# COMPARATIVE ANALYSIS OF LATERAL EARTH PRESSURE ACTING ON BRACED EXCAVATION WALL


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FINAL SEMESTER FINAL YEAR

**Comparative analysis of lateral earth pressure acting on braced excavation wall**

by

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17662

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**CERTIFICATION OF APPROVAL**

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

NOR SYAHIRAH BINTI NAJMUDIN

# ABSTRACT

Braced excavation walls commonly are used for underground basement excavation or open cut excavation projects in urban areas. During the excavation process, it is essential not only considering the stability issues of the construction building itself, but also the potential serviceability problem of adjacent properties due to excessive wall deflection and ground movement.

Construction of embedded retaining wall prior to the excavation process at different ground level will induce deflection along the retaining wall.The deformation of the retaining wall influence by the type of soil, depth of wall penetration, stiffness of the wall, excavation depth, excavation length, strut spacing and elapsed time between excavations.

In this paper, a case study of secant piled wall of Damansara Uptown Retail Sdn. Bhd will be used to back, analyzing the likely properties of the wall that matches the field measurement results. The project focuses on the distribution and the magnitude of the wall, bending moment due to lateral load. A researched and design of the model would be done by manipulating the stiffness coefficient using Mohr-Coulomb model through finite element software (PLAXIS 7.2 software) and compared with the result from the monitoring data of the case study.

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# 1 INTRODUCTION

This chapter provides some background of knowledge that related to the field of study for this project. The subsections divided include the background of study, problem statement and objectives of this project.

## 1.1 Background of study

Deep excavations for high-rise buildings, tunnels, and subway stations in soft clay can cause large settlements and lateral displacements of the ground around the excavation that can cause damage in surrounding properties if the settlements are not controlled by increasing the stiffness of the retaining wall, by placing and preloading the struts as early as possible or by extending the wall down to an underlying stiff layer(Wong & Broms, 1989). Braced excavation in urban area required earth retaining wall to provide permanent lateral support to vertical or near vertical of ground surface to prevent failure of the surrounding properties and allow soil excavation at the required depth. The embedded retaining wall is one of the retaining wall type that was used in the construction of underground basements, tunnel and open cut excavation. According to BS 8002, embedded retaining wall can be in terms of sheet piled wall, diaphragm wall or secant bore piled wall.

Fundamentally, embedded retaining wall consists of two elements which are vertical element that installed prior to excavation and horizontal element or known as bracing that limit the span length and at the same time reduce the development of bending moment in vertical element. Inequity forced exerted on the retaining wall during the excavation process stimulate deflection of the retaining wall.

Numerous semi-empirical studies have been conducted by number of researches to understand the deformation of deep excavation (Leung & Ng, 2007). Peck(1969) produces plots of the maximum vertical settlement normalized by the excavation depth against the distance from the excavation(Zhang, Goh, & Xuan, 2015). The deformation analysis is conducted to predict the wall deflection and stress analysis. These analyses can be done by using Peck's method or Tschebotarioff's and beam on elastic foundation or by using Mohr-Coulomb model through finite element software (PLAXIS 7.2 software). The soil strength, stiffness of the wall and struts are taken in consideration during the analysis.

## 1.2 Problem statement

Various studies have been done to analyses the performance of braced excavation wall by using empirical or semi-empirical method. Prediction of the wall deflection is important to provide expected movement to occur along the excavation process and to control surrounding properties from damage. Analysis with different methods will give different results thus a comparison is done to authenticate the preciseness of the analysis.

Peck or Tschebotarioff and beam on elastic foundation method is used to understand the stress and deformation analysis. In this method, certain assumptions are made for the ease of the analysis. Besides that, stress and deformation analysis also can be done by using finite-element software (PLAXIS 7.2) to stimulate various factors acting on the retaining wall. Due to the fact that limited studies have been done on the comparison of these two methods, this project will be focusing on the design load using Peck's or Tschebotarioff's and analysis finite element software. A series of 2D finite element analysis are performed to get the accurate deflection based on the case study data.

