Analysis on Additional Response of Existing Tunnel

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Abstract

With continuously upgrading and transformation of the urban infrastructure such as railway, road, subway, municipal engineering etc., the scale and the amount of urban underground construction are apparently enlarged. Thus, the newly-built urban underground construction will inevitably face close-space construction or even super close-space construction in the situation of tight urban land, complex underground pipelines and highly three-dimensional architectural layout. The negative environmental effects of the underground engineering construction closed to an existing building have been systematically and thoroughly studied according to the present research results. However, there is insufficient attention paid to the negative environmental effects induced by the construction of a deep foundation pit of narrow and long subway station "parallel with the existing subway section for a long-distance"

Therefore, taking the deep foundation pit of narrow and long subway station "parallel with the existing subway section for a long-distance" in soft clay as a research subject, the ground movement induced by deep foundation pit construction and the additional response of the existing subway section is studied in this thesis

First, the supporting structure deformation and ground settlement induced by the construction of a deep foundation pit of a narrow and long subway station in soft clay and the additional response of the existing subway section are analyzed through numerical simulation method, and the calculation results are compared by utilizing two constitutive models (i.e., Plastic-Hardening model and Mohr-Coulomb model). The results show that the negative environmental effects induced by the construction of a deep foundation pit of narrow and long subway station parallel with the existing subway section for a long- distance are significant and should be paid high attention to. By contrast to the Mohr- Coulomb model, the calculation results using Plastic-Hardening can reflect the characteristic of the deformation for soft clay induced by the construction of deep foundation pit of a narrow and long subway station.

Moreover, a parametric study is conducted by utilizing the Plastic-Hardening model in which the influence of the horizontal distance between the existing subway section and long and narrow deep foundation pit as well as the buried depth of existing subway section and other critical factors on the additional response of the existing subway section induced by the deep foundation pit. The results show that both the horizontal distance between the existing subway section and the long and narrow deep foundation pit as well as the buried depth of the existing subway section has a great impact on the additional response of the existing subway section. The additional response of the existing adjacent subway tunnel decreases with the horizontal distance between the existing subway section and the long and narrow deep foundation pit becoming larger

Keywords: deep excavation, existing tunnel, soft-soil, deformation, plastic-hardening, constitutive model, Mohr-Coulomb

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1. Introduction

Soils are three-phase systems containing mineral particles, air and water. Soils cover the majority of the earth's surface and are widely used as building and foundation materials. Soil mechanics is the engineering discipline concerned with the engineering properties of soils and their behavior under stress. Geotechnical construction on/in soft to incredibly soft soils are frequently fraught with challenges. Due to their susceptibility to deformation and poor shear strength, certain soil types may cause structural damage during construction and the project's life.

The design and construction of the foundation pit excavation in civil engineering have the characteristics of high technical content and great completeness, which tires the present world and causes huge economic losses and serious adverse social effects. This makes some deep and even serious engineering accidents very difficult in some deep foundation excavation projects. This is all because key technology is not design and processed to create tragedy. It can be seen that with the gradual increase in the construction of the deep foundation, the safety factor gradually increases so that some problems are not seen to come.

To remedy this, the technology of deep foundation will be gradually improved through the study of some successful and unsuccessful deep foundation engineering on both sides, as certain theoretical experiences and engineering practice, we have consistently enhanced and advanced the technology and concept of deep foundation construction over time.

Numerous studies have been conducted on various projects involving underground structures in recent years, mostly in urban areas, particularly a development that frequently involves the construction of new structures adjacent to existing metro tunnels. Construction of engineering structures, such as foundation pit excavation and tunneling, some buildings around the metro station, the results in ground settlement and unloading deformation can alter existing shield tunnels' stress and deformation status. This modification will have an impact on the operations of existing subway tunnels Chang et al. (2001) [1] reported that a near excavation damaged a tunnel section in Taipei.

In my thesis, I will compare the deformation of soil and an existing tunnel in a deep excavation area using 3d numerical simulation. Nevertheless, during the modeling, the work will also lead us to discuss the influence of horizontal displacement between the deep excavation and the influence of tunnel depth. By selecting between two constitutive model of soil, namely Plastic-Hardening and Mohr-Coulomb, numerical modeling of the entire excavation process will be carried out, demonstrating the difference and advantage of each. To prevent damage to existing tunnel during and after the excavation of new constructions, numerous measures have been suggested to investigate the interaction between new excavations and existing tunnels. Several semi-empirical or analytical methods for assessing the impact of excavation on existing tunnels were initially offered. Ji and Liu (2001) [2] developed a simple and adaptable method, dubbed the residual stress method, for calculating tunnel movements caused by adjacent excavation. An analysis of the deformation response of tunnels to excavation-induced soil unloading was given by Zhang et al. (2013a) [3]. Zhang et al. (2013b) [4] to ensure construction safety and optimize construction procedures, a series of experimental model tests and field measurements were then performed. According to some model tests, interaction effects are more pronounced at the spring line and crown of the existing tunnel. According to Choi and Lee (2010) [5], the size of an existing tunnel, the distance between the tunnel's centre, and the lateral earth pressure factor on the mechanicalbehavior of the existing and new tunnels were investigated. The numerical method can simulate the tunnel–soil interaction under complex conditions. For example, Do et al. (2014) [6] used the FLAC3D tool to study the forces caused between tunnels and the displacement field evolution when a new tunnel is built next to an old tunnel. Karakus et al. (2007) [7], Hage Chehade and Shahrour(2008) [8], Chakeri et al. (2011) [9], Liu et al.(2011b) [10], Hasanpour et al. (2012) [11], and other researchers conducted numerical analyses to determine the impact of neighboring tunnel building on existing tunnels.

Many researchers have studied the soil behavior and its influence around an existing nearby tunnel in a deep excavation area such as Shanghai urban planning exhibition center with an excavation depth of 11.5m, an excavation in South Tibet road with an excavation depth of 6.45m, an excavation in Huangpu district with an exaction depth of 14.4m, etc.

Among many other things, my job will be to create a foundation pit excavation simulation around an existing nearby tunnel and to carry out the deformations results of the tunnel and some structural elements throughout the excavation process. The two constitutive models that I will use to compare the results will be the MC and PH constitutive models, and finally, I will be able to demonstrate by graphs which are the most recommendable and desirable for analyzing tunnel movement and ground settlement during excavation. Many studies on the deformation of soft soil have been done using flac2d, flac3d, plaxis2d, plaxis3d, any, etc.… to demonstrate the main modeling techniques employed for the simulation of several key characteristics of the excavation and construction (such as over-excavation, reduction of struts stiffness, deviation in strut position, ground surface settlement, the influence of steel strut rigidity during construction, pile deflection).

In several cases, predicted deformation values were compared to observed deformation values in both horizontal and vertical directions. In the majority of cases, the model study indicated more significant deformation. In horizontal deformation, the variation was comparatively smaller and was expected to be due to the combined effect of wall stiffness and soil stiffness. On the other hand, vertical deformation variation was comparatively higher and was expected to be due to conservative estimation of soil stiffness. After complete excavation, the maximum vertical deformation was much more significant than the maximum horizontal deformation. The horizontal movement was restricted due to the installed supports.

Furthermore, the combined effect of the previously installed wall from both sides of the excavation may have reduced the deformation.

Soil excavation can cause ground movements, which can have a negative impact on existing structures. This is especially true when digging underground through loose, saturated soils, which are common in urban areas. Retaining walls are used to limit soil disturbance and, as a result, free surface subsidence.

TBM (tunnel boring machine) is used for most tunnel excavation studies to reduce or limit soil disturbance and its impact on tunnel construction. The main factors that create the complexity of the simulation of the mechanized tunneling procedure are:

- The significant role of the 3d geometry,
- The gaps between the shield and the surrounding soil,
- The face pressure,
- The time-dependent behavior of the grout material and
- The structural system of the segmental lining (radial and longitudinal joints).
- Numerous additional elements and characteristics that I did not mention above will be considered during my simulation work

1.2 *Objective*

The main goal of this thesis is to use a flac3d simulation numerical model to evaluate and predict the deformation behavior of soil (soft soil) in a deep excavation area (excavation depth 16.4m) and its influence on an existing nearby tunnel with a diameter of (6m).

In this simulation work, I will analyze and discuss the impact of the horizontal distance between the tunnel and the foundation pit on the ground and retaining wall deformations and the effect of the tunnel depth on the ground and retaining wall deformations. Flac3d will also be used to conduct a comparative study of the results of two constitutive models (MC and PH).

My thesis work will be based on:

- The 3d numerical simulation's using flac3d
- How to use the Plastic-Hardening (PH) and Mohr-Coulomb (MC) constitutive models to model the soil
- How to evaluate the sensitivity of additional response of existing tunnel to excavation and soil parameters easily
- How to validate the model performance
- How to identify and predict the worse deformation behavior (displacement) during simulation of the excavation.
- To discuss the difference of deformation (displacement) of the soil between the two constitutive models (PH and MC model)
- To discuss the effect of excavation on an existing tunnel
- How to estimate the settlement of the ground surface
- To evaluate the deformation of some structural elements

Nowadays, as excavation operations focus increasingly on the areas surrounding existing tunnels, my task will be to add something new to this thesis, to be able to solve certain problems via the use of computer tools, and I hope that by the end of my project, I will have found some solutions.

This thesis work is the first simulation one that I will conduct on an official basis, and I intend to complete it in the most efficient manner possible to produce satisfactory results that can be used in the future by other civil engineers to solve various problems associated with tunnel excavation and excavation in general. Given that human error occurs and no one is flawless, it is likely that minor mistakes will occur during this job; however, I will make every effort to reduce them so that the results are acceptable and adaptable to a variety of other projects similar to this one.

1.3 *Challenge*s

With a soil excavation depth of 16m and a diameter of 6.3m for the existing tunnel that I will excavate during simulation, I will attempt to determine what can happen during simulation of my model regarding the behavior of soil and its influences on the nearby existing tunnel during excavation, how to compare the surface settlement results of MC and PH and determine which one is better

When numerical excavation simulations are performed, the results will assist us in determining which of these two constitutive models of soil is superior and more suitable for use in carrying out excavation projects.

Additionally, the results will assist us in predicting the approximate values of vertical and horizontal deformation of soil (soft soil) and some structural elements.

Numerous researches has been conducted on tunnel excavation, soil excavation around an existing tunnel in an urban environment, and soil excavation around previously constructed buildings, among others. ... we have witnessed several adverse effects on already built infrastructures, which have resulted in material losses and even fatalities. My goal is to develop innovative strategies for mitigating these excavation consequences through the use of computer tools. The constitutive model's MC and PH will be employed

During this thesis work, I will identify and compare the surface settlement during tunnel excavation, I will identify and compare the ground settlement during foundation pit excavation, and I will show the wall deflection after the foundation pit excavation (left side and right side) by using flac3d

It is essential nowadays to solve all these problems because right now the world is under construction, especially in cities which are overcrowded, and there is a demand for a new structure which arises every time. So engineers are building overnight, and often we have infrastructure overloads, which with each new construction come with new problems and new challenges to meet, especially since the behaviors of the soil are different from one place to another with respect to their chemical, physical and mechanical properties

In this thesis, it would be imperative to find a general solution to all these problems at the same time but which is not too obvious to find. Nevertheless, with the development of technology in parallel with civil engineering, I hope in the near future that we can find a common solution applicable to all these problems.

1.4 Motivation

My motivation in this thesis is to learn how to improve and use geotechnical engineering tools (programs) in simulations to predict any deformation during any construction project in a soft soil area.

My country is currently under construction, and the main construction projects are frequently carried out on weak soils, causing enormous damage due to a lack of precaution, which can be remedied if there is a good mastery of the computer tools related to geotechnics to predict all damages before the project begins

My decision to pursue this deep excavation simulation work around a nearby existing tunnel is also justified by the fact that there has yet to be a tunnel construction project in my country; thus, the realization of this project will be a significant challenge for me, and I hope to be able to do it one day in my country and solve some geotechnical engineering issues

To meet the challenges and contribute to my nation's development, I would have to have excellent civil Engineering training since a lot of places in my country have fragile land that leads to a lot of destruction, and so that the ground needs to be improved in time before any project starts

This often encourages me to perform this kind of simulation work to gather a lot of experience to deal with and discover appropriate solutions to my country's problems

1.5 Research content and Keys

The main research of this work is to show how to evaluate and predict the deformation behavior of soil (soft soil) in a deep excavation area and its influence on an existing nearby tunnel by using the flac3d numerical simulation model.

The work will focus on:

- The 3d numerical simulation
- The soil modeling using (PH) and (MC) constitutive model
- The evaluation of the model sensitivity to excavation
- The validation of the model performance
- The identification of the deformation behavior (displacement) and the effect of excavation on an existing tunnel during the simulation work
- To discuss the difference of deformation (displacement) of the soil between the two constitutive models (PH and MC model)
- To estimate the settlement of the ground surface settlement during the excavation of the tunnel and the foundation pit
- To evaluate the deformation of some structural elements (wall)
- To show the influence of the tunnel depth and the horizontal displacement during the excavation

1.6 Research Structure

This research work is divided into six chapters. Chapter 1 is the introducing part of the research work. It provides a general overview of the background underlines the research problems, defines the objectives, scope and significance of the study. Chapter 2 is the literature review. It outlines detailed information about the research background, the empirical assessment of settlements, transverse surface settlement, horizontal displacement, tunnel deformations caused by adjacent soil excavations, and Constitutive model. Chapter 3 is the introducing part of the methodology. In this chapter, the project overview including the excavation steps, the material parameters and the numerical simulation program are presented. Chapter 4 discusses the comparison between results from PH model and MC model. The overall distribution of horizontal and vertical displacement, the overall stress distribution, the ground surface settlement, wall deflection and the additional response of existing tunnel induced by deep excavation between PH and MC are compared and discussed. Chapter 5 is the studying part of the influence of the keys parameters for PH constitutive model. In this chapter, the influence of the horizontal distance, the Influence of the tunnel depth and the additional response of existing tunnel induced by deep excavation is discussed. Chapter 6 is the concluding part of the research work. It summarizes the main conclusions and findings, and gives some recommendations for future work.

