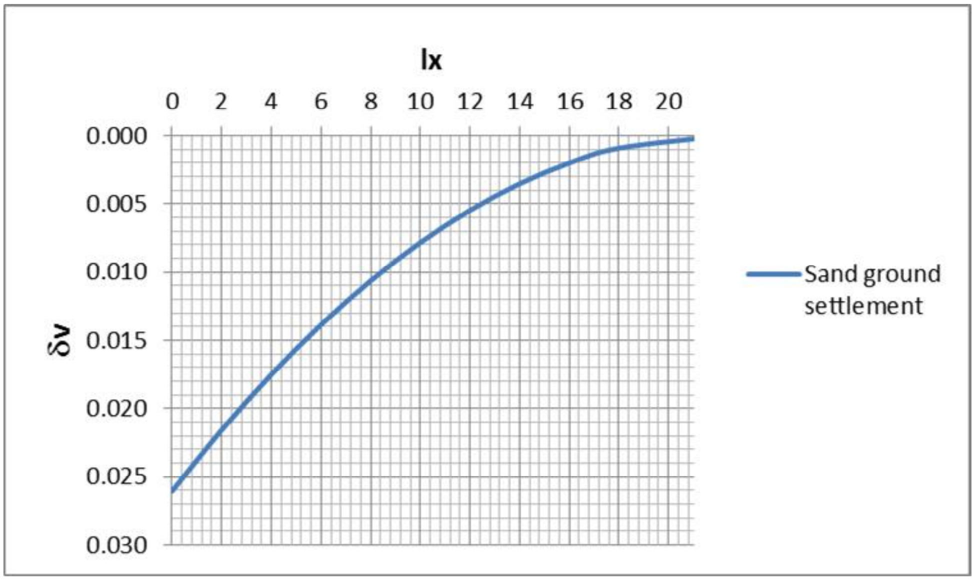


Figure 30 Bowles's method estimation of ground surface settlement for sand

4.3.3 Clough and O'Rourke's method

Clough and O'Rourke (1990) proposed various types of envelopes of excavation induced ground surface settlements for different soils on the basis of case studies. According to their studies, excavation in sand or stiff clay will tend to produce triangular ground surface settlement. The maximum settlement will be found near the retaining wall. The envelopes of ground surface settlement are shown in Fig below whose influence ranges from $2H_e$ to $3H_e$ where H_e is the final excavation depth. Excavation in soft to medium clay will produce a trapezoidal envelope of ground surface settlement. The maximum ground surface settlement occurs in the range of $0 < d/H_e < 0.75$ while $0.75 < d/H_e < 2.0$ is the transition zone where settlement decreases from the largest to almost none.

For Sand Settlement envelope

Height of excavation He = 8.5 m

d	d/He	δv/δvm
0	0	1
4.25	0.5	0.75
8.5	1	0.5
12.75	1.5	0.25
17	2	0

Table 18 Clough and O'Rourke's method for sand settlement envelope

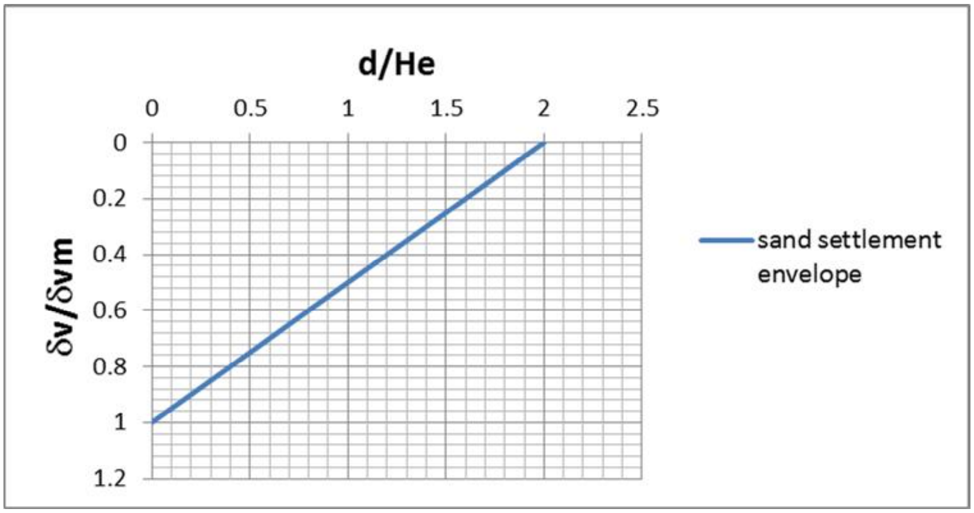


Figure 31 Clough and O'Rourke's method estimation of ground surface settlement for sand

For Stiff clay Settlement envelope

Height of excavation He = 8.5 m

d	d/He	δv/δvm
0	0	1
4.25	0.5	0.83
8.5	1	0.67
12.75	1.5	0.5
17	2	0.33
21.25	2.5	0.17
25.5	3	0