A set of monitoring equipment will be installed on the secant piled wall during the construction process to evaluate the design performance of the constructed wall. For this project a set of inclinometer from the case study will be used to back analyzing the predicted wall deflection. The inclinometer measured tilt and deformation behind the retaining wall and the result measure the horizontal displacement of the retaining wall at different levels of excavation.

## 1.3 Objectives

The objectives of this research are discussed below:

I. To analyze the horizontal wall deflection under different level of excavation and soil properties using finite element software; PLAXIS 7.2.

II. To determine the soil coefficient by comparison between the predicted wall deflection from PLAXIS 7.2 and field measurement.

## 1.4 Scopes of study

A case study of inclinometer reading from secant pile wall for Damansara Uptown Retail project will be used to back analyze by using beam on elastic foundation method and the design load will be done by using semi- empirical approach such as Peck's method or Tschebotarioff's method. The data provided from the case study will be used to determine the suitable type of retaining wall, geometry, and soil parameter. The soil strength and stiffness properties, and the wall stiffness were varied to study the wall deflection behavior. Software PLAXIS version 7.2 and Mohr-Coulomb soil constitutive model is used to yield criterion. (Li, Nakamura, Cai, & Ugai, 2008)

# CHAPTER 2

# 2 LITERATURE REVIEW

## 2.1 Lateral earth pressure

Movement of retaining wall can occur in the form of simple translation or by rotation at the bottom due to the lateral pressure against it. Rankine and coulomb method can be used to calculate the earth load acting on the retaining structure. Rankine's calculation gives lateral earth pressure coefficients that are ratios of horizontal to (notional) vertical effective stress at any depth and can be categorized into three categories which are, at-rest, active and passive earth pressure.

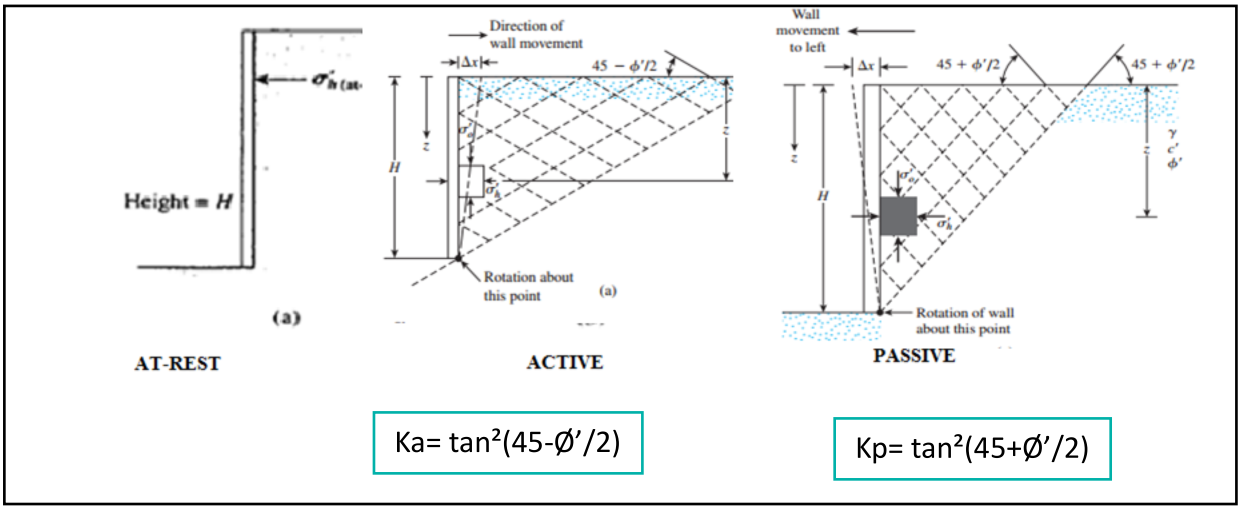


Figure 1: Lateral earth pressure at rest, active and passive

At- rest pressure wall is in a static condition and active pressure is when the retaining wall rotates at the bottom and tilt away from the soil ,whereas passive pressure, the retaining wall tilts toward the soil(DAS, 2014). During the construction process the upper portion of the soil mass next to the excavation area subjected to lateral deformation due to unbalance lateral earth pressure. In the design process, allowable displacement is the main criteria when deciding the required support system for embedded retaining wall in urban areas.