2. Literature review

The majority of urbanization is usually associated with soil excavation to build surface and subsurface facilities. Excavations are typically carried out in densely populated areas. As a result, it is necessary to assess the effects of excavations on surrounding structures such as buildings, tunnels, bridges, etc... It is necessary to predict the behavior of excavation in advance to deal with some situations. Before excavation, the most important job to do to ensure the safety and serviceability of surrounding properties, especially in soft soil areas, is to predict ground movement and take necessary measures to mitigate any adverse situation. A project's success depends on careful planning and preparedness to avoid any adverse effects on existing structures

Quantitative prediction of deformation, groundwater condition, and other factors depend on accurate interpretation of numerical tools and precise calculations of soil parameters. Numerous studies demonstrate that numerical analyses can be quite efficient in predicting the behavior of soil during excavation and support system installation. As a result, it aids in the necessary planning necessary to assure the safety of nearby structures. The accuracy of the analysis, however, is dependent on the judicious estimation of soil parameters Bhatkar , Barman et al. (2017) [12]. A determination of the appropriate tunneling method that decreases the tunneling risks on adjacent structures is a big challenge in soft ground tunneling. The difficulty comes from many and critical factors involved in the process, such as the potential for ground loss because of tunneling, variable ground conditions under a hard point, and the effect of tunneling on the integrity of existing structures. Tunneling advance rate as a tunneling parameter has been reported as a factor that affects the ground movements caused by TBM excavation

TBM EPB and slurry machines are commonly used in urban tunneling projects since they decrease the displacements induced by tunnel excavation, ensuring high performance in a wide range of ground conditions, low cover depths, and high groundwater pressures.

In this case of excavation, I will do the numerical simulation, and I will try to see what will happen to the behavior of the soil and its influence on the exiting tunnel during all the steps of excavation by using the PH and MC constitutive model

Knowing that capturing the proper soil behavior is a significant challenge, exceptionally soft soil that has an uncontrollable deformation while we are doing excavation, that induce vertical and horizontal deformation of some structural elements, surface settlements and lateral deformation of different retaining systems, damage of some nearby buildings; it will be necessary and preferable to do a numerical analysis on its behavior before doing any activity of construction. For the accurate prediction of the performance of deep excavation, especially the ground movements, the adopted soil model must be calibrated using soil properties corresponding to geotechnical conditions at the construction site

This thesis will present a realistic full 3d simulation of a deep excavation with the finite difference method base program flac3d

When the engineer designs a tunnel structure, he guarantees that the structure is safe with respect to structural collapse and ground deformations during its project. Depending on ground conditions and tunneling method, he must choose an appropriate method of analysis and derive or even invent a structural model as a structural idealization. By applying equilibrium and compatibility to the model, the engineer has to arrive at those criteria that are factors in deciding whether or not the design is safe.

Ground movements are an important topic to consider for tunnel design when planning a tunnel in soil. Various support measures are used to ensure stability and limit deformation depending on the method of tunnel construction. Urban tunneling aims to keep ground deformations to a minimum, but in deep tunneling, tolerable deformations might be much more significant. Whatever tunneling method is used, the ground will be loaded or unloaded, and deformations will occur, resulting in a settlement. Deformations are a major design topic for excavations in urban areas or near tunnels, as differential settlements can damage existing structures

In the period of planning an excavation project, the engineer has to rely on a method of analysis, from which he may derive criteria whether the design is suitable, safe, and economical

2.1 The empirical assessment of settlements

2.1.1 Transverse surface settlement

The empirical method, which is often referred to as the most common practical method for predicting ground movement, is based on a Gaussian distribution. Schmidt (1969) and Peck (1969) [13] were the first to demonstrate that the Gaussian function can well describe the transverse settlement trough that occurs after tunnel construction in many cases:

$$S_v(y) = S_{vmax}.\, e^{-(\frac{y^2}{2i^2})} \qquad (2.1)$$

Where S_{vmax}represents the settlement above the tunnel axis, y is the horizontal distance from the tunnel axis, and i the horizontal distance from the tunnel axis to the settlement trough's point of inflection. Integrating Eq(2.2) yields the volume of the settlement trough (per unit light of tunnel) V_s.

$$V_s = \int S_v(y).\, dx = \sqrt{2\pi}.\, i.\, S_{vmax} \qquad (2.2)$$

In addition to the settlement volume V_s, the ground loss V_t must be considered. It is the volume of ground that has deformed into the tunnel after it has been built. The settlement volume is roughly equal to the ground loss when tunneling in the undrained ground, but it is slightly smaller in the drained ground. Indeed, dilation and swelling caused by unloading can cause soil expansion, resulting in $V_s<V_t$ **(Cording and Hansmire, 1975)** [14]. Differences, however, tend to be minor, and it can be assumed that $V_s \sim V_t$ Because ground loss varies more or less linearly with tunnel volume, it is useful to consider the ground loss ratio

$$GLR = \frac{V_t}{A_t} \approx \frac{V_s}{A_t} \qquad (2.3)$$

Where A_t is the tunnel volume per unit of length. It follows the Eq(2.3)

$$S_{vmax} \approx \frac{A_t}{i \cdot \sqrt{2\pi}} \cdot GLR \qquad (2.4)$$

$$S_v(y) \approx \frac{A_t}{i \cdot \sqrt{2\pi}} \cdot GLR \cdot e^{-\frac{y^2}{2i^2}} \qquad (2.5)$$

2.1.2 Width of the settlement trough

- Homogenous ground

The distance from the tunnel axis to the inflection point i, which is determining the width of the settlement trough, has been subject to many investigations. Depending on ground conditions, **Peck (1969)** [13] proposed a relationship between tunnel depth z_0 and tunnel diameter D, depending on ground conditions. Following Peck's suggestion, many other authors have proposed similar relationships, such as **Cording and Hansmire (1975)** [14] or **Clough and Schmidt (1981). O'relly** [15]**and New (1982)** [16] presented results from multiple linear regression analyses performed on field data, confirming a strong correlation between i and tunnel depth but not with tunnel diameter (except for very shallow tunnels with a cover to diameter ratio less than one) or construction method. The stated that for most practical purposes, the regression lines might be simplified to the Eq(2.6)

$$i = K \cdot z_0 \qquad (2.6)$$

where K is a trough width parameter, with $K \sim 0.5$ for clayey ground and $K \sim 0.25$ for sandy ground, the approach of Eq(2.6) has been generally confirmed by **Rankin (1988)** [17], who presented a variety of tunnel case histories in clayey, sandy, residual, and in the mixed ground. **Mair and Taylor (1997)** [18] presented a large number of tunneling data. The regressions confirm the findings of **O'relly and New (1982)** [16] for clayey soils, with a trough width parameter ranging in between 0.4 and 0.6, with a mean value of $K=0.5$. However, for sandy soils, they obtain K

ranging in between 0.25 and 0.45, with a mean value of 0.35, indicating a somewhat wider settlement trough

Layered ground: Often, tunnels are constructed in the layered ground, including both clayey and sandy ground layers. For tunnels in the layered ground, **New and O'relly (1991)** [19] proposed a relationship for i :

$$i = K_1 \cdot z_1 + K_2 \cdot z_2 \qquad (2.7)$$

Where K_1 is the trough width parameter for ground layer with thickness z_1 and K_2 is the trough width parameter for ground layer 2 with thickness z_2, respectively. **Mair and Taylor (1997)** [18] also discussed this formula, and they report that it agrees reasonably well with field observations of tunnels in sands overlain by clay layers. However, when sandy layers overlay clays, they found Eq(2.7) to be less evident. Nevertheless, in combination with estimated ground losses, it would seem that Eq(2.7) may be used for the first prediction of surface settlements, both for open and closed face tunneling.

Subsurface settlement: When tunneling in urban areas, one may have to consider the interaction with deep foundations or existing tunnels. This leads to the need to have information about the development of subsurface settlement profiles. **Mair et al. (1993)** [20] analyzed subsurface deformations from tunnels in clays as well as centrifuge tests in clay. They showed that subsurface deformations could also be reasonably approximated by a gaussian distribution. A possible extension of Eq(2.6) for subsurface settlement profile is:

$$i = K \cdot (z_0 - z) \qquad (2.8)$$

Where z is the depth of the subsurface profile being considered, **Mair et al. (1993)** [20] observed that the value of i for subsurface profiles is significantly larger than would be predicted with a constant K. To match the data for tunnels in clay, **Mair et al. (1993)** [20] proposed the expression considering subsurface measurements of tunnels **Moh et al. (1996)** [21] analyzed tunnels in loose sands, and **Dyer et al. (1996)** [22] obtained similar relationships for tunnels in silty sands

$$K = \frac{0.175 + 0.325 \cdot (1 - z/z_0)}{(1 - z/z_0)} \qquad (2.9)$$

2.1.3 Horizontal displacement

When tunnels are constructed in urban areas, some damage to buildings may occur due to horizontal ground displacement. However, there are relatively few tunnel case histories in which horizontal or structural movement has been quantified. **O'reilly and New (1982)** [16] proposed that resultant ground displacement vectors point towards the centre. This assumption leads to the distribution of surface horizontal ground displacement given by:

$$S_h(y) = \frac{y}{z_0} \cdot S_v(y) \qquad (2.10)$$

Using Eq(2.1) and Eq(2.5) in Eq(2.10), the horizontal surface displacement can be written as:

$$S_h(y) = \frac{y}{z_0} \cdot S_{vmax} \cdot e^{-\frac{y^2}{2i^2}} \approx \frac{y}{z_0} \cdot \frac{A_t}{i \cdot \sqrt{2\pi}} \cdot GLR \cdot e^{-\frac{y^2}{2i^2}} \qquad (2.11)$$

Consistent with field observations by **Cording and Hansmire (1975)**[14], the theoretical horizontal displacement, S_{hmax}, occurs at the settlement trough's point of inflection, where $S_v(y) = 0.6 \cdot S_{vmax}$. Hence Eq(2.10) can be written as:

$$S_{hmax} = \frac{i}{z_0} \cdot 0.6 \cdot S_{hmax} \qquad (2.12)$$

Using Eq(2.11) and Eq(2.12), the horizontal displacement yields:

$$\frac{S_h(y)}{S_{hmax}} = 1.65 \cdot \frac{y}{i} \cdot e^{-\frac{y^2}{2i^2}}. \qquad (2.13)$$

When considering tunnel-induced horizontal deformations on existing buildings, horizontal strains are important. Horizontal strains may be obtained by differentiating the horizontal displacement with respect to y

2.1.4 Longitudinal surface settlement

Aside from the traverse settlement profile, the longitudinal profile is also important. Longitudinal settlements must be analyzed in cases where information on the three- dimensional influence of settlements is required, such as when buildings are subjected to twisting and respective torsion forces. **Attewell and Woodman (1982)** [23] demonstrated how to calculate the longitudinal settlement profile by treating it as a collection of longitudinal point sources and superimposing the settlement craters caused by each point source. Assuming that the incremental longitudinal settlement trough is a gaussian curve, it follows logically that the longitudinal settlement trough should have the shape of a cumulative probability curve. The settlement above the tunnel centerline at location x cab be obtained from the equation:

$$S_v(x) = S_{vmax} \quad (2.14)$$

where x is the distance along the settlement trough's longitudinal axis from the tunnel face, **Attewell and Woodman (1982)** [23]established a reasonable level of validity for the assumption of a cumulative probability function by evaluating various field studies reports. According to **Attewell et al. (1986)** [24], the settlement just above the tunnel face (x=0) is 50% of the maximum settlement S_{vmax}. This may be more appropriate in the case of open face tunneling. However, when closed face tunneling is used, settlements ahead of the tunnel face are considerably reduced**. Mair and Taylor (1997)** [18] concluded that substantially lower values of 25%-30% are required for closed face tunneling, resulting in a translation of the longitudinal settlement profile. **Craig and Muir Wood (1978)** [25] studied shield tunnels in the United Kingdom. They stated that the maximum settlement percentage occurring before, over, or behind the shield varied for several reasons. **Craig and MuirWood (1978)** [25] said that in most cases, 80%-90% of the maximum settlement would be completed when the face of the tunnel had travelled one to two times the depth of the tunnel past the point of observation. Settlements begin along the tunnel's centerline at a distance about equal to half the width of the transverse settlement trough. Wall type can be an important factor in deep excavation performance. Diaphragm walls are still, are constructed in situ and in contact with the soil, and are essentially watertight. **Goldberg et al. (1976)** [26] analyzed case histories and *determined* that employing diaphragm walls in weak souls reduced movement to approximately that of sheet pile walls in weak soil limiting movement. **Clough and O'rourke (1990)** [15] pointed out that the use of diaphragm walls eliminates void closure and running soil problems that can occur with soldier pile and lagging walls.

Constitutive models are important in finite difference method analysis of deep excavations. The understanding of deep excavations has evolved as the constitutive model used in finite difference analyses of deep excavations has improved.

Constitutive models are important because understanding the many aspects of deep excavation performance requires constitutive models that exhibit many of the aspects of real soil behavior. Some finite difference studies demonstrate that using advanced constitutive models in conjunction with accurate modeling of construction can yield analytical results that agree well with measured performance.

2.2 Tunnel deformations caused by adjacent soil excavations

The unloading impact of excavations might result in the deformation of nearby tunnels, which can have a negative impact on their operation and safety. However, systematic studies of the deformation characteristics of tunnels located alongside excavations are limited.

Based on the simulation results, the deformation characteristics of tunnels at different positions and the deformation of the retaining structure is analyzed.

The existing tunnel may be inevitably affected by the excavation, including its deformation. It can be obtained that the location of the tunnel has an important influence on the deformation of the existing tunnel **Zheng and Wei (2008)** [28]. When the tunnel is below the axis of excavation, it doesn't show any displacement in the horizontal direction for the whole tunnel, and the heave decreases with the relative distance of the tunnel increasing. When the tunnel is directly under the base of the retaining wall, its deformation will experience distortion. When the tunnel lies outside of the retaining wall, the tunnel shows obvious responses both in vertical and horizontal directions, especially its deformation toward the excavation base due to the unloading.

For tunnel safety, circumferential deformation should be paid enough attention. The tunnel crown, invert, and the location at the spring line provides the deformation at tunnel typical locations both in horizontal and vertical directions. **Hu, Yue et al. (2003)** [29] stated that it could be obtained that the results for deformation show a decreasing trend with an increase of the relative distance between excavation and existing tunnel.

Many studies examined the effects of various parameters on tunnel response, including the tunnel's relative position to the excavation, the tunnel's diameter, the excavation's dimensions, and tunnel protection measures. However, more studies are being carried out towards the reduction of tunnel deformations during excavation **Xu et al. (2013)** [30].

Several studies have mentioned that when the excavation is laterally adjacent to a tunnel, the maximum vertical displacement of the tunnel is influenced by the control exerted by the retaining structure. **Ai et al. (2008)** [31] observed that when excavation is over a tunnel, the vertical displacement of the tunnel is mostly affected by the ratio of the tunnel's burial depth to the depth of excavation.

The longitudinal deformation of the adjacent tunnel is mainly caused by the unloading

effect of the foundation pit sidewall, which is parallel and close to the tunnel.