Table 19 Clough and O'Rourke's method for stiff clay settlement envelope

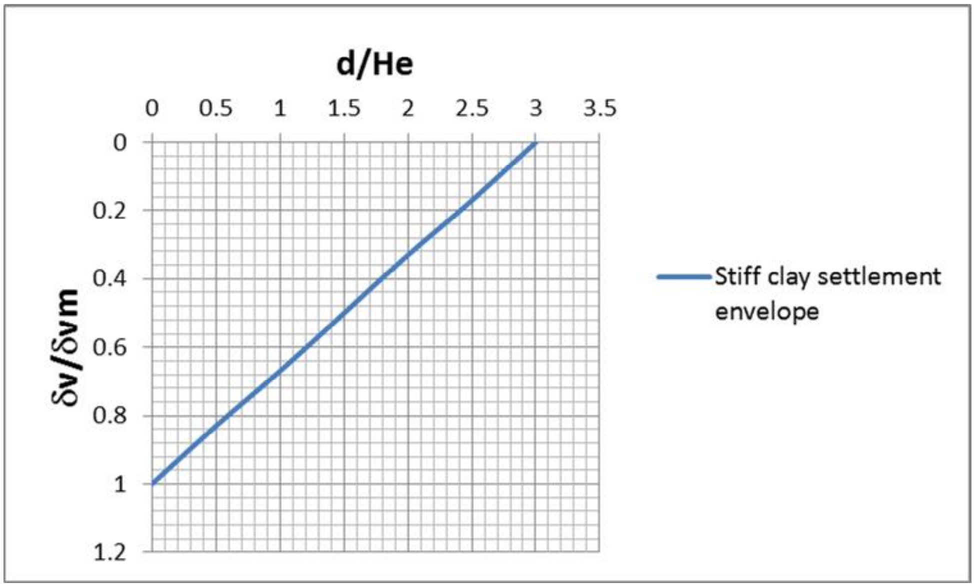


Figure 32 Clough and O'Rourke's method estimation of ground surface settlement for stiff clay

For Soft clay Settlement envelope

He 8.5 m

d	d/He	δv/δvm
0	0	1
4.25	0.5	1
6.375	0.75	1
8.5	1	0.67
12.75	1.5	0.33
17	2	0

Table 20 Clough and O'Rourke's method for soft clay settlement envelope

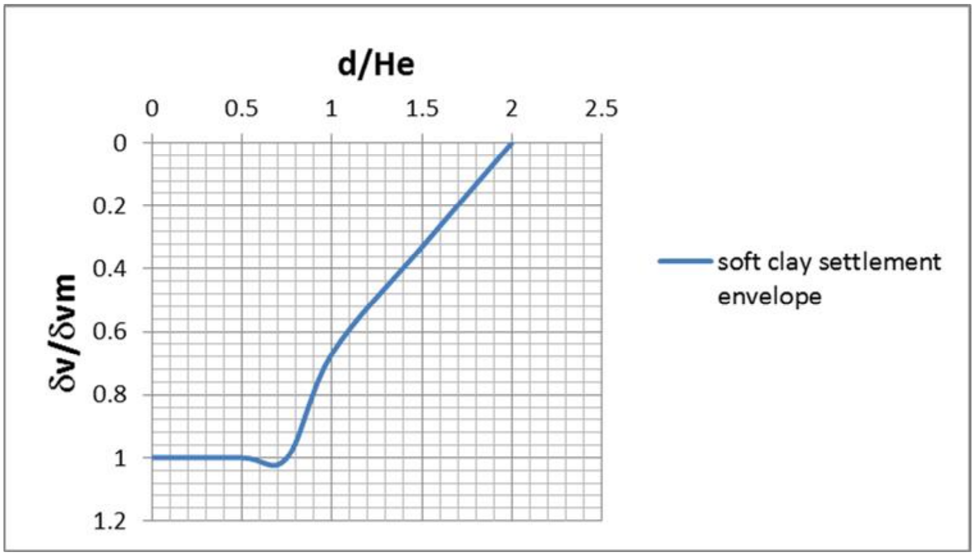
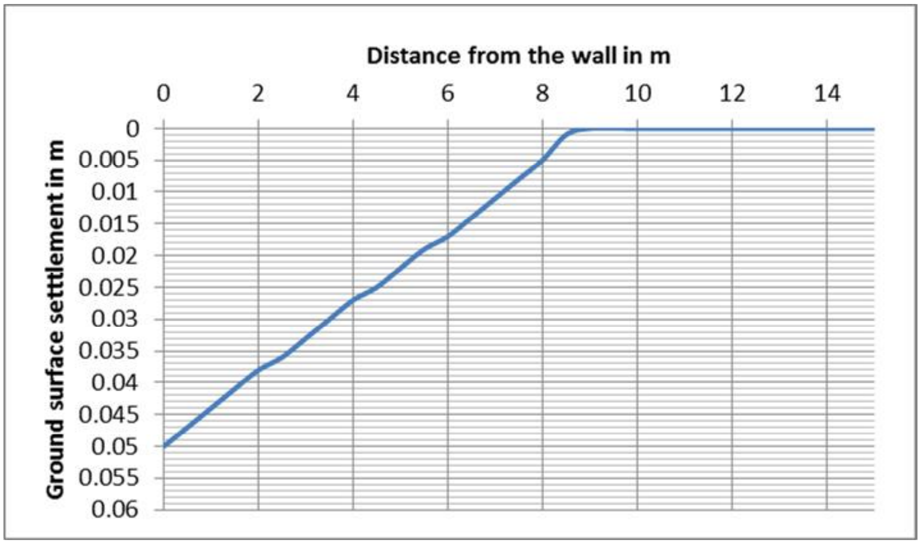


Figure 33 Clough and O'Rourke's method estimation of ground surface settlement for soft clay