## 2.2 Deformation of braced excavation wall

Braced excavation wall may deform due to the dimension of excavation, wall stiffness, strut spacing and soil stiffness, groundwater conditions and soil properties (Kung, Juang, Hsiao, & Hashash, 2007). Soil surrounding the retaining wall consists of various types of soil that make it impossible to predict the accurate value of pressure behind and in front of the retaining wall during design phases. The review has been made by Long[7)] on 300 case histories of wall and ground movement due to deep excavation not consider the geographical boundaries and variations in local standard of specification. The collected information are grouped into four categories which are stiff to medium-dense soil, predominantly stiff to medium-dense soil with embedment into stiff stratum, predominantly stiff to medium-dense soil with low safety factor against base heave; and cantilever work (Long, 2001).

Long concluded that retaining wall with a large safety factor against excavation base heave normalize lateral movement value $\delta_{h\ max}$ are frequently between 0.05%H where H is the excavation depth and normalized maximum vertical settlement values $\delta_{v\ max}$ are usually lower, at values frequently between 0 and 0.20% H.

For retaining wall that retain a significant thickness of softer material (greater than 0.6 of excavation depth) with stiff material at dredge level and large factor against base heave, the $\delta_{h\ max}$ and $\delta_{v\ max}$ values increase significantly from the soil stiff cases. For retaining wall embedded in stiff stratum that retain significant thickness of soil material and with stiff material at dredge level and large factor against base heave, the $\delta_{h\ max}$ and $\delta_{v\ max}$ values increase significantly from where stiff soil exist at dredge level.

Lastly, for a case with a case with low safety factor against base heave, large movement ($\delta_{h\ max}$ of 3.2% of excavation depth) has been recorded and for cantilever wall, the normalized maximum lateral movement at average 0.36% excavated depth.

## 2.3 PECK'S condition

Peck's work is well known and much used in practice. He used case history data, mostly sheet pile and soldier pile walls, to produce plots of maximum vertical settlement dv max, normalized by the excavation depth H, against distance from the excavation(Long, 2001). A subdivision of the problem was made by separating the data into three zones as follows:

• Zone I: sand/soft to hard clay/average workmanship

• Zone II: very soft to soft clay with either a limited depth of soft clay beneath excavation or a significant depth of soft clay,a but with a high margin of safety against excavation base heave

• Zone III: very soft to soft clay with a low margin of safety against excavation base heave

Values of dv max/H varied between a maximum of 1.0% for Zone I to >2% for Zone III.

Figure below shows a summary of wall movement against soil properties by Peck. Smaller wall movement and ground settlement in stiffer soils (Zone I) compared with softer soil (Zone II)(Peck, 1969).