When the excavation depth is in the soil layer near the buried depth of the adjacent tunnel, the longitudinal deformation of the tunnel by the side of the foundation pit will increase sharply. Thus, more attention should be paid to the control of the tunnel's deformation in the working condition, and with the increase of the retaining structure's deformation, the longitudinal deformation of the adjacent shield tunnel and its influence range also increases. The longitudinal deformation of the adjacent shield tunnel decreases with the increase of the distance between the foundation pit and the tunnel. Thus, the foundation pit's excavation has a great influence on the adjacent shield tunnel at a shallow burial depth. Furthermore, the excavation's impact on the tunnel decreases as the burial depth of the adjacent tunnel increases.

The design theory of controlling deformation has been widely used in foundation pit engineering. **Xu, Qian and Zhou (2016)** [32] concluded that it is important to control the effect of the foundation pit's excavation on the adjacent tunnel by taking the deformation of the retaining structure as the control index in the design stage. As a result, when studying the impact of foundation pit excavation on the nearby tunnel, it is also reasonable to use the sidewall unloading model while accounting for retaining structure deformation.

Based on my current research, I can conclude that the calculation method for predicting tunnel deformation caused by foundation pit excavation is insufficient, so more research and discussion are required. Moreover, the long-term interaction between tunnel and soil (soft soil) needs to be further studied.

2.3 Constitutive model

This simulation project will be carried out using two constitutive models of soil, namely: Plastic-Hardening (PH) constitutive model and Mohr-Coulomb (MC) constitutive model (plastic model group). It is essential to understand these two soil constitutive models, their benefits and modes of application concerning the soil's physical, mechanical, and chemical properties.

- Plastic-Hardening constitutive model

It's an elasticity model with shear and volumetric hardening.

- Mohr-Coulomb constitutive model

The Mohr-Coulomb model is the most often used model for describing shear failures in soils and rocks. **Vermeerand Borst (1984)** [33], for example, describe laboratory test results for sand and concrete that are consistent with the Mohr-Coulomb criterion (FLAC3D).

3. Methodology

3.1 Project Overview

This project takes the vertical excavation of a foundation pit as an example to investigate the deformation behavior of the ground and its influences on and nearby existing tunnel. The foundation pit measures 17.5m in width and 16.2m in depth. The continuous underground wall, which measures 0.8m in thickness and 31m in total depth, serves as the building envelope of the foundation pit. Six layers of the foundation pit are excavated. Each layer is excavated at a different depth, totaling 16.2m. The existing subway tunnel has a buried depth of 24 m. The tunnel's trend is parallel to the foundation pit's length direction, and the distance between the tunnel and the foundation pit is 3m.To simulate my present simulation work, I will use finite difference method base program code flac3d to carry out the numerical analysis. The existing nearby tunnel diameter is 6m and his lining is 0.35m. The tunnel is located on the right side of the foundation pit excavated part, and the separation distance of the retaining walls is approximately 17.5m, the thickness of the ground connecting wall is 0.8m. The type of soil excavated is soft soil. It will be modeled using the PH and MC constitutive models.

The size of the model is as shown in figures 3-1; 3-2. In order to simplify the model, a plane model is used. X is the transverse direction of the foundation pit tunnel, Z is the gravity direction, and the longitudinal Y-direction is 2m.

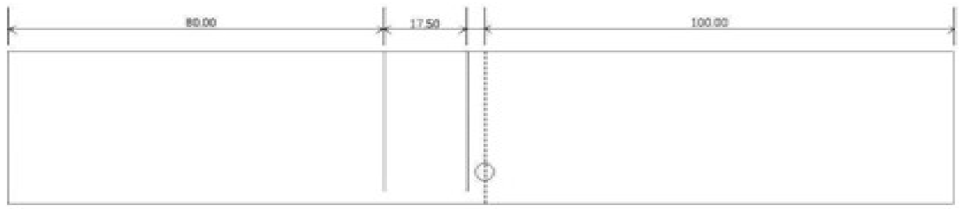

Figure 3-1. Model size 1

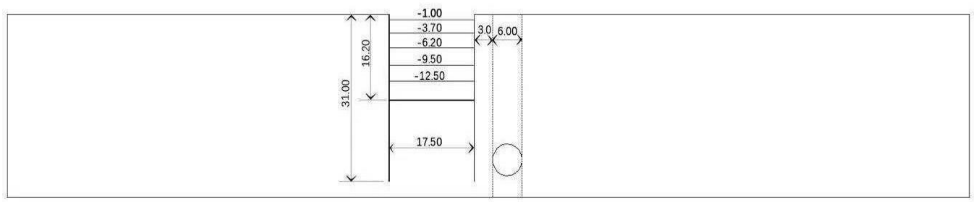

Figure 3-2. Model size 2

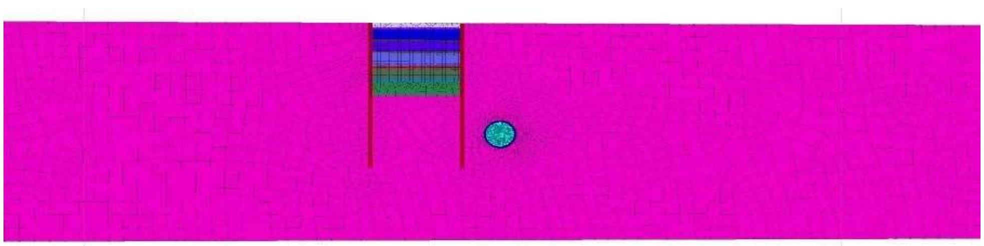

Figure 3-3. Overall model

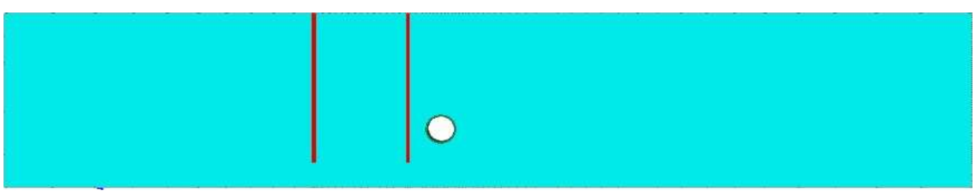

Figure 3-4. A Partial area of tunnel excavation

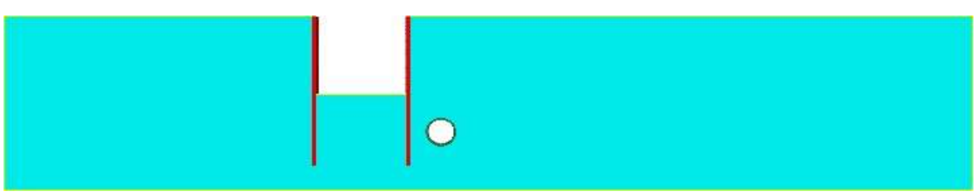

Figure 3-5. Calculation model after excavation

Figures 3-3, 3-4, and 3-5 show the overall dimensions of my model, present all of the structural elements of the model in general, show the position of the tunnel to be excavated, the foundation pit to be excavated, and the model after the tunnel and foundation pit excavation

3.2 Excavation Steps

3.2.1 Shield tunnel excavation steps

The simulation work of my model will first start with the excavation of the tunnel while taking into account all the parameters of the tunnel materials. After that, start the foundation pit excavation while also taking into account all the mentioned parameters.

The tunnel excavation process will be carried out as follows:

- Excavation;
- By releasing 40% of the unbalanced nodal force in the radial direction and calculate;
- By adding the lining to release 60% of the unbalanced node force in the radial direction and calculate;

3.2.2 Foundation pit excavation steps

The foundation pit excavation process will also be carried out as follows:

- Firstly we start to add an active ground connecting wall;
- Then excavate till -1.6m from the ground level, and calculate
- After the first calculation, we excavate till -4.4m, and then we set up concrete cross braces 1 to -1m;
- Then excavation till -7m, and set steel support cross brace 1 to -3.7m;
- Then excavate till -10.2m, and set steel support cross brace 1 to -6.2m;
- Then excavate till -13.2m, and install steel support cross bracing from 2 to -9.5m;
- And then Excavate till -16.2m, and install steel support cross brace 2 to -12.5m;

NB: The cross brace 1 cross-section size 0.0028m2/m and the cross brace 2 cross- section size 0.0046m2/m,

3.3 Material parameters

The tables below group together the parameters of the structural elements, of the tunnel, and the ground (according to the constitutive model). These values will be used during my simulation work.

We can see them as follows:

Tunnel		
Tunnel/foundation pit	*E*	*μ*
Lining	34.5GPa	0.2
Grouting	400MPa	0.2
Wall/support		
Ground wall/concrete support	28GPa	0.25
Steel cross brace	207GPa	0.28

Table 1. Material parameters

(1) Soft soil	*E*50ref	E_{ur}ref	*μ*	*c*	*φ*
PH model	1.01MPa	8.08MPa	0.35	10.37kPa	29

Table 2. PH constitutive model soil parameters (soft soil)

(1) Soft soil	*E*	*μ*	*c*	*φ*
MC model	2.2MPa	0.35	10.37kPa	29

Table 3. MC constitutive model of soil parameters (soft soil)

3.4 Numerical Simulation Program

The first part of my simulation work will compare the MC and PH constitutive models, with a tunnel depth of 24m and a horizontal distance of 3m between the tunnel and the deep excavation. Second, I will examine the impact of the horizontal distance between the deep excavation and the tunnel using three different distances (6, 9 and 15m). Then I will discuss the impact of tunnel depth using three different tunnel depths (24, 18 and 12m). The ground surface settlement, wall deformation, and the impact of foundation pit excavation on the existing tunnel will all be investigated. The table below summarizes the various simulation cases:

Simulation case No.	Constitutive model of soil	Depth (m)	The horizontal distance between the tunnel and deep excavation (m)
1	MC	24	3
2	PH	24	3
3	PH	24	6
4	PH	24	9
5	PH	24	15
6	PH	18	3
7	PH	12	3

Table 4. Numerical Simulation cases

4. Comparison between results from PH model and MC model

4.1 Overall distribution of horizontal and vertical displacement

4.1.1 Displacement in MC model

- Along the X-axis:

The main lateral displacement zones along the X-axis are depicted in the figure below.

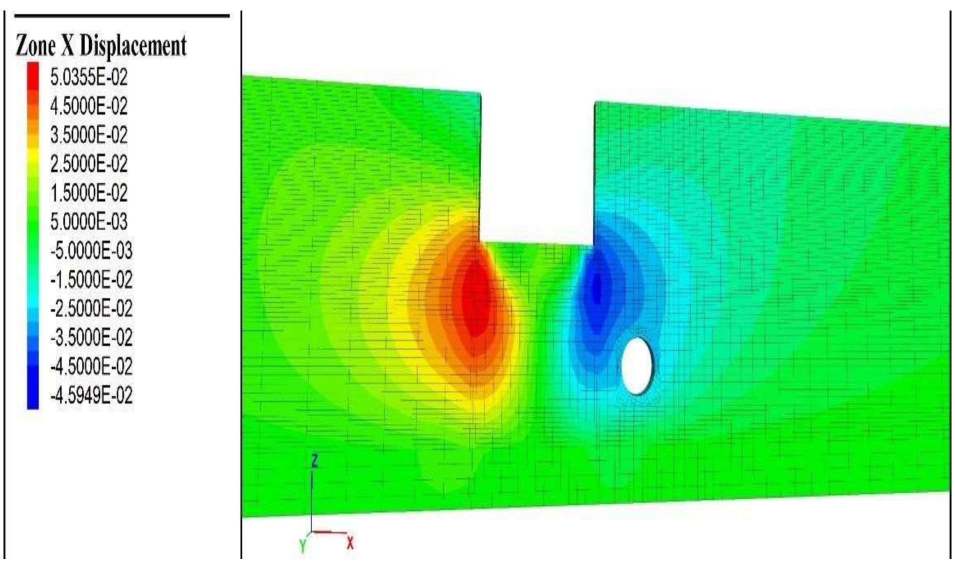

Figure 4-1. MC model displacement along the X-axis

The above figure presents the contours of horizontal soil displacement. The settlements are observed near the retaining wall from the excavation bottom and near the existing tunnel.

- Along the Z-axis:

The main displacement zones along the Z-axis are depicted in the figure below.

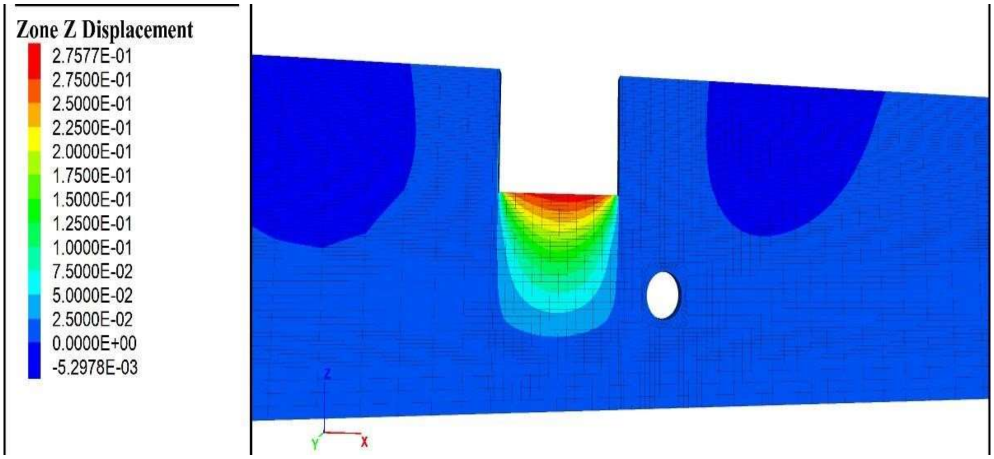

Figure 4-2. MC model displacement along the Z-axis

The contours of vertical soil displacement are depicted in the figure above. The settlement is close to the retaining walls, with the most critical part located below the last level of the excavated part of the foundation pit.

4.1.2 Displacement in PH model:

- Along the X-axis:

The main lateral displacement zones along the X-axis are represented in the figure below.