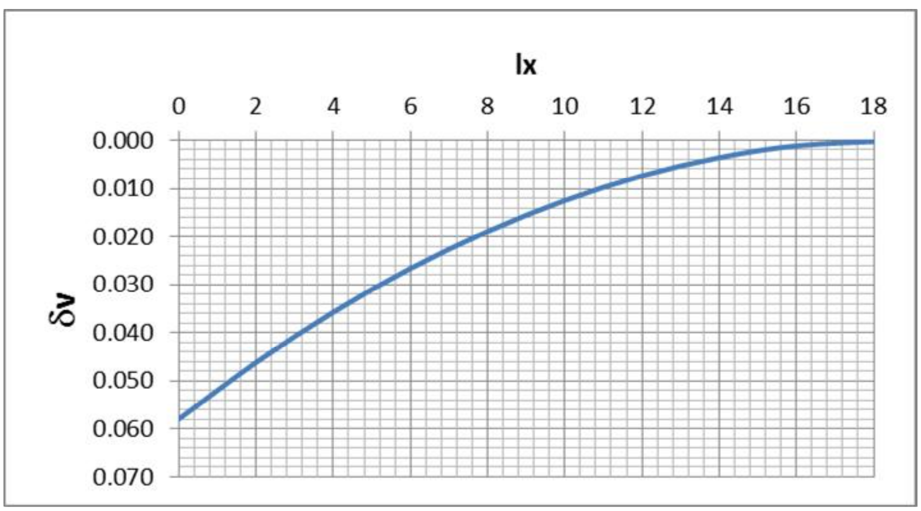
5. DISSCUSSION

For the analysis done by the PLAXIS software and Hand calculation methods the deformation outputs for the three soil types can be summarized and discussed as follows:

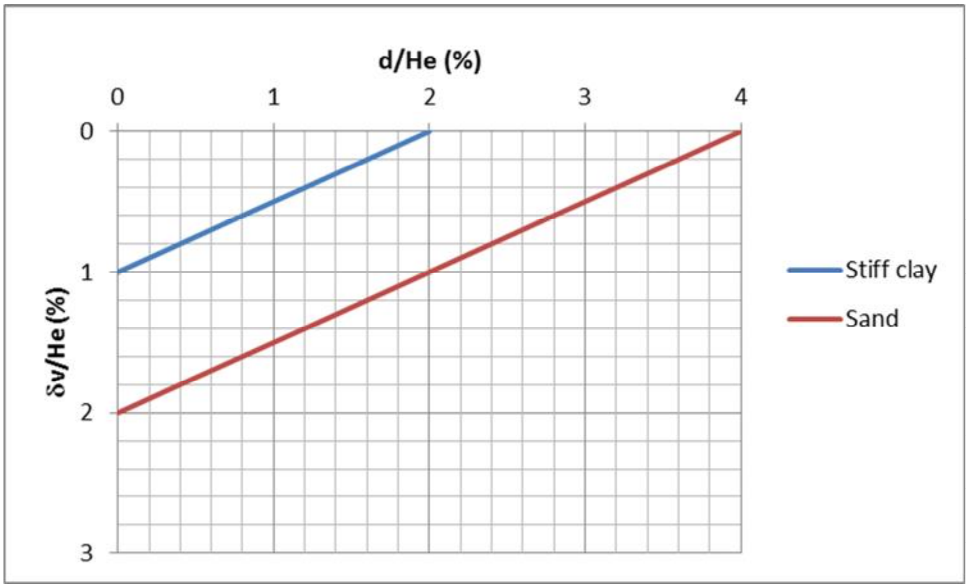
Case 1 soft clay



(a)



(b)



(c)

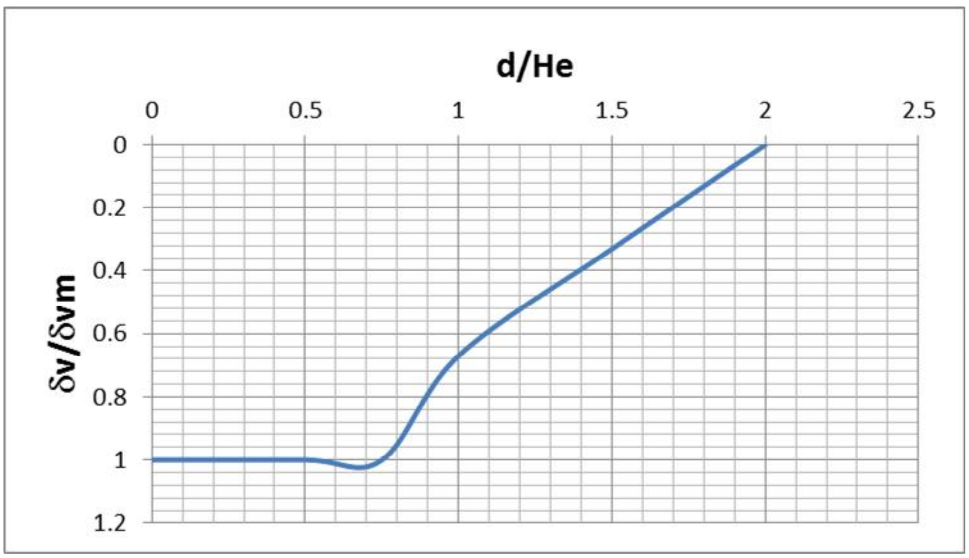
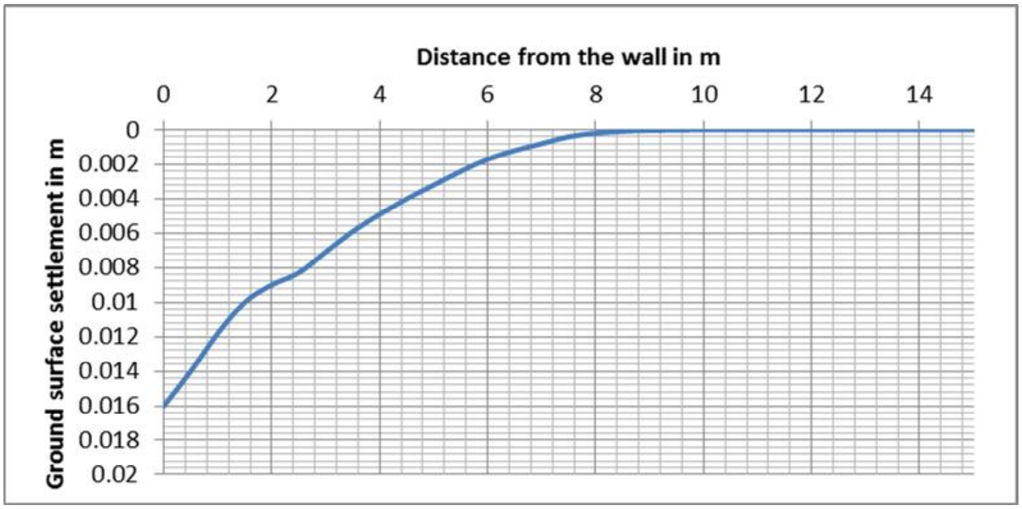