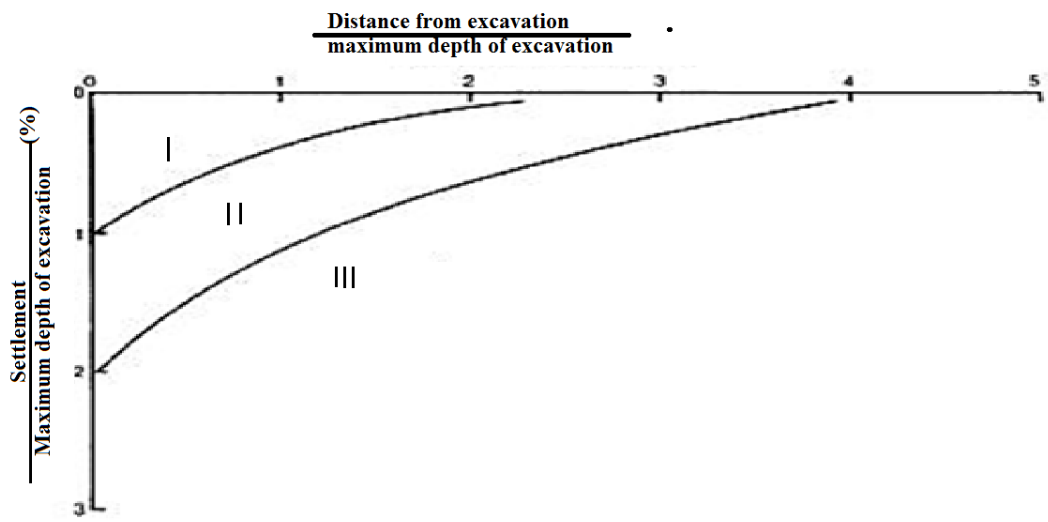


Figure 2: Observed settlement behind excavation(Peck, 1969).

## 2.4 Factors influence retaining wall deformation

There are a few factor that influence the deformation of retaining. The first one is the factor of safety that use in design. The smaller the factor of safety, the weaker the stability of the excavation. Next factor is soil stiffness that will reduce the deformation of retaining wall as the value of the soil stiffness increases (Ou, 2006). The deformation of wall also can be decrease when the stiffness, width and depth of the wall increased. However, (Hsieh,1999) state that increasing in wall stiffness will reduce deformation only at certain degree.

### 2.4.1 Soil stiffness

Soil stiffness or modulus of elasticity can be estimated from many field and laboratory tests results, empirical equation and tabulated values. Many researchers have proposed some empirical equation for calculation Young Modulus,Es. (Brahma & Mukherjee, 2010). Bowles proposed empirical correlation that can be used to estimate Es which are:-

1) Correlation between Es and su for normally consolidated sensitive clay (Bowles,1997) :-

   Es= (200 to 500) * su

2) Correlation between Es for undrained cohesion (Bowles, 1997):-

   E = 600 c u

   cu= undrained cohesion.

3) Correlation between Es and non-cohesive soils (Bowles, 1997):-

   E = 750 + 80 N (t/m2)

   N = SPT value Correlation between Es with standard penetration values.

Es= 0.32N+4.8 for clayey sand (Mpa)

Es=0.3N+1.8 (Mpa) for silts, sandy silt, or clayey silt.

Besides that, a research based on clayey sand, and sand have been made by Webb [15] and he proposed these equations:

Es=0.5N+7.5 for sand (Mpa)

Es=0.33N+1.66 for clayey sand (Mpa)

FEM back analysis have been used to determine the alluvial soils in Taipei(Muntohar & Liao, 2013). The researcher come out with an equation for Young's modulus of elasticity (Es) of the alluvial soil in Taipei which are :-

$E_s$= 5.878 N $^{0.685}$ for clay

$E_s$=5.959 $N^{0.993}$ for silty-sand deposit.

In the U.S. Army Corps of Engineer- Engineer Manual 1110-1-1904 on the settlement analysis. Typical Elastic Moduli of soils based on soil type and consistency are listed on the table below:-

| Soil | $E_s$ (tsf) | $E_s$ (Kn/m²) |
|---|---|---|
| very soft clay | 5 - 50 | 479 - 4788 |
| soft clay | 50 - 200 | 4788 - 19152 |
| medium clay | 200 - 500 | 19152 - 47880 |
| stiff clay, silty clay | 500 - 1000 | 47880 - 95761 |
| sandy clay | 250 - 2000 | 23940 - 191521 |
| clay shale | 1000 - 2000 | 95761 - 191521 |
| loose sand | 100 - 250 | 9576 - 23940 |
| dense sand | 250 - 1000 | 23940 - 95761 |
| dense sand and gravel | 1000 - 2000 | 95761 - 191521 |
| silty sand | 250 - 2000 | 23940 - 191521 |

Table 1: Typical Elastic Moduli of soil

## 2.5 Design of ground anchor

Stiffness of ground anchor also the main factor that influenced the deformation as well as depth and width of the excavation, penetration depth and depth to hard stratum beneath the excavation ,stiffness of the wall, EI and soil coefficient(Wong & Broms, 1989). The vertical faces of the cut need to be protected by temporary bracing system to avoid undesirable displacement of retaining wall. Generally bracing system consists of two elements which are vertical and horizontal element.