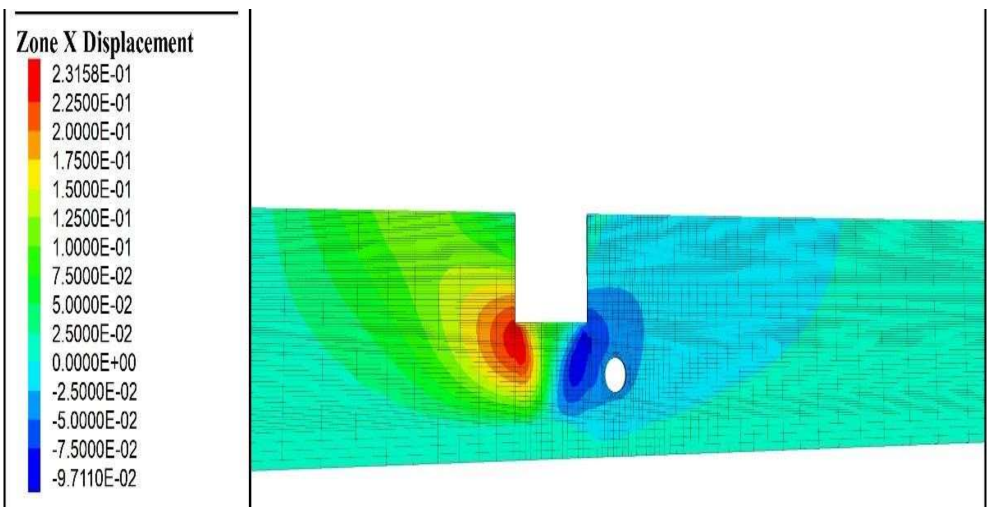

Figure 4-3. PH model displacement along the X-axis

The contours of horizontal soil displacement are depicted in the figure above. Settlements are observed near the retaining wall from the excavation bottom and near the existing tunnel as for MC model. But, the observed results of the ground settlement are more critical in this case.

- Along the Z-axis:

The settlement is close to the retaining walls, with the most critical part located below the last level of the excavated part of the foundation pit.

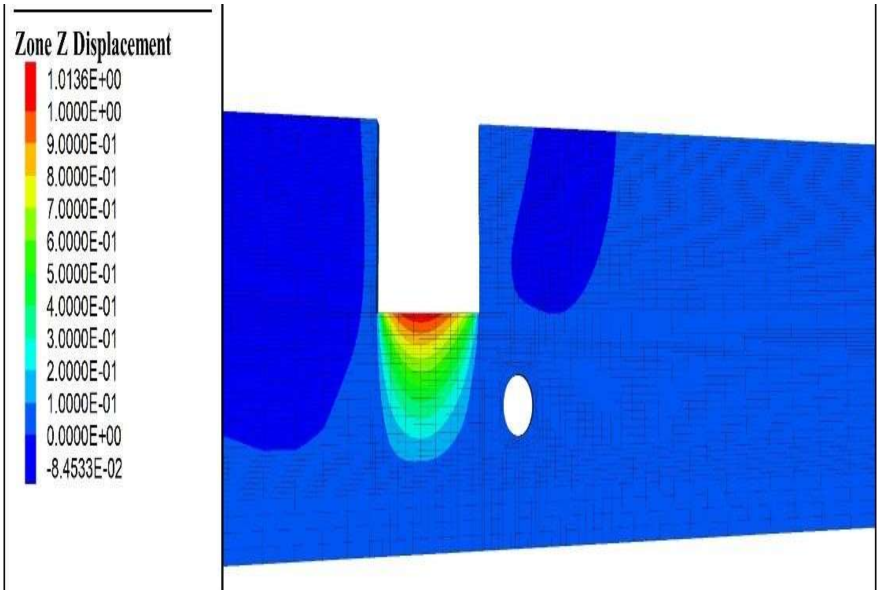

Figure 4-4. PH model displacement along the Z-axis

By comparing the displacement results obtained during the foundation pit excavation, we can conclude that the results for PH along the two axes (X, Z) change and are higher than the MC results.

4.2 Overall stress distribution:

4.2.1 Zone stress in MC model:

- Maximum principal stress

The maximum principal zone stress can be seen in the figure below:

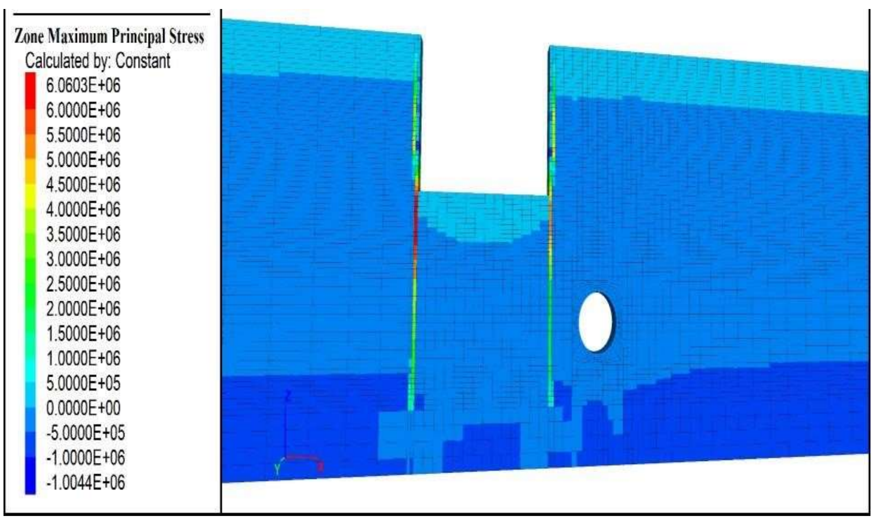

Figure 4-5. MC maximal principal stress

The maximum principal zone stress is near the retaining walls around the last level of the excavation, as shown in figure 4-5.

- Minimum principal stress

The minimum principal zone stress can be seen in the figure below:

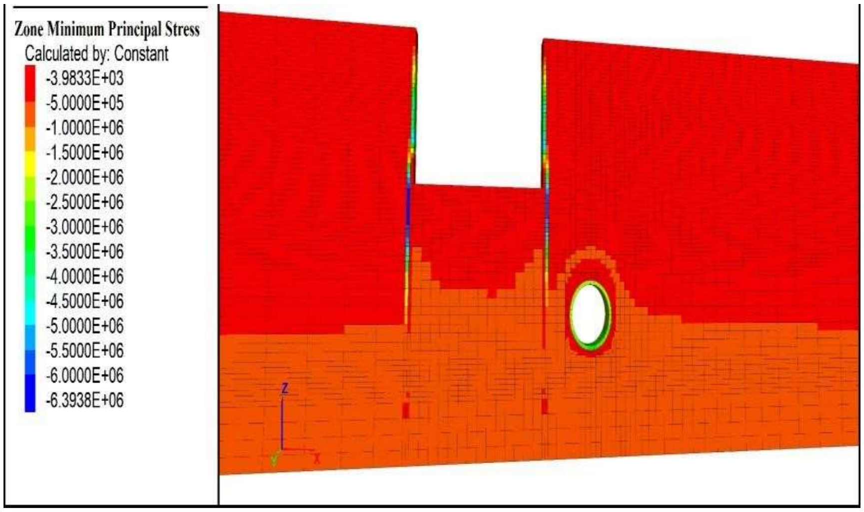

Figure 4-6. MC minimum principal stress

- Maximum effective stress:

The maximum zone stress can be seen in the figure below:

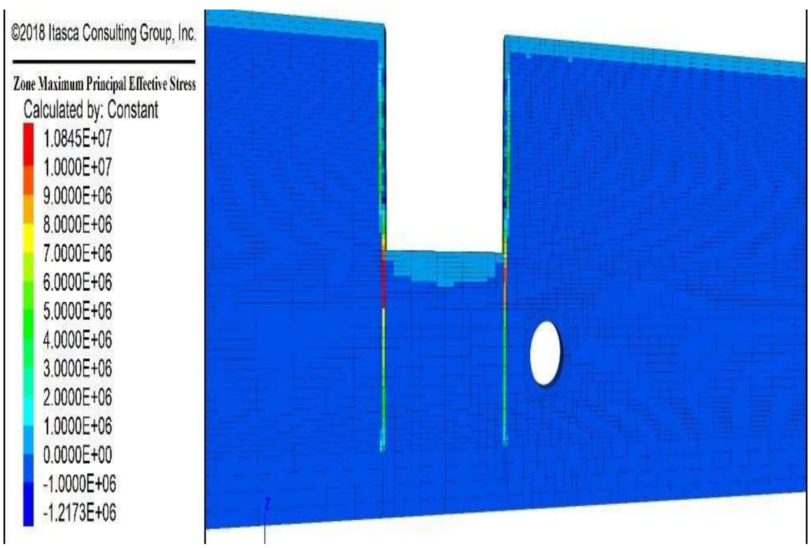

Figure 4-7. MC maximum Effective stress

The maximum effective stress is also found near the retaining walls around the last level of the excavated foundation pit area, as shown in Figure 4-7.

- Shear stress

The shear stress zone can be seen in this figure below:

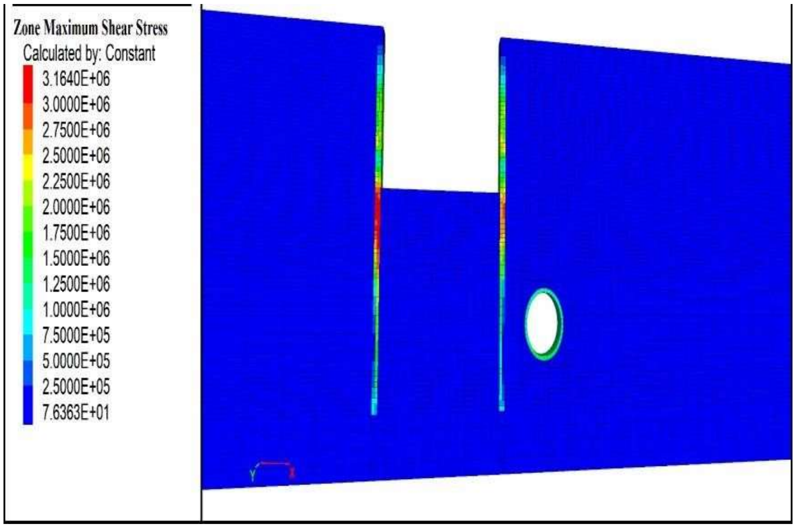

Figure 4-8. MC Maximum shear stress zone

Figures 4-8 show that the maximum shear stress zone is also near retaining walls and below the last excavated foundation pit area.

4.2.3 Zone stress in PH model:

- Maximum principal stress

The maximum principal zone stress can be seen on this figure below:

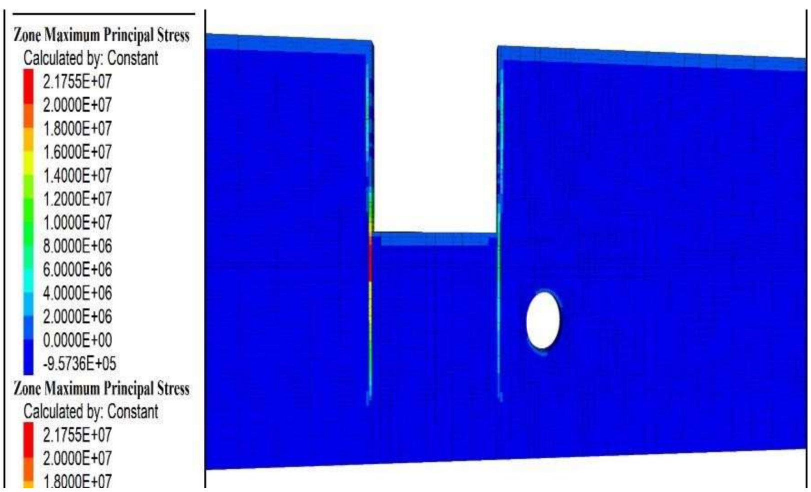

Figure 4-9. PH Maximum principal stress zone

According to the figure above, the maximum principal stress is located near retaining walls, but mainly on the left side of the foundation pit, just below the last level of the excavated part.

- Minimum principal stress:

The minimum principal zone stress can be seen in the figure below:

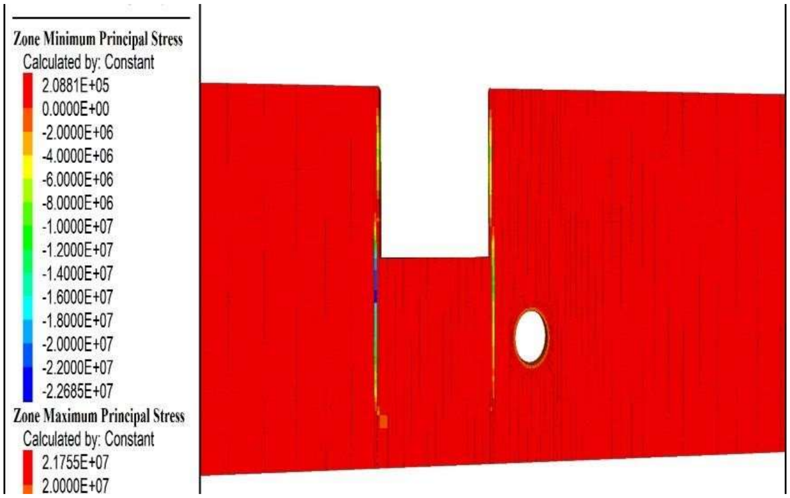

Figure 4-10. PH Minimum principal stress zone

- Maximum effective stress:

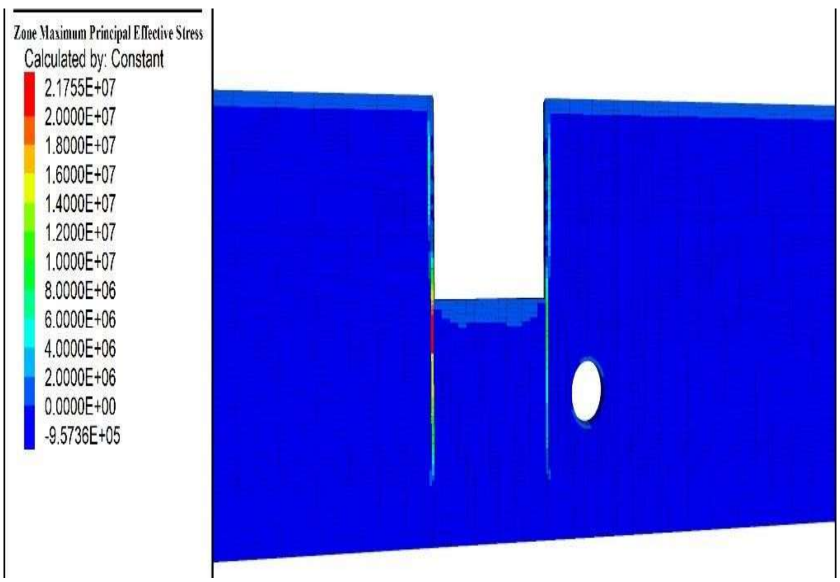

Figure 4-11. MC Minimum principal stress zone

Figure 4.11 shows that the maximum effective stress zone is near the retaining walls surrounding the last level of the excavated foundation pit area.