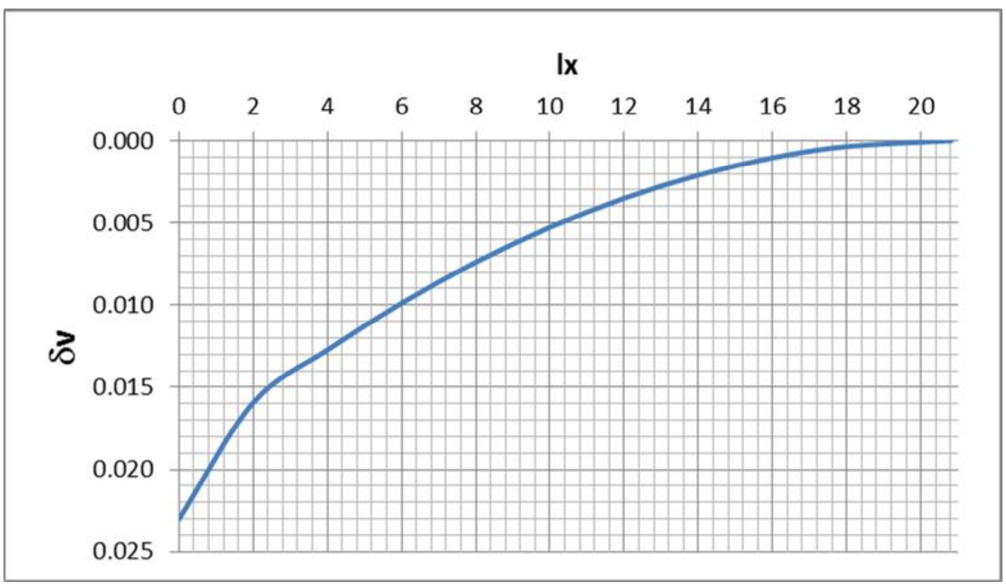
Figure 34 Estimation of ground surface settlement for soft clay using (a) Plaxis software (b) Bowles's method (c) Peck's method (d) Clough and O'Rourke's method

The outputs of the Plaxis software and the hand calculation methods have some variation as can be seen from the above figures. The Plaxis software outputs are smaller from the rest in both vertical ground settlement and range of influence or impact as the distance from the wall with a value of 0.05m and 10m respectively. The Bowels method has a vertical settlement which is 1.16 times higher than the Plaxis output and the range of influence is 128.6% higher also. Peck's method has an output of vertical settlement which is 130% higher and range of influence 240% higher than Plaxis. Clough and O'Rourke's method gives a settlement distribution where the maximum deformation sustains up to 0.75d and then it starts to decline.

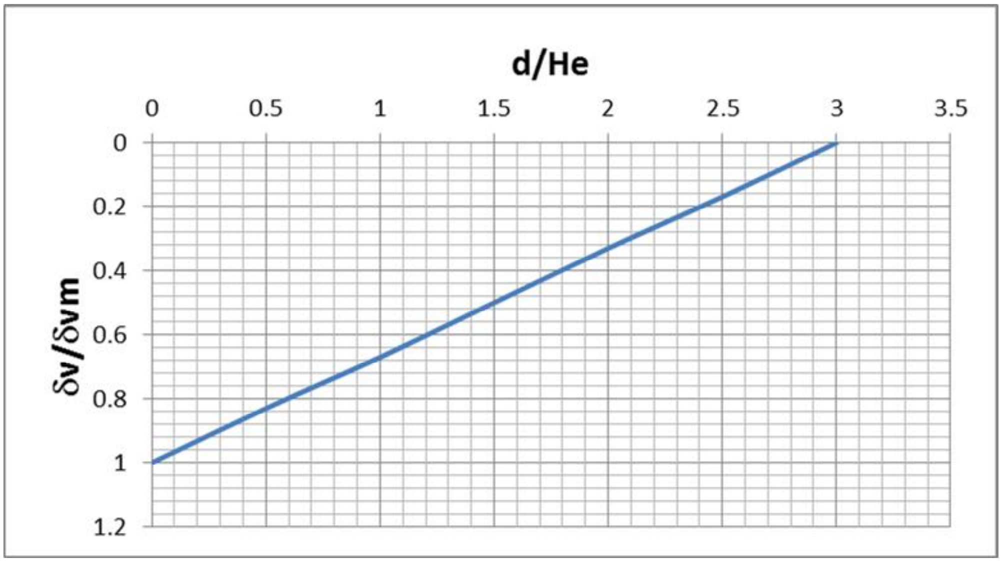
Case 2 Stiff clay



(a)



(b)