The vertical elements (e.g. piles) is installed prior to excavation, and the horizontal elements (e.g. internal bracing or tie-backs) are installed as excavation progresses down, thereby limiting the span length so as to reduce bending moments developed in the vertical elements(Gil-Martín, Hernández-Montes, Shin, & Aschheim, 2012). Peck (1969) compiled measurements of surface settlement profiles, lateral wall deflections, and strut loads for sheet pile and soldier pile walls with cross-lot bracing(Hashash & Whittle, 1996).

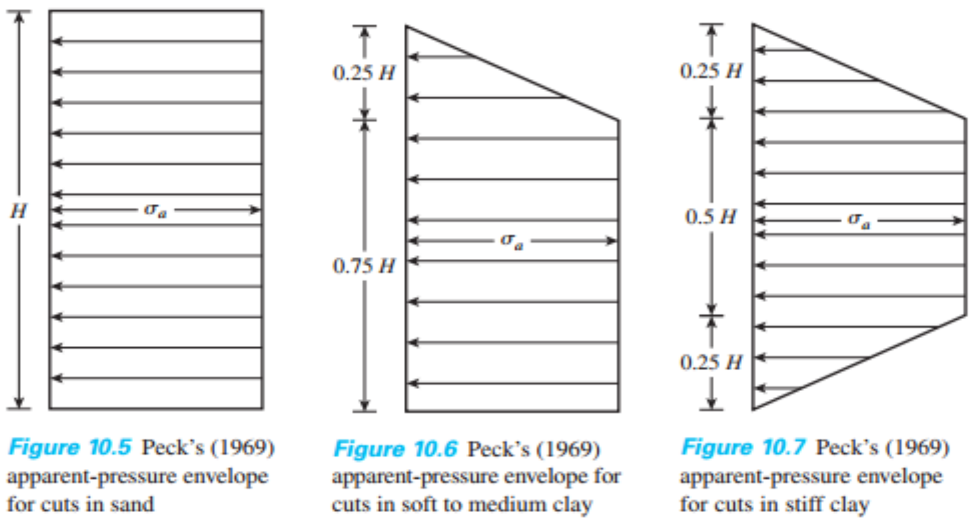


Figure 3 : Peck's(1969) apparent pressure diagram

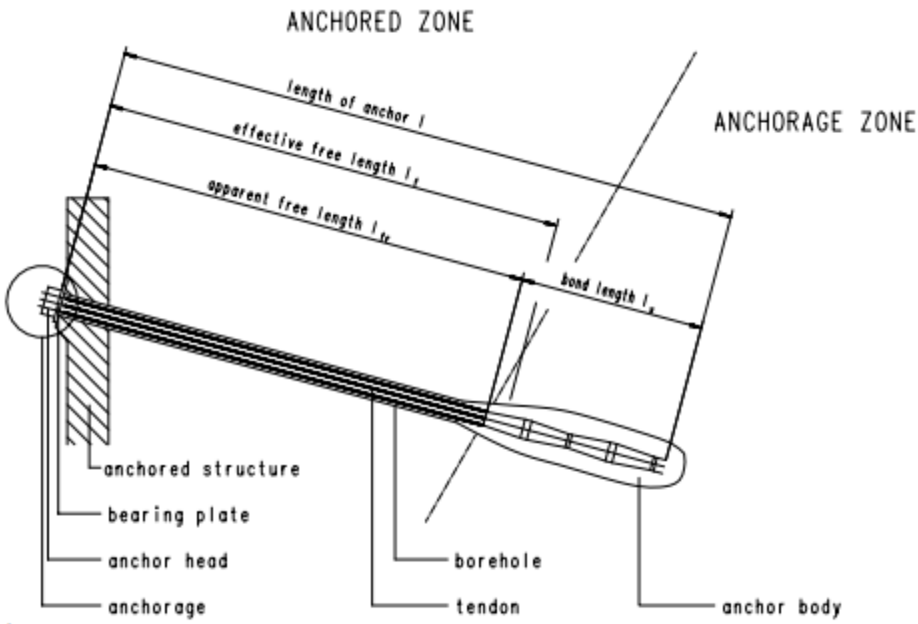


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Figure 3 : Component of ground anchor