The majority of the soil stress zone after foundation pit excavation is located near the retaining walls, with the most critical part located beneath the last excavated part of the foundation pit.

The stress increases as the excavation of the foundation pit progress. As we can see by comparing the stress results obtained during the excavation, the results for PH along the two axes (X, Z) are more important than the results for MC.

4.3 Ground surface settlement:

4.3.1 Ground surface settlement after tunnel excavation

The ground will settle following tunnel excavation, the results will be obtained by simulation, and the MC and

PH constitutive models will be compared based on the observed results.

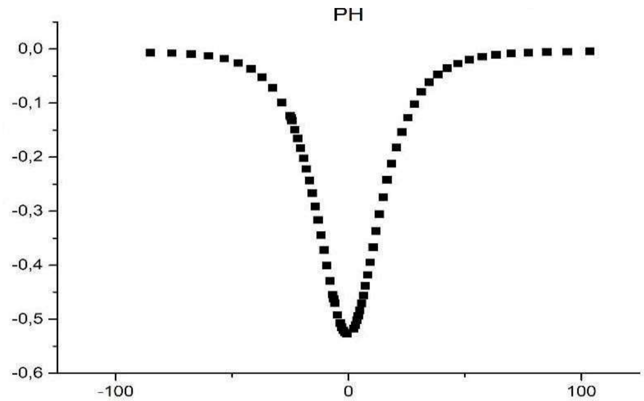

Figure 4-12. PH ground Surface settlement after tunnel excavation

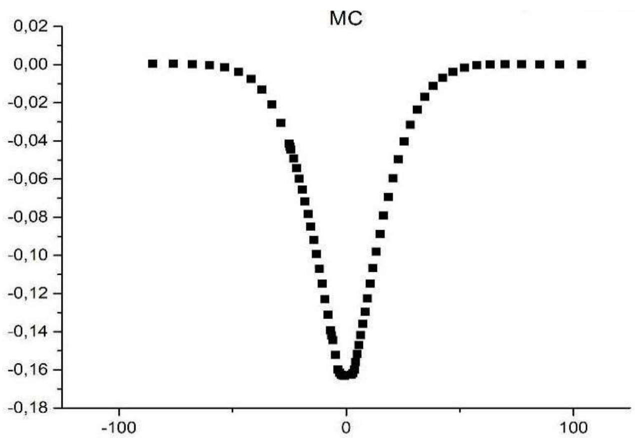

Figure 4-13. MC ground Surface settlement after tunnel excavation

Figures 4-12 and 4-13 show that after observing the results, the value of the ground settlement for the PH model increases, and its maximum value is 0.53m, whereas the maximum value of the MC is around 0.17m; thus, we can conclude that PH is better to use than MC results because of the accuracy of PH results.

4.3.2 Ground settlement during foundation pit excavation:

After the tunnel excavation, the next step was the foundation pit excavation. The excavation will be carried out in six stages, during which the ground will settle, and we will also observe the deformation of the retaining walls. We will see the increase of the ground settlement and the wall deformation as the excavation progresses. The results of the PH and MC constitutive models will be compared once the six stages of foundation pit excavation are completed.

We can see the different results below after simulation:

- PH ground settlements result after the foundation pit excavation (right side)

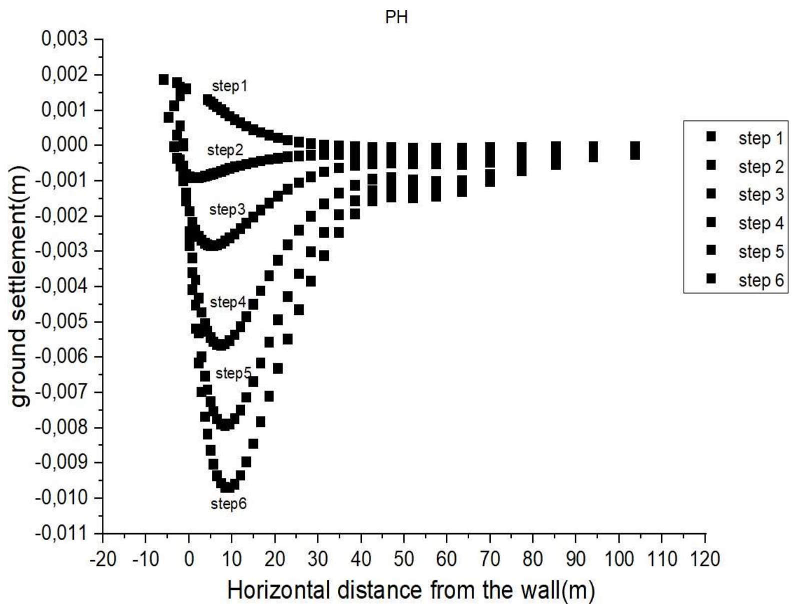

Figure 4-14. PH Ground settlement after the foundation pit excavation (right side)

- PH ground settlement results after the foundation pit excavation (left side)

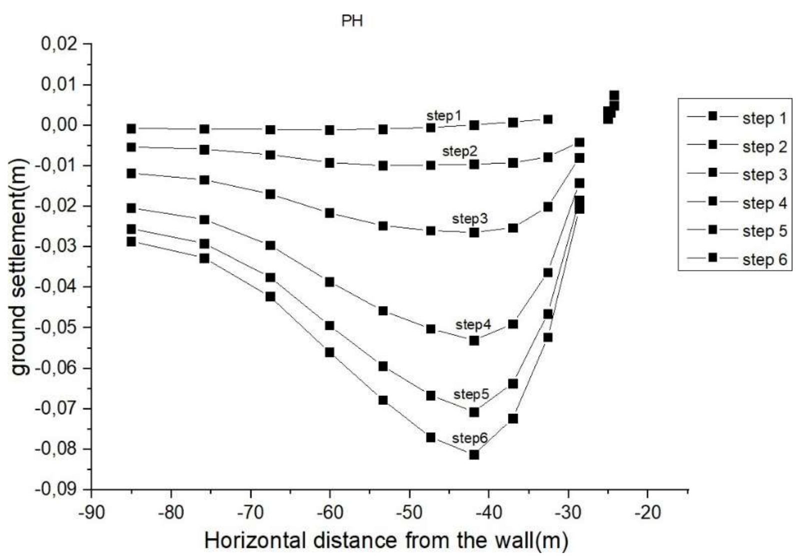

Figure 4-15. PH Ground settlement after the foundation pit excavation (left side)

- MC ground settlements result after the foundation pit excavation (right side)

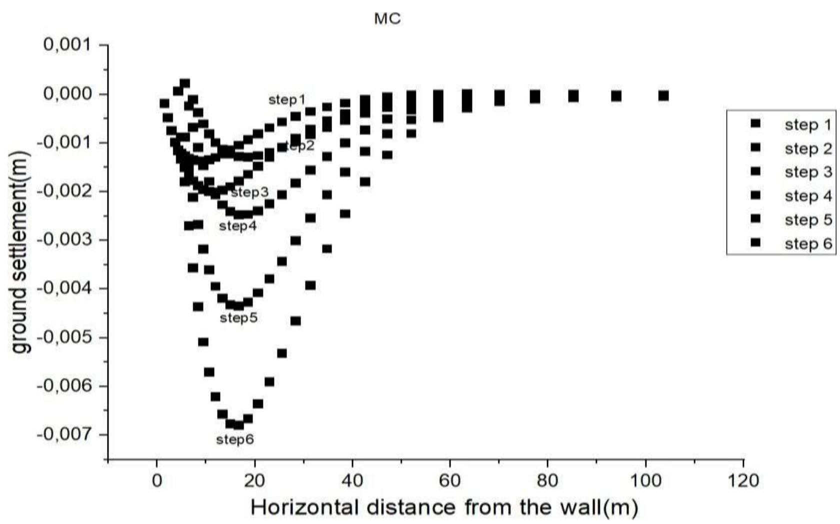

Figure 4-16. MC Ground settlement (right side) after the foundation pit excavation

- MC ground settlements result after the foundation pit excavation (left side)

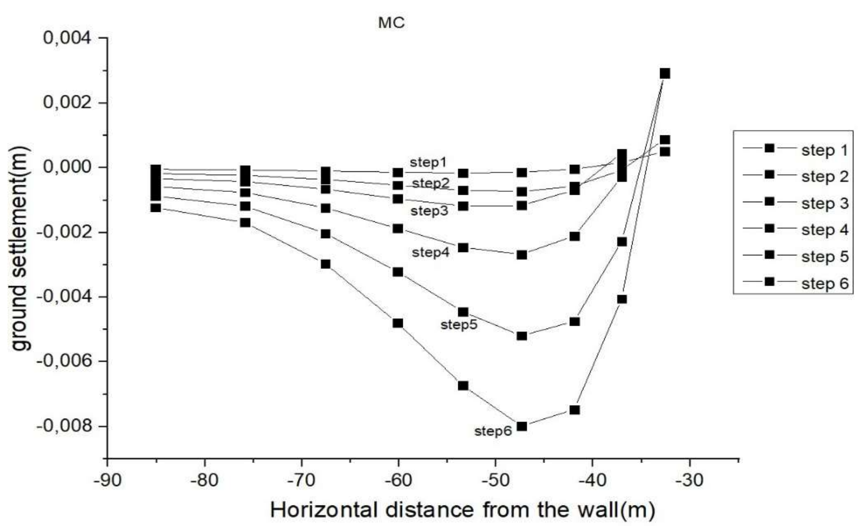

Figure 4-17. MC Ground settlement after the foundation pit excavation (left side)

According to the graphs of PH and MC ground settlements on both sides, the magnitude of the ground settlement is similar, but the PH model result is more important than the MC model result. The maximum value of the ground settlement for PH on the right and the left side is 0.01m and 0.083m, respectively, and for MC, it is 0.007m and

0.081m, so PH is preferable to use because of the accuracy of its result.

4.4 Wall deflection:

4.4.1 Deflection of wall on right side

During the foundation pit excavation, we can see the behavior of the soil and its settlement, and at the same time, we will notice the lateral displacement of the retaining wall on both sides. The displacement will be recorded after all the six stages of the excavation, during which the retaining wall deformation will increases as the excavation progresses.

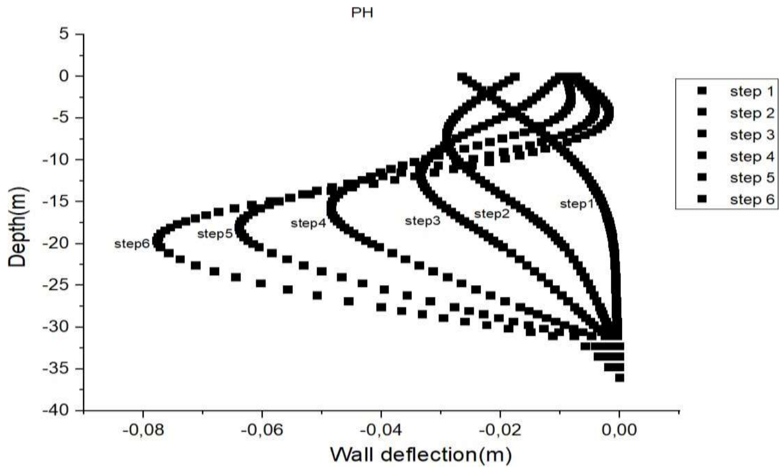

Figure 4-18. PH wall deflection (right wall)

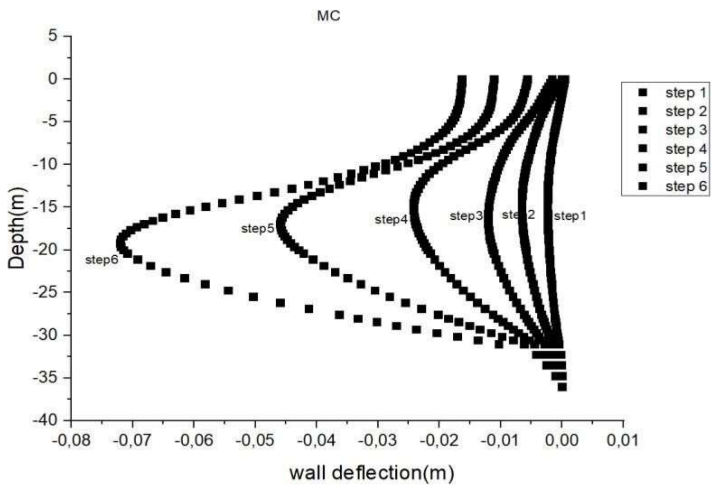

Figure 4-19. MC wall deflection (right wall)

According to figure 4-18 and figure 4-19, we can see that the maximum value of the wall deformation on the right side for MC model is less than PH model. The maximum value of the wall deformation on the right side for PH and MC are respectively 0.08m and

0.07m, therefore PH is better to use.

4.4.2 Deflection of wall on left side:

The wall displacement on the left side will be recorded after all the six stages of the excavation, during which the retaining wall deformation will increases as the excavation progresses. We can see in the figures below:

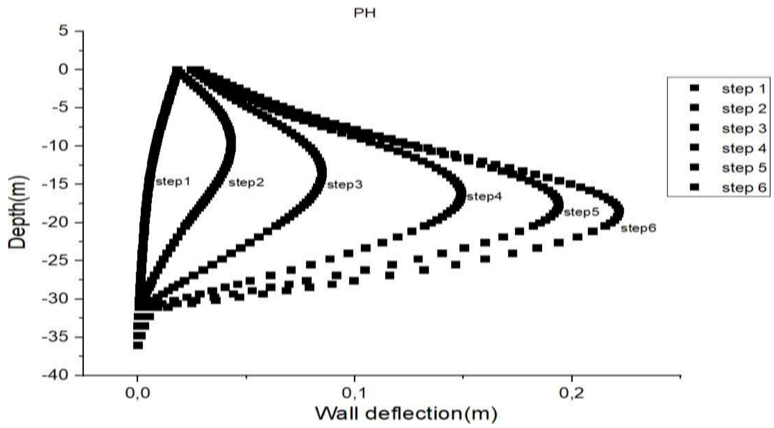

Figure 4-20. PH wall deflection (left side)

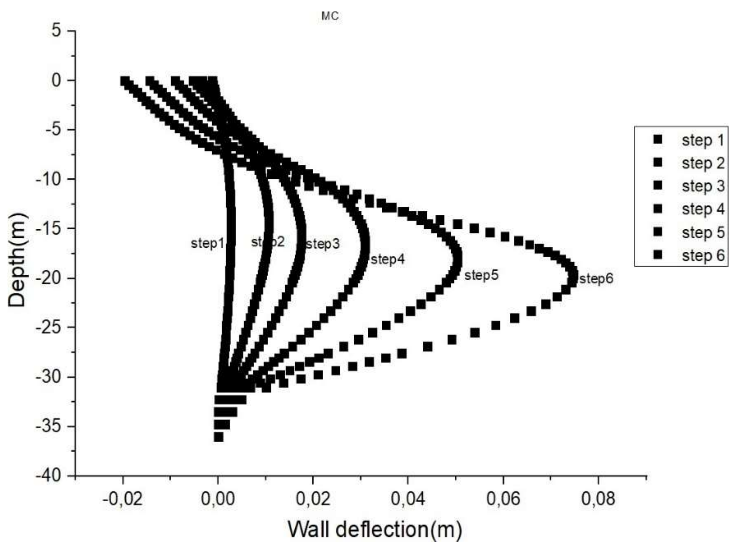

Figure 4-21. MC wall deflection (left side)

According to figures 4-20 and figure 4-21, the maximum value of the wall deformation on the left side for MC model is less than PH model. The value of the wall deformation on the left side for PH and MC are respectively 0.26m and 0.077m. Therefore PH is better to use.