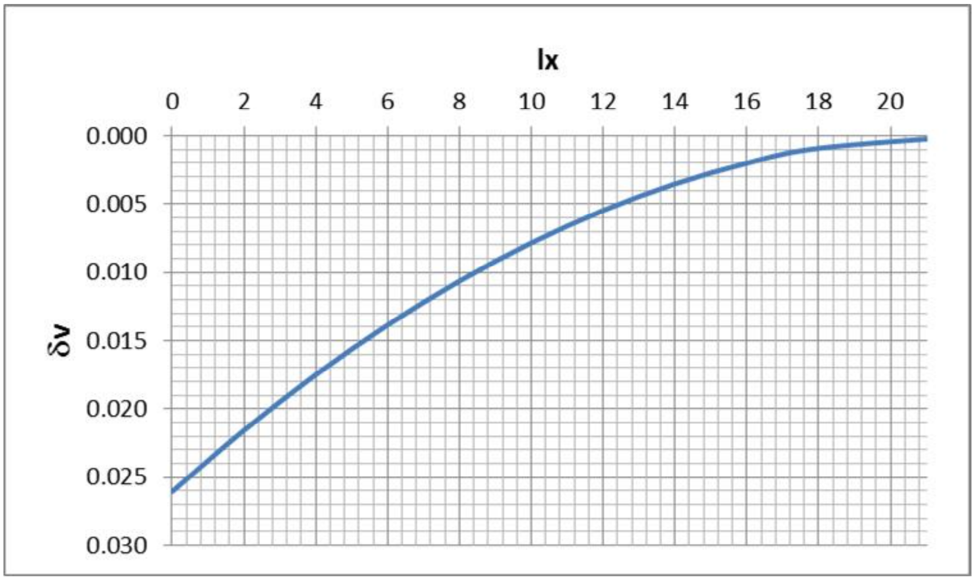


(c)

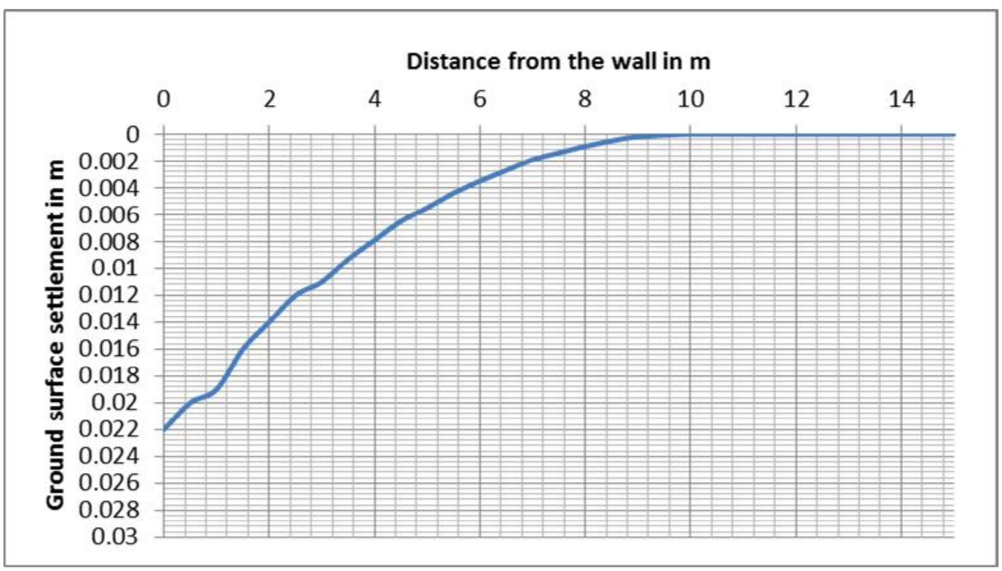
Figure 35 Estimation of ground surface settlement for soft clay using (a) Plaxis software (b) Bowles's method (c) Clough and O'Rourke's method

The plaxis software gives a vertical ground settlement and range of influence or impact as the distance from the wall with a value of 0.016m and 8.5m respectively. The Bowels method has a vertical settlement which is 1.44 times higher than the Plaxis output and the range of influence is 190% higher also. Peck's method has an output of vertical settlement which is 193.75% higher and range of influence of 150% higher than Plaxis. Clough and O'Rourke's method gives a settlement distribution where the range of influence or impact as the distance from the wall reaches up to 3 times the excavation depth.

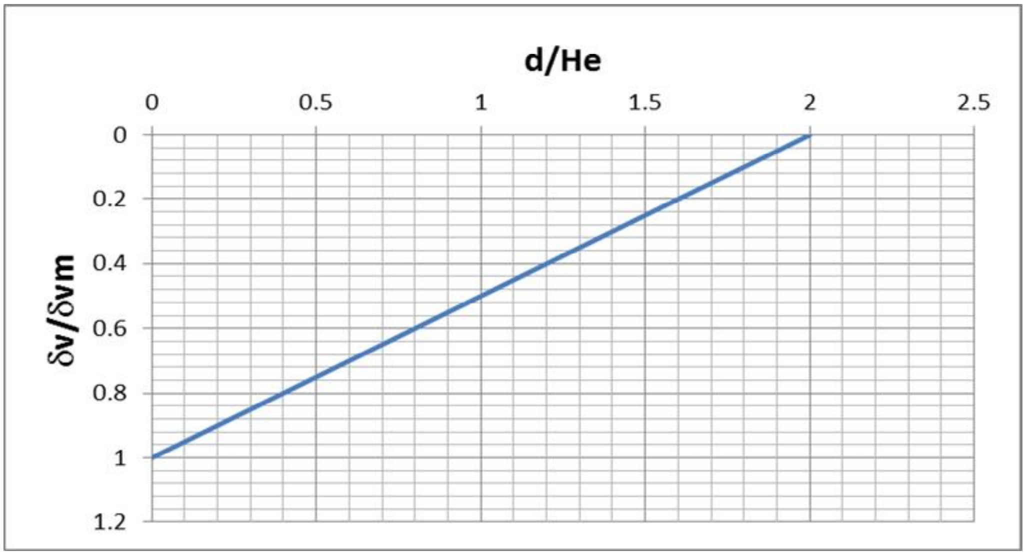
Case 3 Medium dense sand



(a)