Ground anchors consist of three parts which are the head that transmitting anchor force to structure, free length tendon and last part is grouted anchor that transmitted the tensile force to the surrounding ground. Case study has shown that increasing the bond length for typical soil anchors beyond 9 to 12 m does not result in substantial increases in resistance. (Sabatini, Pass, & Bachus, 1999)

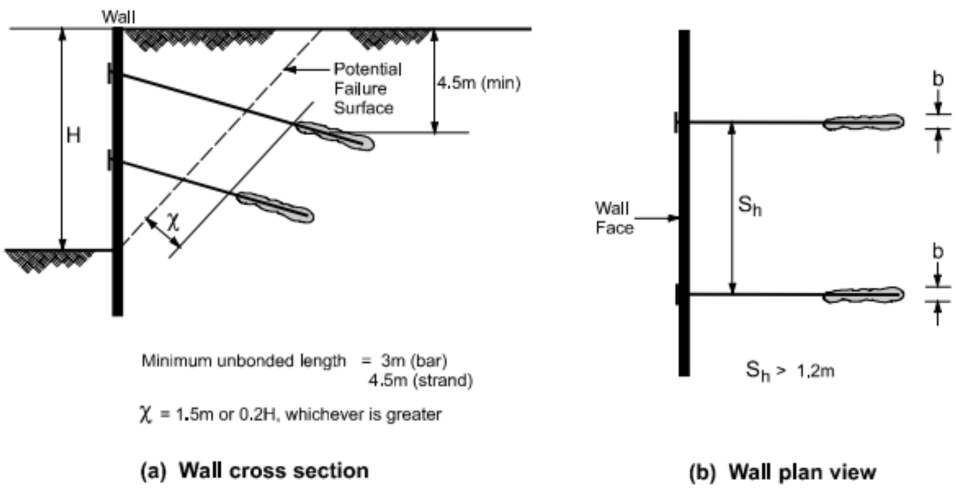



Figure 4 : Vertical and horizontal spacing requirement for ground anchor

**Total Anchor Length between 9 and 18 m:**

Due to geotechnical or geometrical requirements, few anchors for walls or for tiedown structures are less than 9 m long. A minimum unbounded length of 3 m for bar tendons and 4.5 m for strand tendons should be adopted. These minimum unbounded lengths are compulsory to avoid intolerable load reduction resulting from pre-stress losses transfer due to creep in the pre-stressing steel or the soil seating losses during load transfer.

**Ground Anchor Inclination between 10 and 45 degrees:**

Ground anchors are regularly installed at angles of 15 to 30 degrees below the horizontal although angles of 10 to 45 degrees are within the capabilities of most contractors. Regardless of the anchor inclination, the anchor bond zone must be developed in arrears possible slip surfaces and in soil or rock layers to develop the necessary design load. To minimize vertical loads resulting from anchor lock-off loads, anchors should be installed as close to horizontal as possible. However, grouting of anchors installed at angles less than 10 degrees is not common unless special grouting techniques are used (Sabatini et al., 1999)

## 2.6 Finite Element method

The lateral displacement, the settlement, and the heave of a deep excavation in soft clay can be estimated with the finite element method (FEM)(Wong & Broms, 1989). The finite-element method also provides a framework for performing numerical experiments to evaluate the effects of individual parameters on ground movements(Hashash & Whittle, 1996). The finite element discretization must be performed to allow for three different types of equilibrium equations to be satisfied. The beam on elastic foundation use differential to analyze the deflection, slope, moment, and shear, respectively(Krabbenhoft, Damkilde, & Krabbenhoft, 2005). The beam element resists loads by bending and shearing that corresponding deformation would be in the form of rotation and translation.