4.5Additional response of existing tunnel induced by deep excavation

- Tunnel top deformation:

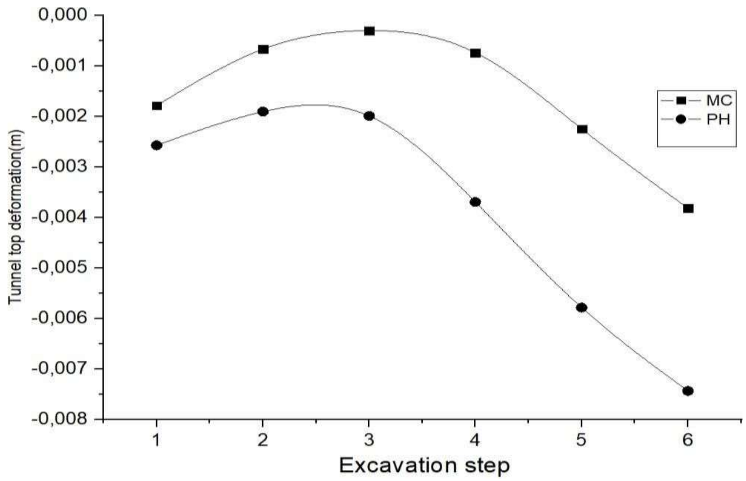

Figure 4-22. MC and PH tunnel top deformation

NB: Figure 4-22 shows that the tunnel top deformation for the MC model is less than the PH model, with a value difference of about 0.0037m.

- Tunnel invert deformation:

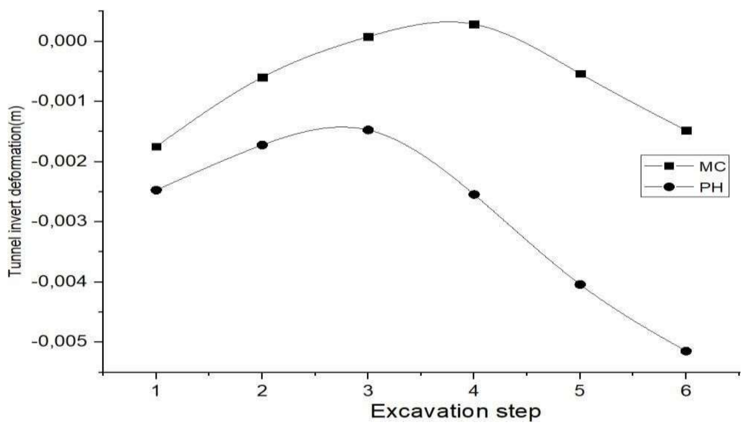

Figure 4-23. MC and PH tunnel invert deformation

NB: Figure 4-23 shows that the tunnel down deformation for the MC model is also less than the PH model, with a value difference of about 0.0036m.

- Tunnel left side deformation:

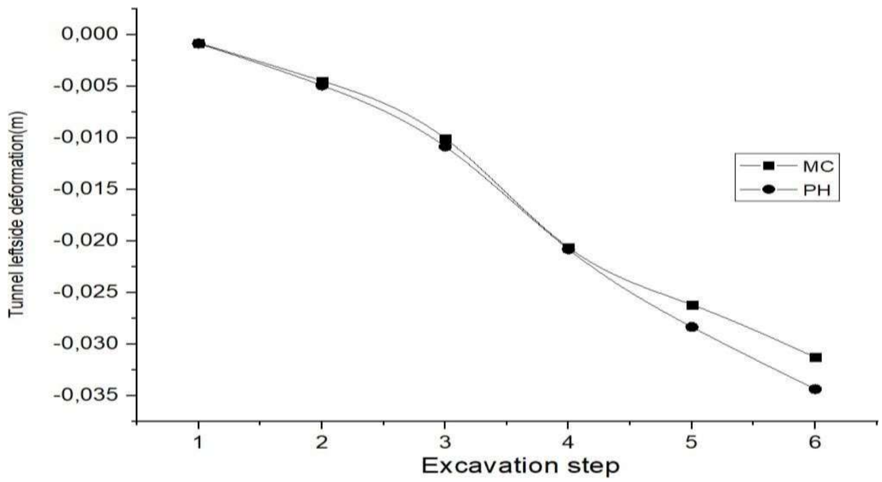

Figure 4-24. MC and PH tunnel left side deformation

PS: According to figure 4-24, the tunnel deformation on the left side for the MC model is less than the PH model, with a value difference of about 0.005m.

- Tunnel right side deformation:

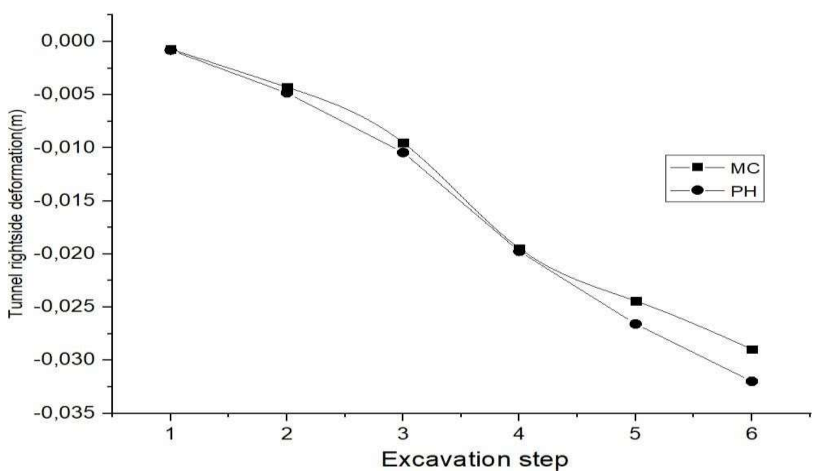

Figure 4-25. MC and PH tunnel right side deformation

NB: According to figure 4-25, the tunnel response on the right side for the PH model is greater than the MC model, with a difference in the value of about 0.0025m; thus, the PH model is preferable.

4.6 Conclusive remarks:

After the tunnel excavation, we notice that the value of the ground settlement for PH model is higher than the MC model by 0.36m; therefore, we can conclude PH is better to use than MC.

After the foundation pit excavation, we observed that the ground settlement for PH model on both sides is higher than MC ground settlements on both sides, but we can also notice that the ground settlements on the left side for PH and MC are a little bit similar in magnitude; therefore we can conclude that PH is better to use.

Concerning the wall deformation, we notice that the value of the deformations on both sides for MC model is less than PH model, so we can conclude that PH is better to use than MC.

For the tunnel response to the adjacent soil excavation of the foundation pit, we noticed that the PH model results on both side are higher than MC model; therefore, here also, we can say that PH is better to use.

Through the obtained results, we can conclude in general that the Plastic-Hardening constitutive model yields more accurate results compared to Mohr-coulomb constitutive model.

After the comparative study comes to the Parametric Analysis of Plastic-Hardening Constitutive model.

5. Influence of key parameters:

5.1 Ground settlement after foundation pit excavation

- Ground settlement on the right side:

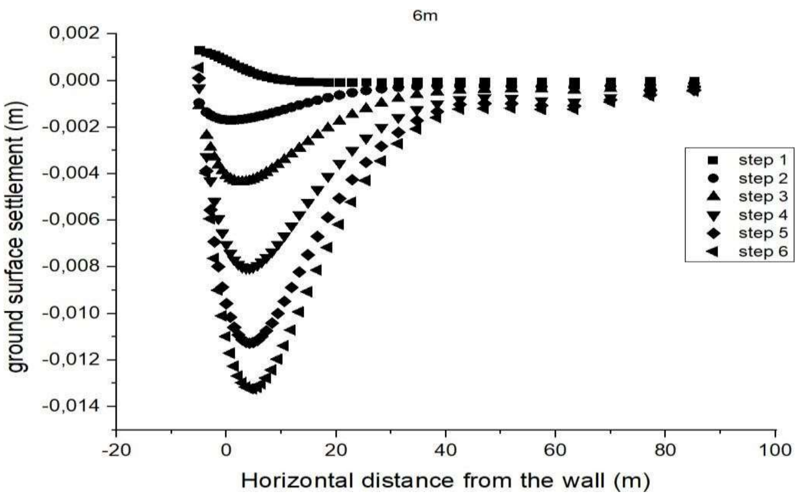

Figure 5-1. PH ground settlement at 6m

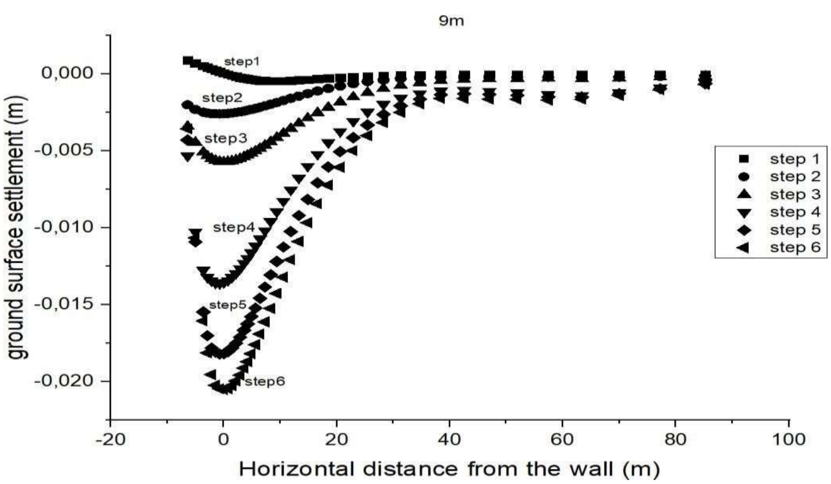

Figure 5-2. PH ground settlement at 9m

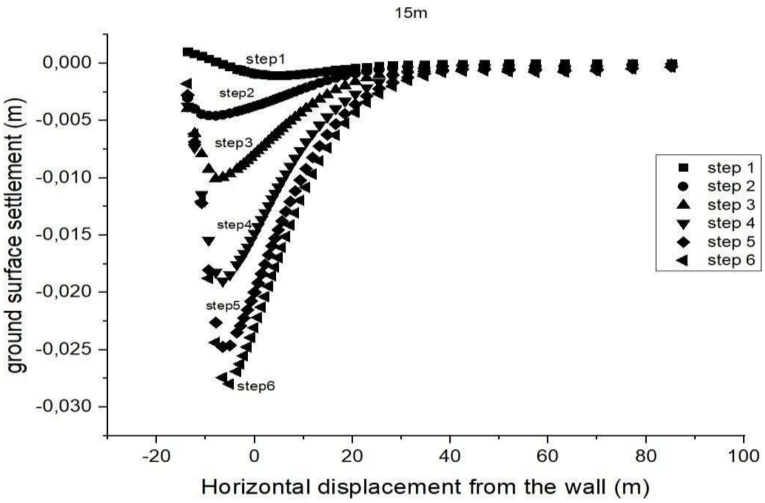

Figure 5-3. PH ground settlement at 15m

PS: We can see that when the horizontal distance between the excavation and the tunnel increases, the ground settlement on the right side also gradually increases on average by

0.004m.

- Ground settlement on the left side:

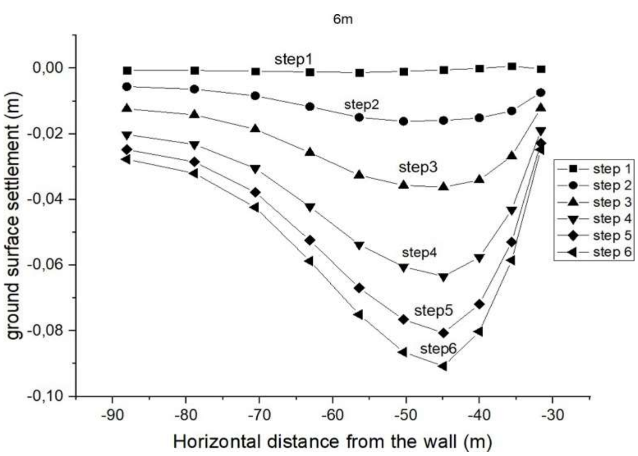

Figure 5-4. PH ground settlement at 6m

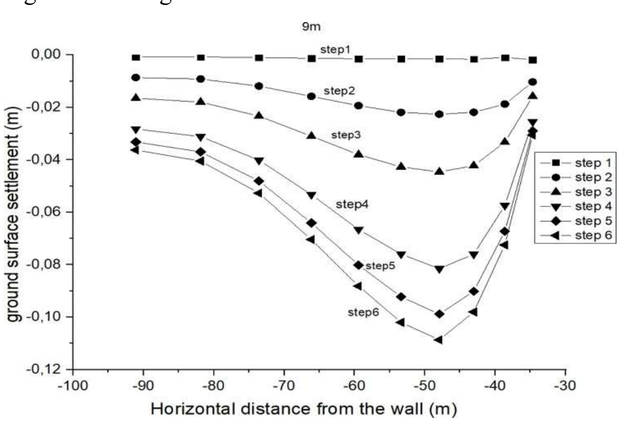

Figure 5-5. PH ground settlement at 9m

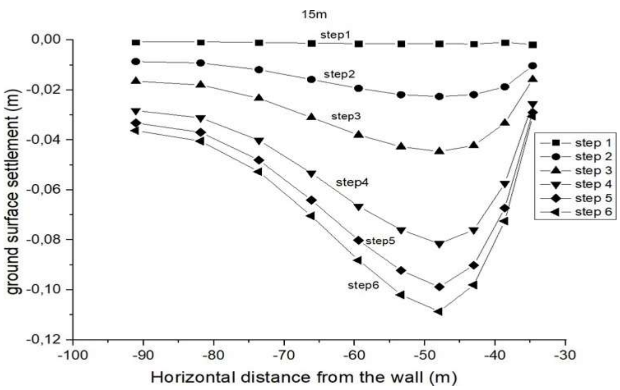

Figure 5-6. PH ground settlement at 15m

PS: We can see that when the horizontal distance between the excavation and the tunnel changes from 6m to 9m, the ground settlement on the left side increases by 0.02m, but when it varies from 9m to 15m, we notice a slit increase in ground settlement, but they are also similar in magnitude.