(b)



(c)

Figure 36 Estimation of ground surface settlement for soft clay using (a) Bowles's method (b) Plaxis software (c) Clough and O'Rourke's method

The Plaxis software gives a vertical ground settlement and range of influence or impact as the distance from the wall with a value of 0.022m and 9m respectively. The Bowels method has a vertical settlement which is 1.3 times higher than the Plaxis output and the range of influence is 230% higher also. Peck's method has an output of vertical settlement which is 172.75% higher and range of influence of 283% higher than Plaxis. Clough and O'Rourke's method gives a settlement distribution where the range of influence or impact as the distance from the wall reaches up to 2 times the excavation depth.

The above three cases can be summarized as follows:

Soil type	Maximum ground deformation (m)		
	PLAXIS	Bowles's method	Peck's method
soft clay	0.05	0.058	0.065
Stiff clay	0.016	0.023	0.031
Medium dense sand	0.022	0.029	0.038

Table 19 Comparison of Maximum ground deformation for PLAXIS and Hand calculation methods

From the table above the results show as that the vertical ground settlement and the range of impact from the wall obtained by the PLAXIS software is lower as compared to the Hand calculation methods.

6. CONCLUSION AND RECOMMENDATION

6.1 Conclusion

1. The ground deformations around a deep excavation are significantly influenced by the type of soil. It is important, therefore, to obtain accurate estimates of soil parameters in order to obtain accurate estimates of ground deformation. Soft clay soil shows more ground deformation than Stiff clay & medium loose sand.

2. From the point of view of the hand calculations, which are developed based on many actual case studies, the Plaxis software underestimates the vertical ground settlement. This can be due to many reasons which some are the accuracy of the modeling of the soil and supporting structure (which can have few drawbacks of their own), mesh coarseness, iterative precision of the software, and the different assumptions taken in the staged construction process.

3. Parametric study has also been carried out on elastic modulus to observe its influence on the overall settlement of the ground surface. As it's known its increment decreases the ground settlement, by increasing the stiffness the soil which also decreases the lateral wall deformation.

6.2 Recommendation

The use of Primary data's rather than secondary data's for the analysis process is much helpful to better understand and improve the conclusions made on these paper. Also using other software's to test their outcomes and how it goes with the results that are found here. The deep excavation & the supporting system have areas left to be further researched and studied. So other researches on this area can be undertaken such as parametric studies by varying the embedment depth and also anchor force.

7. REFERENCES

1. Gebreselassie Berhane (2003), Experimental, Analytical and Numerical Investigations of Excavations in Normally Consolidated Soft Soils. Kassel university press GmbH

2. Kulhawy, F.H. and Mayne, P.W. (1990), Manual of Estimating Soil Properties for Foundation Design. Cornell University, New York

3. Swiss Standard SN 670 010b (1989), Characteristic Coefficients of soils, Association of Swiss Road and Traffic Engineers

4. Carter, M. and Bentley, S. (1991), Correlations of soil properties. Penetech Press Publishers, London.

5. Leonards, G. A. Ed., (1962), Foundation Engineering. McGraw Hill Book Company

6. Dysli, M. and Steiner, W. (2011), Correlations in soil mechanics, PPUR

7. West, T.R., (1995). Geology applied to engineering. Prentice Hall, 560 pp.

8. Peterson Mathias (2012), In depth study of lateral earth pressure: A comparison between hand calculations and PLAXIS, CHALMERS UNIVERSITY OF TECHNOLOGY, Goteborg, Sweden

9. Ou Chang-Yu (2006), Deep Excavation: Theory and Practice. Taylor & Francis Group, London,UK

10. Bowles, J. E., (1997), Foundation Analysis and Design. McGraw Hill Book Company

8. APPENDIX

Appendix 1 PLAXIS MODELS

The Plaxis model used in this paper is an anchored pile type. This model type has ϕ40cm pile with a spacing of 1.0m. The width of the excavation is 30m but due to its symmetry it's modeled as only the half section. It also has an anchor rod with three strands each carrying 85% of their maximum capacity which is 300KN in total.

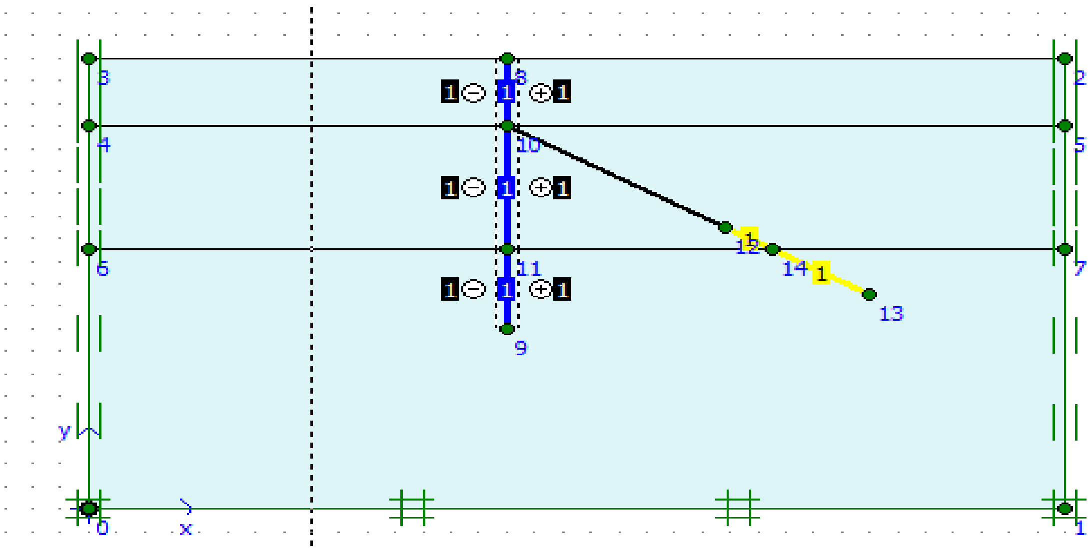


Figure 37 Soil Model

The final ground surface deformation outputs for the different cases are shown in the analysis section of this paper but for detail explanation the different stages of deformation for each step can be shown. Here is one sample for the soft clay case.