PLAXIS has been successfully used for the modeling and analysis of different types of retaining wall structures under varying loading conditions and the predicted performance of the walls were verified by field measurements(Bilgin, 2010). It is essential for finite element analysis of geotechnical problem to choose an appropriate soil constitutive model. Few basic and practical soil constitutive model are Hooke's law, Mohr- Coulomb, Drucker Prager and Duncan- Chang model. Mohr-Coulomb mode is used for yield criterion and Drucker Prager is used for plastic potential while Duncan- Chang model defined the relationship between the principal stress and tangential elastic modulus (Li et al., 2008). Common practice in geotechnical analysis of cohesive-frictional soils we assume yielding to be governed by the Mohr–Coulomb yield criterion(Krabbenhoft et al., 2005).The Mohr-Coulomb model is one of the models that has been used to model the constitutive relationship of the soil behavior. It is an elastic perfectly plastic model and a combination of Hooke's law and Coulomb's failure criterion. Five parameters involved in the model which are Young's Modulus (E), Poisson's Ratio (v), friction angle ($\phi$), cohesion (c) and dilatancy angle ($\psi$). The model has limited capabilities in determining the deformation behavior before failure and if used in excavation or retaining wall analysis it may lead to large pit bottom heave. However, the model can be used to predict the deformation but accuracy might be less than 50% (Brinkgreve, 2005).

## 2.7 Site monitoring

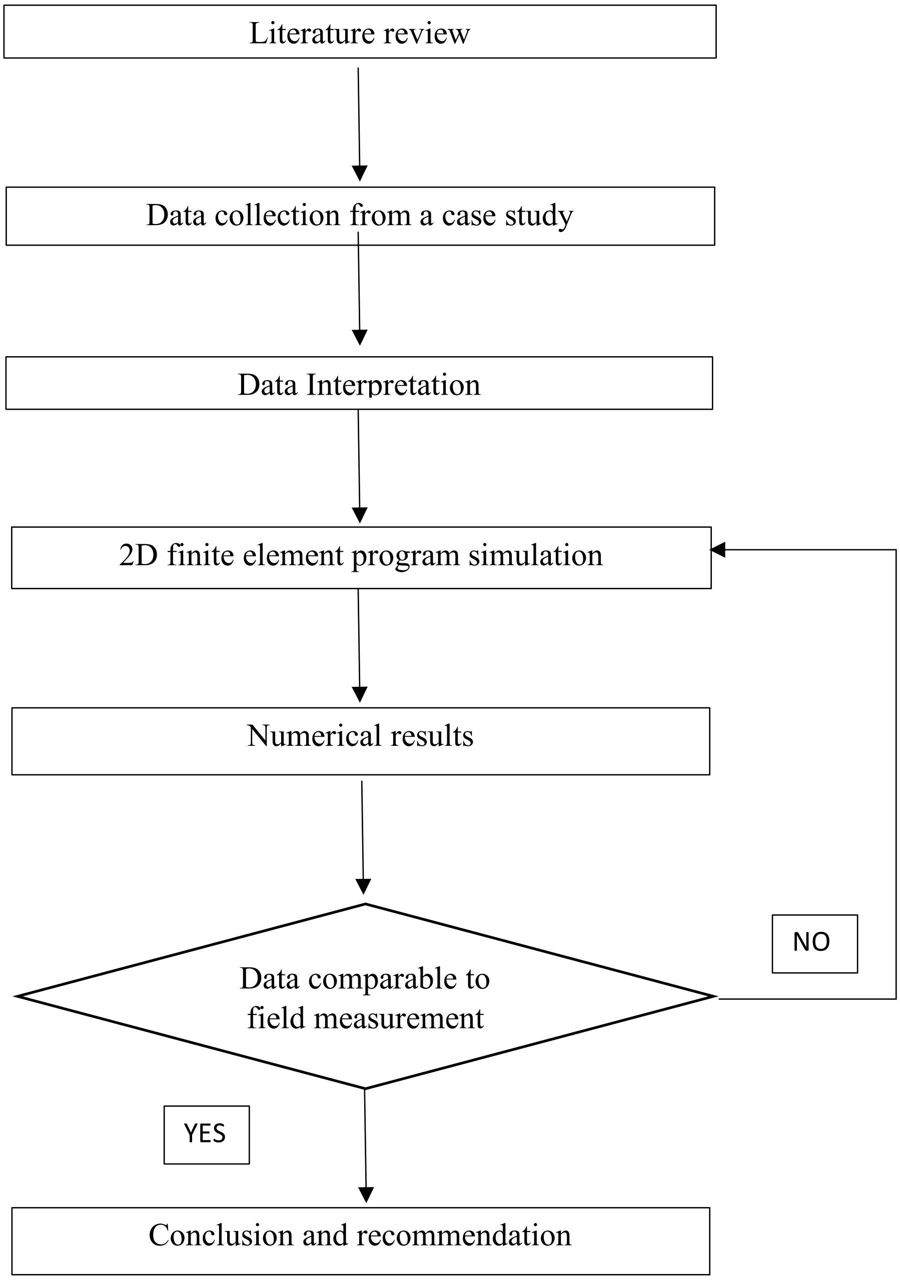
Inclinometer is an instrumental that has been used to measure landslide movement, monitoring the deflection of piles and retaining walls and also to monitor horizontal movement of embankments. The typical inclinometer components consist of permanent installed guide casing, a portable probe with gravity sensing transducer, a portable readout unit and cable that link the read out unit with the probe. Casing with four orthogonal grooves is installed in a borehole in the ground or within a retaining wall. The grooves are designed to fit the wheels of the inclinometer probe. The angle of the probe from the vertical axis is measured in both directions with the use of a sensitive gravity pendulum, tilt meters, or a servo accelerometer. The deflections are calculated automatically from this angular measurement and from the distance between the wheels.