5.1.2 Wall deflection:

- Wall deflection on the right side

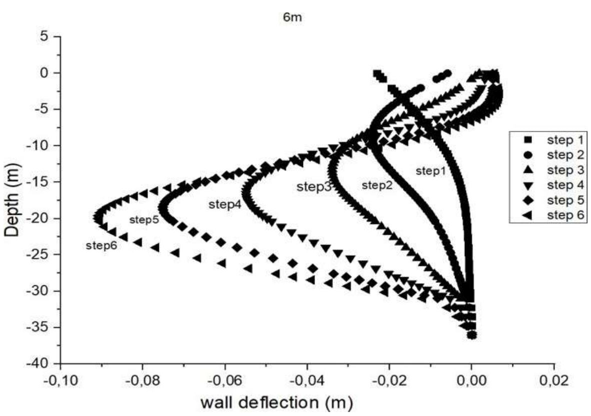

Figure 5-7. PH wall deflection at 6m

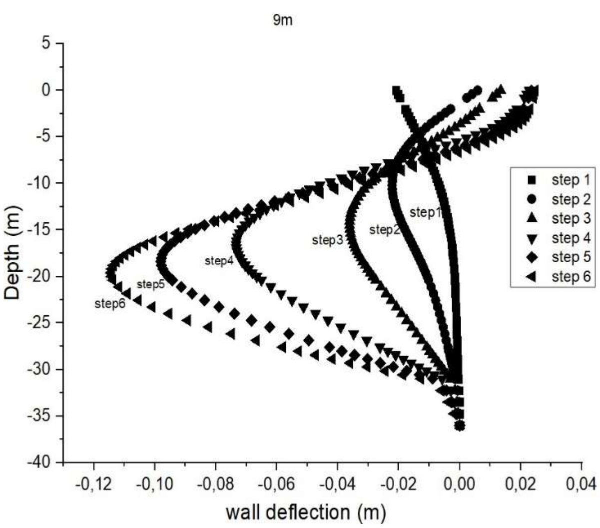

Figure 5-8. PH wall deflection at 9m

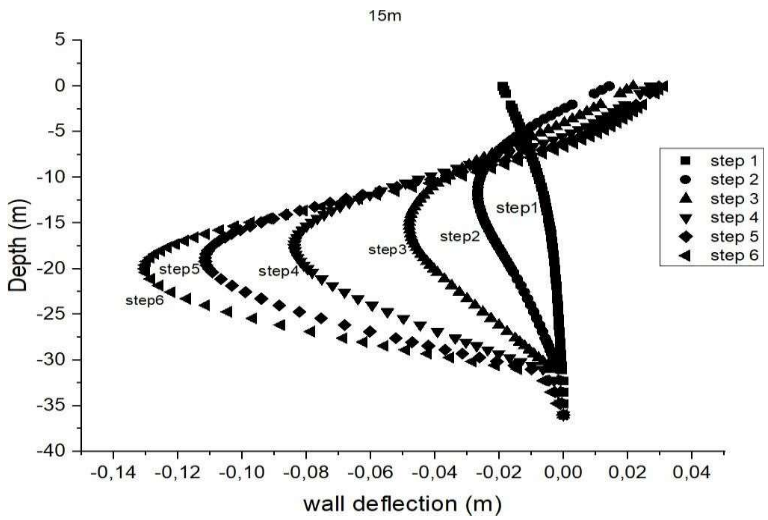

Figure 5-9. PH wall deflection at 15m

PS: We discovered that the wall deformation increases in value as the horizontal distance between the excavation and the tunnel increases. When we extended the distance from 6 to 9 meters, the deformation increased by 0.02 m, and when we increased the distance from 9 to 15 m, the deformation increased again by 0.02 m.

- Wall deflection on the left side:

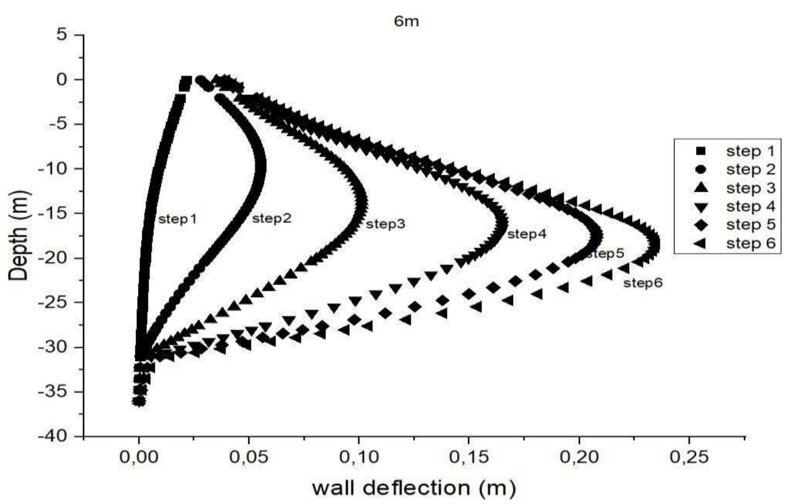

Figure 5-10. PH wall deflection at 6m

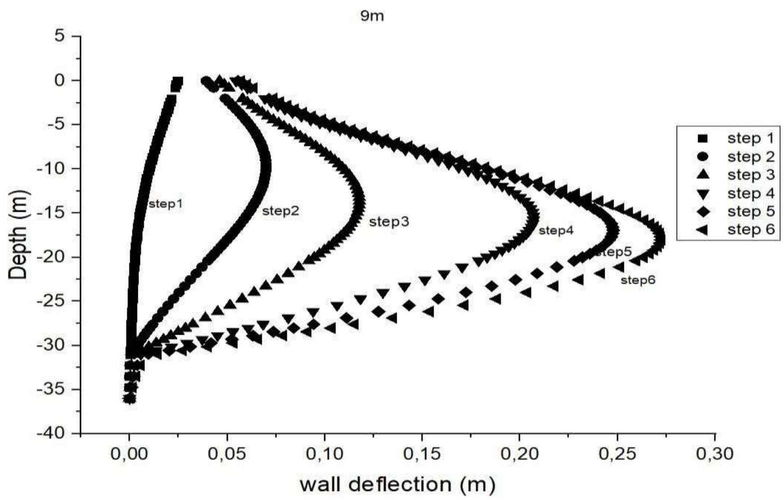

Figure 5-11. PH wall deflection at 9m

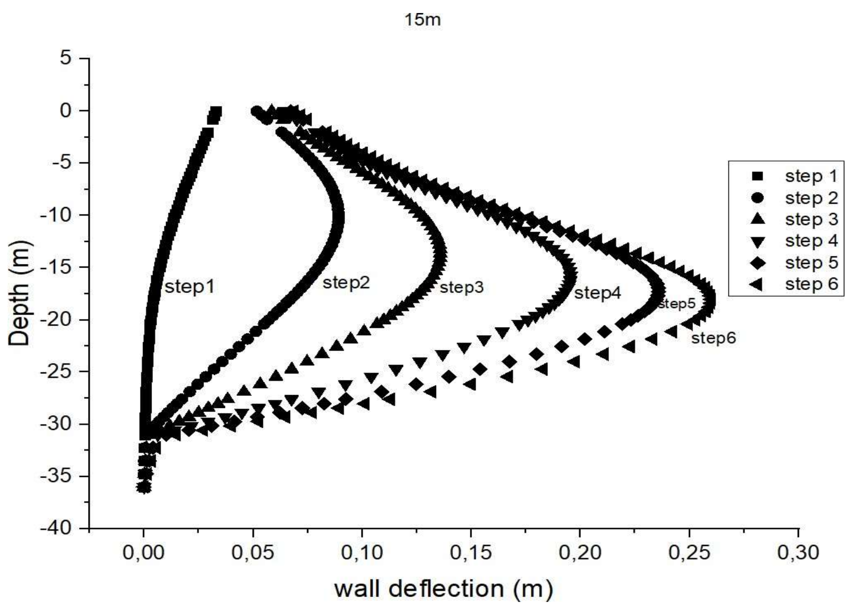

Figure 5-12. PH wall deflection at 15m

PS: We noticed that the deformation of the wall increases in value with the increase of the horizontal distance between the excavation and the tunnel, but the deformation of the wall on the left side is more important than on the right side. The difference in deformation on the left side is about 0.03m.

5.1.3 Additional response of existing tunnel induced by deep excavation:

- Tunnel top deformation:

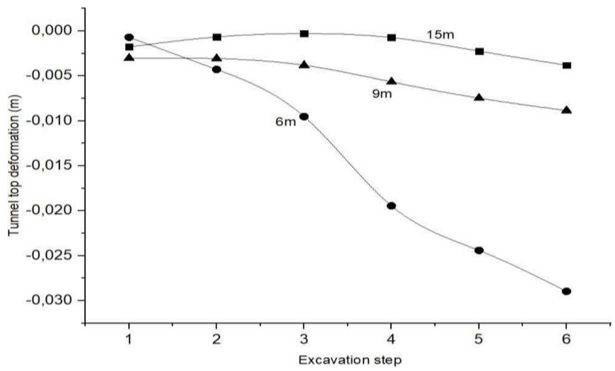

Figure 5-13. Tunnel top deformation

PS: According to fig 5-13, we noticed that as the horizontal distance between the excavation and the tunnel increases, the deformation of the upper part of the tunnel decreases, the maximum values of deformation at 6m, 9m, and 15m from the excavation are 0.028m, 0.008m, and 0.002m, respectively.

- Tunnel invert deformation:

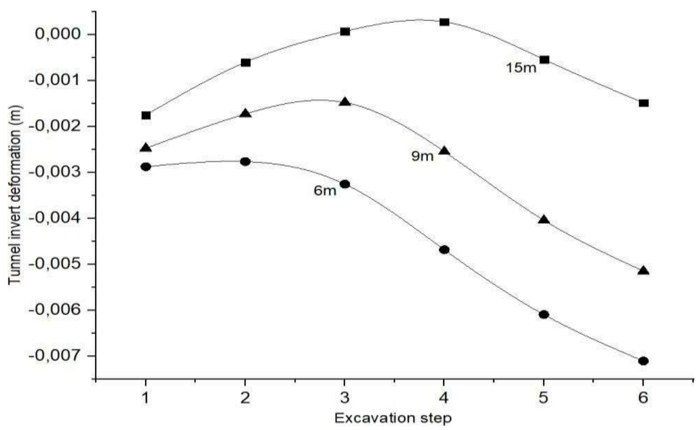

Figure 5-14. Tunnel invert deformation

PS: In fig 5-14, we can also see that as the horizontal distance between the excavation and the tunnel increases, the deformation of the bottom part of the tunnel reduces, with maximum values of 0.0072m, 0.0053m, and 0.0013m at 6m, 9m, and 15m from the excavation, respectively.

- Tunnel deformation on the left side:

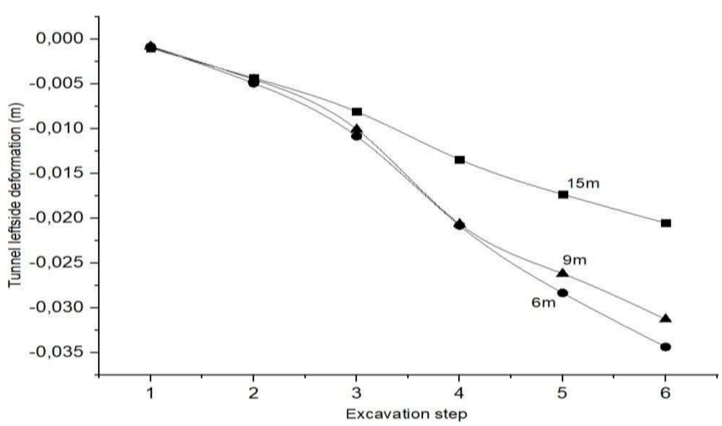

Figure 5-15. Tunnel left side deformation

PS: We can also notice here that as the horizontal distance between the excavation and the tunnel increases, the deformation on the left side of the tunnel decreases and the maximum values of the deformation at 6m, 9m and 15m from the excavation are respectively 0.035m,

0.031m and 0.017m.

- Tunnel deformation on the right side:

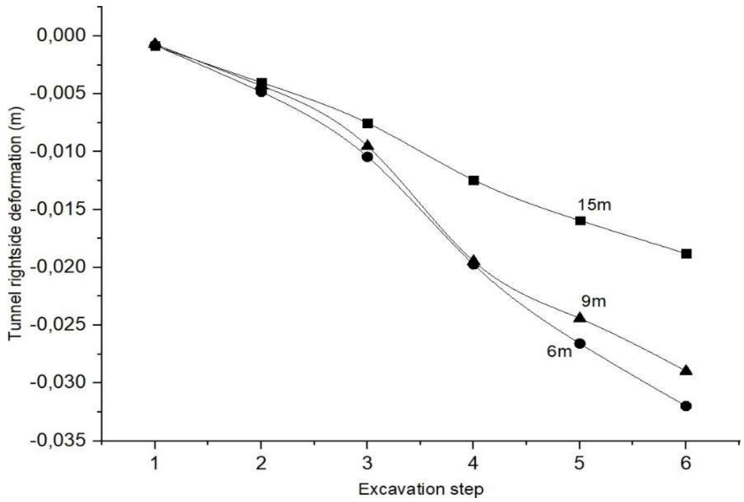

Figure 5-16. Tunnel right side deformation

PS: We observed that as the horizontal distance between the excavation and the tunnel increases, the deformation on the right side of the tunnel decreases, and the maximum values of deformation at 6m, 9m, and 15m from the excavation are 0.0072m, 0.0053m, and 0.0013m, respectively.

5.2 Influence of the tunnel depth

5.2.1 Ground surface settlement

The effect of tunnel depth and diameter D will be investigated utilizing three depths: 24m, 18m, and 12m with a diameter of 6m, resulting in H/D=4m, H/D=3m, and H/D=2m, respectively.

- Ground surface settlement after tunnel excavation, according to the ratio H/D

The figure below presents the ground surface settlement with different depths of the tunnel.