Phase 1

- This stage consists of the installation of the pile/plate in to the soil.
- The installation process causes the consolidation of the soil due to the drag force of the installed pile.

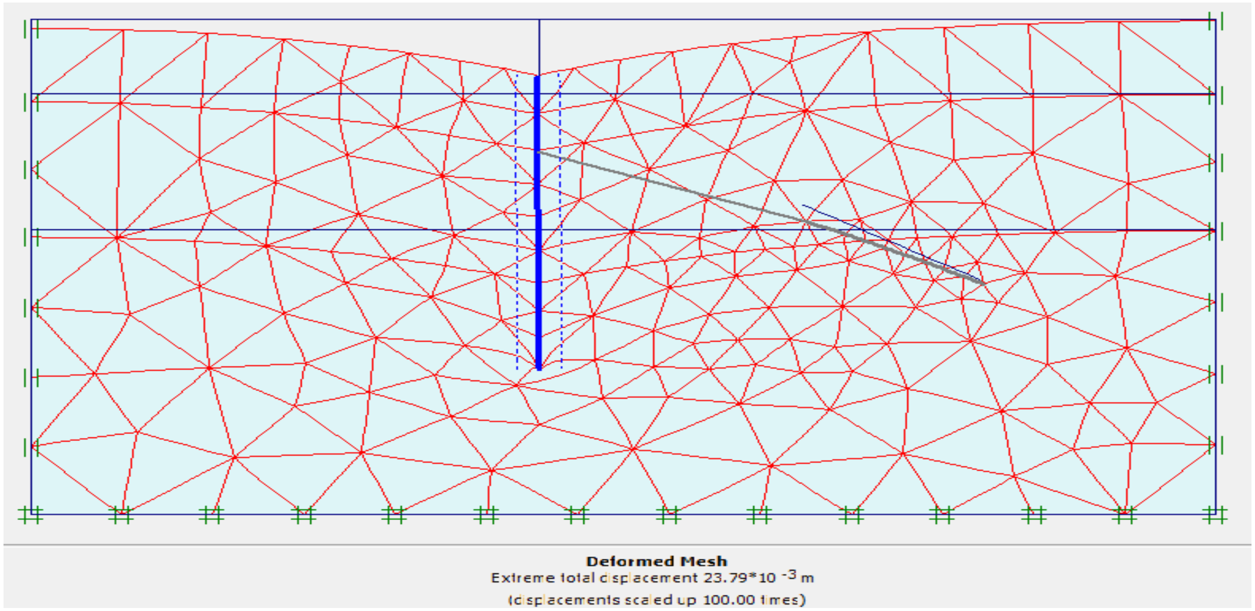


Figure 38 Deformed shape after phase 1

Phase 2

- **This phase consists of the excavation of the first layer of the soil which will cause expansion/dilation of the soil on the excavated part & the deformation on the wall & ground starts to appear.**

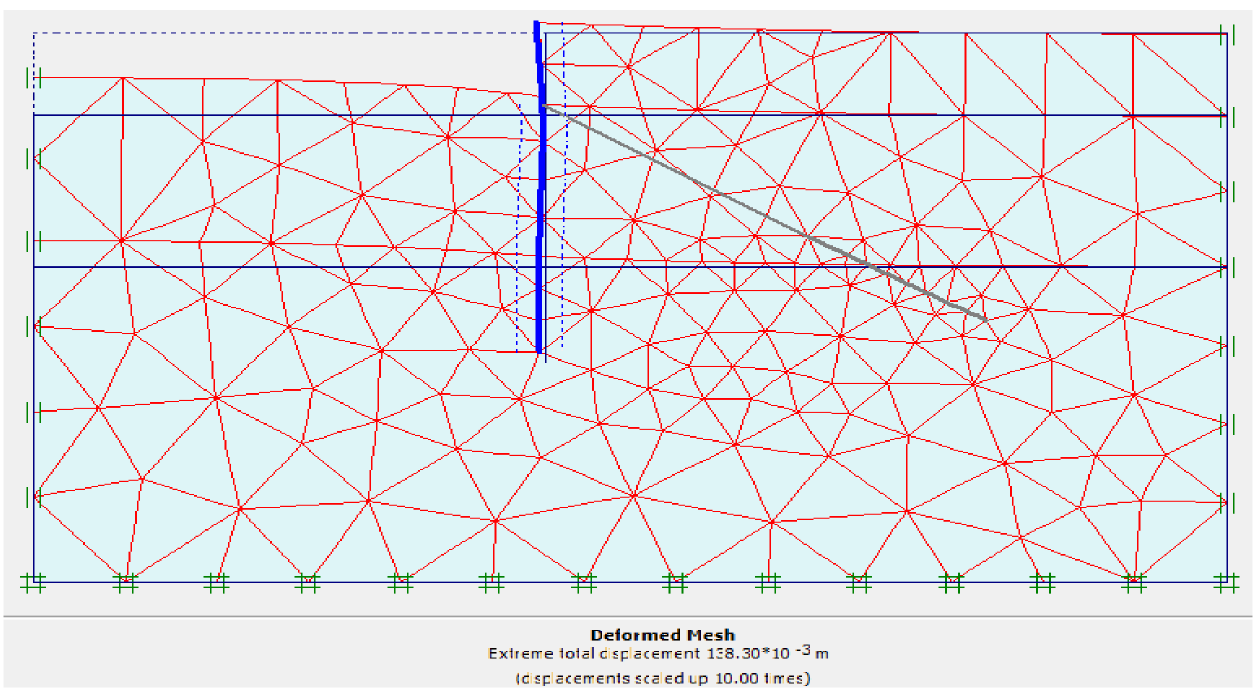


Figure 39 Deformed shape after phase 2

Phase 3

- **The installation of the anchor at this stage causes the wall to deflect backwards.**

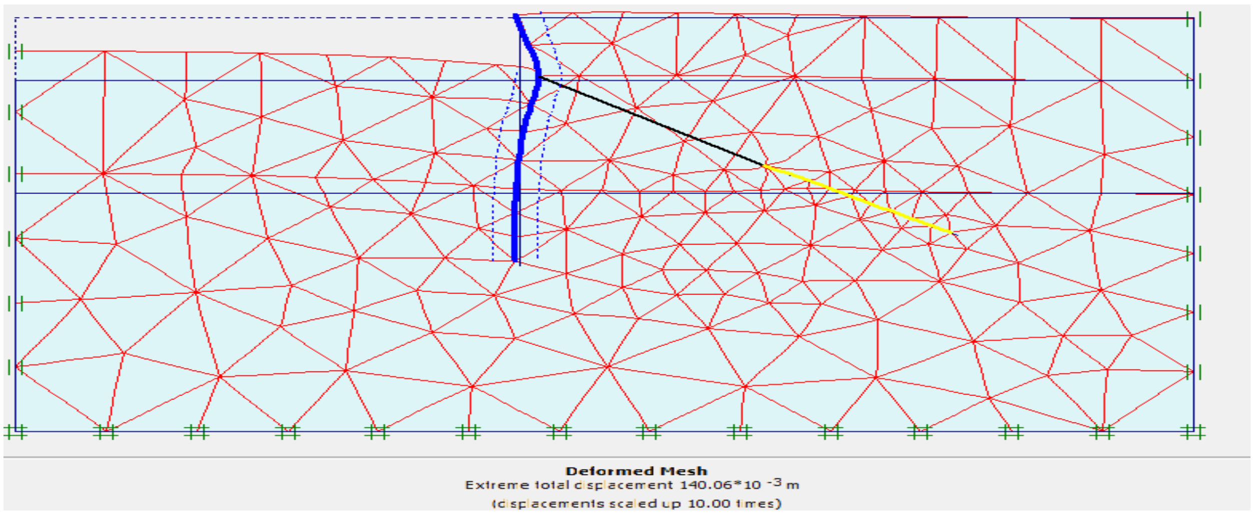


Figure 40 Deformed shape after phase 3

Phase 4

-This is the final stage & the wall & the ground deformation can be found. Also other needed outputs can be presented in graph or table form.

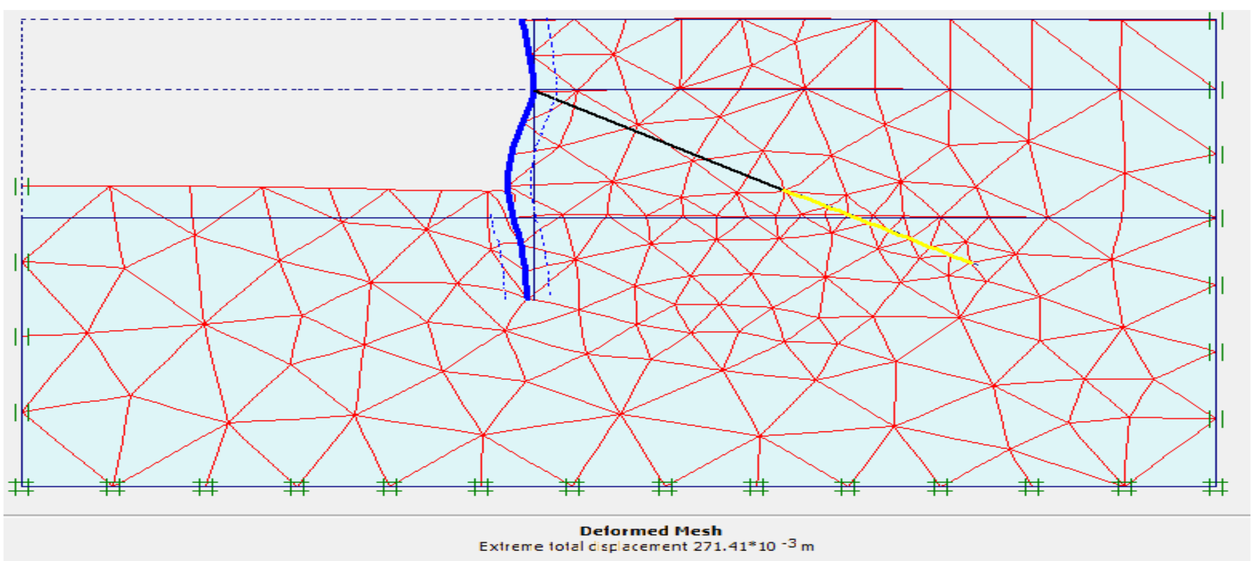


Figure 41 Deformed shape after phase 4 (final deformation)