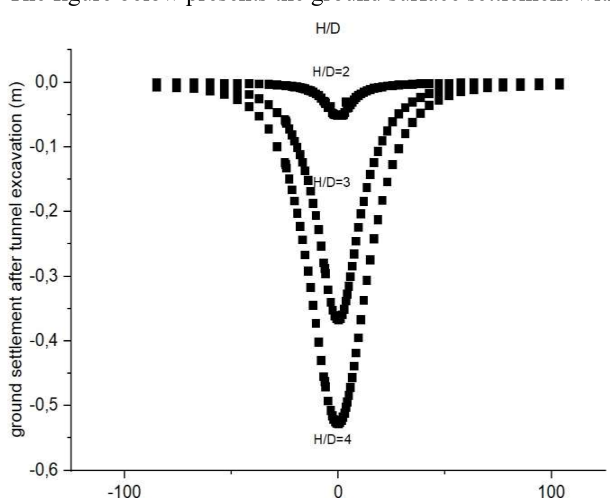

Figure 5-17. PH ground surface settlement after tunnel excavation according to H/D ratio

PS: The ground surface settles as the tunnel depth increases, as shown in fig 5-17. The maximum ground surface settlement at 24m, 18m, and 12m depths is 0.54m, 0.39m, and 0.05m, respectively.

- Ground settlement after foundation pit excavation, according to the ratio H/D

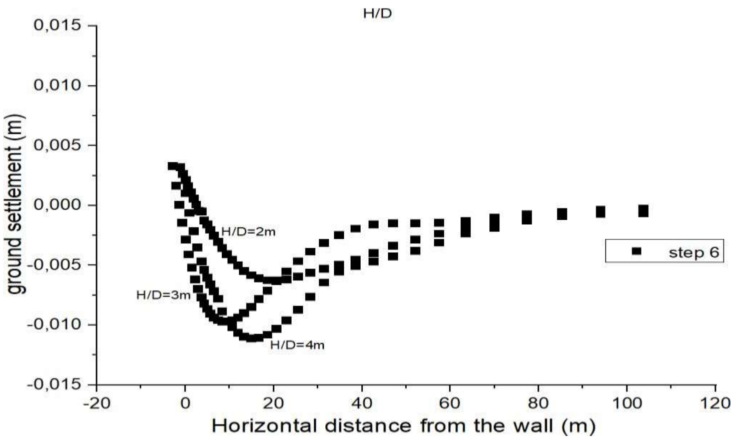

Figure 5-18. Ground settlement (right side) after the foundation pit excavation, according to the H/D ratio

PS: After excavating the foundation pit, we noted that as the tunnel depth increased, the ground settlement increased as well. The maximum values of ground settlement at 24m, 18m, and 12m depths are 0.012m, 0.010m, and 0.006m, respectively.

5.2.2 Wall deflection:

- Wall deflection (right side) after foundation pit excavation, according to the ratio H/D:

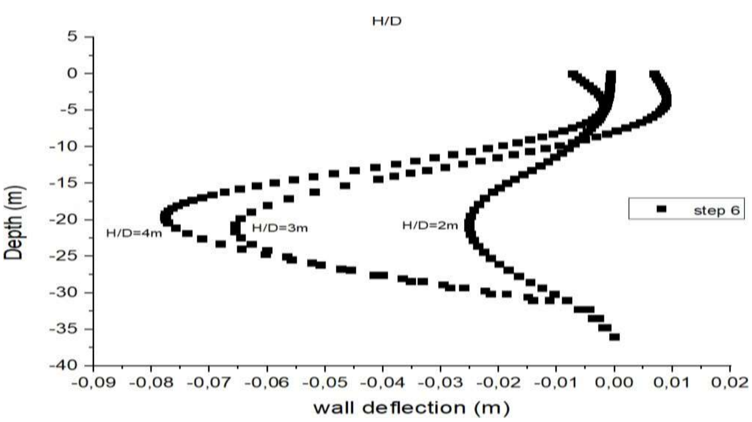

Figure 5-19. Wall deflection (right side) according to H/D ratio

PS: The deformation of the wall (right side) increases With the increase in the tunnel depth. The maximum wall deformation is 0,08m, 0,063m and 0,023m, at 24m, 18m and 12 m depth, respectively.

- Wall deflection (left side) after the foundation pit excavation, according to the ratio H/D:

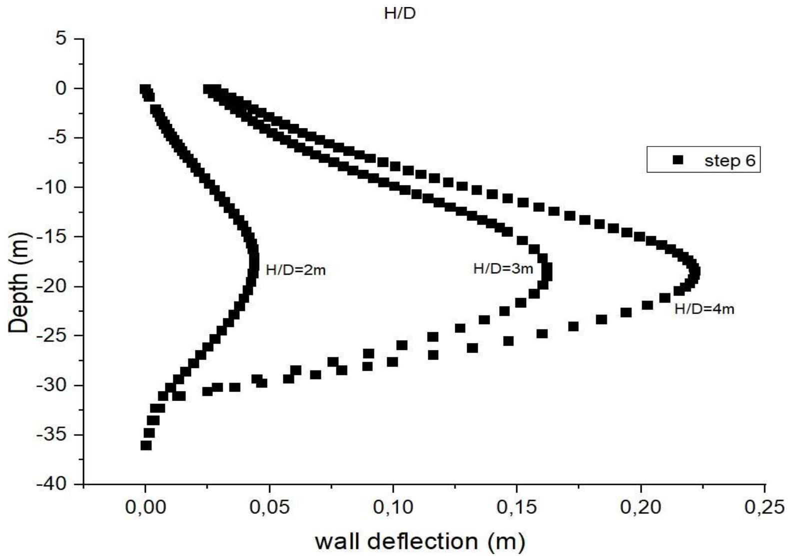

Figure 5-20. Wall deflection(left side) according to H/D ratio

PS: With the increase in tunnel depth, the deformation of the wall (left side) increases. The maximum wall-deformation value at a depth of 24m, 18m and 12m is 0.03m, 0.16m and 0.23m, respectively.

5.2.3 Additional response of existing tunnel induced by deep excavation:

- Tunnel top deformation

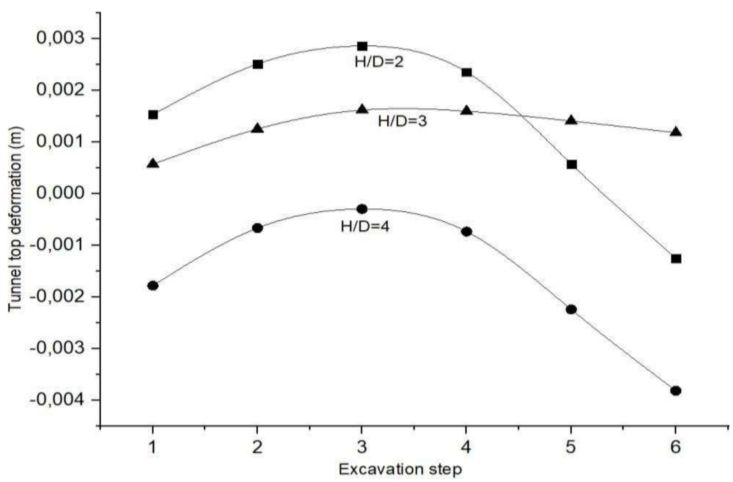

Figure 5-21. Tunnel top deformation according to H/D ratio

PS: The tunnel top deformation increases with the increase of the tunnel depth.

- Tunnel invert deformation:

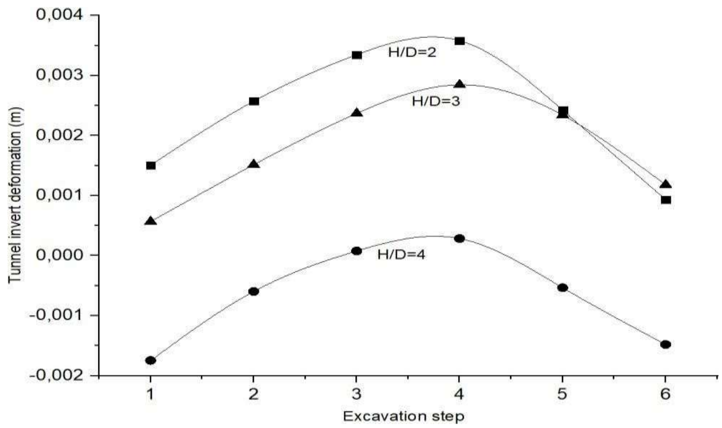

Figure 5-22. Tunnel invert deformation according to H/D ratio

- Tunnel deformation on the left side:

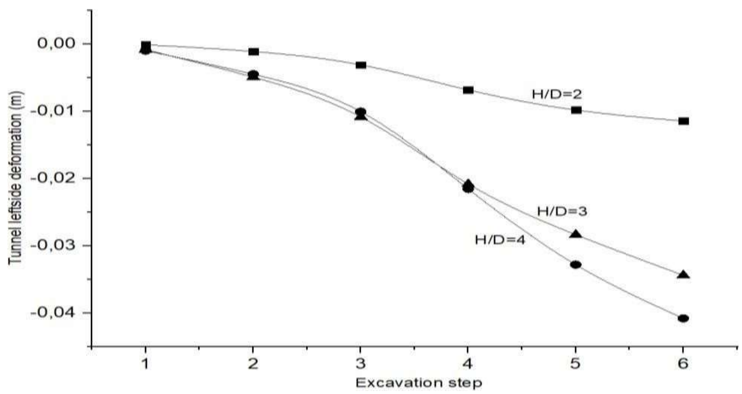

Figure 5-23. Tunnel left side deformation according to H/D ratio

- Tunnel deformation on the right side:

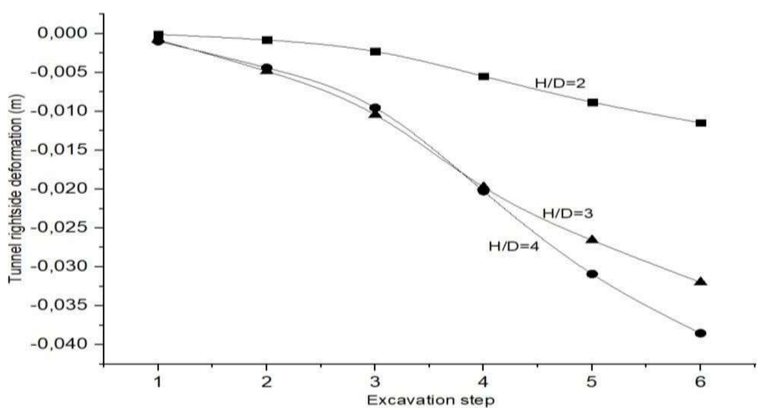

Figure 5-24. Tunnel right side deformation according to H/D ratio

5.3 Conclusive remarks

According to the results after doing the parametric analysis, we can notice that:

- We can see that when the horizontal distance between the excavation and the tunnel increases, the ground settlement gradually increases as well.
- The deformation of the wall increases with the increase of the horizontal distance between the excavation and the tunnel.

- The response of the tunnel to the excavation becomes less important with the increase of the horizontal distance between the excavation and the tunnel.
- The settlement of the ground surface increases with the increase of the tunnel depth
- The deformation of the wall increases with the increase of the tunnel depth.
- The response of the tunnel to the excavation becomes more important with the increase of the tunnel depth.

6. Conclusion and recommendation

During my simulation work, I can conclude that significant settlements may occur during wall construction for the given soil condition. From the comparison of the above calculations, it can be seen that both MC and PH models can better reflect the law of ground settlement caused by foundation pit excavation and the lateral displacement of the diaphragm wall. Although there is a certain difference between the two, the surface settlement reflected by the two and the lateral deformation of the retaining wall of the retaining structure is a little bit similar in magnitude.

The surface settlement result of MC is less than the PH result, the wall deformation for MC result is also smaller than the PH calculation model result; therefore we can say that PH results are good to use because it gives better and accurate results.

We can see the increase of the lateral deformation on both sides for PH and MC, but we will deduce that the PH sidewall lateral deformation is greater on both sides of the foundation pit than the MC sidewall deformation. It's very important to consider these lateral deformations of the retaining wall to be able to take into account the side effects of the excavation of the foundation pit, which produces lateral deformations of the retaining walls, contributes to the ground settlement, and also produces deformation on the existing tunnel.

During the parametric analysis of the Plastic-Hardening constitutive model, I noticed that :

- When the horizontal distance between the deep excavation and the tunnel increases, the settlement of the ground gradually increases.
- When the horizontal distance between the deep excavation and the tunnel increase, the wall deflection gradually increases.
- With different depths of the tunnel before the foundation pit excavation, the more the tunnel depth is high, the more the ground surface settlement is high.
- With the different depths of the tunnel, after the foundation pit excavation, the more the tunnel depth is high, the more the settlement of the ground is high.
- With the different depth of the tunnel, after the foundation pit excavation, the deflection of the walls is influenced, and the more the tunnel depth is high, the more the deformation of the wall become high.
- With the increase of the horizontal distance between the excavation and the tunnel, the response of the tunnel to the excavation becomes less important.
- The response of the tunnel to the excavation becomes more important with the increase of the tunnel depth.

By the end, I will say that the Plastic-Hardening model is very good to use to evaluate the ground settlement, the lateral displacement, the deflection of the retaining walls, and to evaluate the tunnel response to the adjacent excavation of soil because the Plastic-Hardening constitutive model produces better and more accurate results compared to Mohr-Coulomb model and thus I could use those results to predict all the deformation that occurs while doing any project that includes tunneling.

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In life, I have found that good things go so quickly that you can't even imagine. My four years of study at Zhejiang University of Science and Technology went by so quickly that I don't even believe the time has come yet; I am aware that I will soon be graduating from school, and my life will change from a student at ZUST University to a worker in a new company. In my very first year at ZUST, coming from a faraway country in West Africa, I was a new foreign student who knew nothing about china and who still did not know about social life and the way of being in Chinese society, who didn't know anything about the way of life, who didn't know anything about the behavior, who didn't know about the Chinese culture and the student life of my host university ZUST. But in my first year, I learned the Chinese language with my Chinese language teachers, who taught me everything about the way of life of Chinese people; they introduced me to Chinese cultures, which are very rich and very diverse. I learned a lot about China from my teachers, and now I feel in harmony and harmony with the Chinese people, who are very welcoming and very kind. As of today, my first year seems to me as if it was yesterday, and I still remember my first contacts here in China since the first time I set foot there, but now I am on the point of saying goodbye to this charming place that I love very much, especially the city of Wuhan and very specially my school ZHEJIANG UNIVERSITY OF SCIENCES AND TECHNOLOGY.

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