# CHAPTER 3

# 3 METHODOLOGY

The important thing about research study is to understand the fundamental of braced excavation system and the analysis of lateral earth pressure acting on braced excavation wall. Therefore, the literature review of this project aims to give the author a better understanding on lateral earth pressure, design of struts, and finite element method for geotechnical engineering.

The flowchart below shows the project methodology.



- Data collected from a case study of Damansara Uptown Retail project will be used. This project consists of 4 level basement car park and the construction phase are divided into two which are retail and residential area. The retaining wall geometry, soil characteristics and construction procedure for the horizontal deflection analysis of this project will be according to the case study of Damansara Uptown Retail project phase 1( retail area).

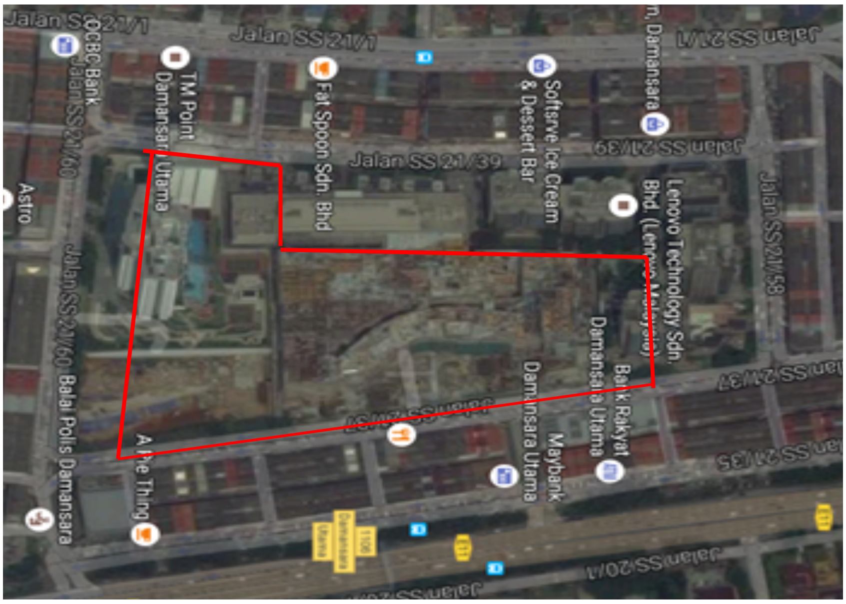



Figure 5: location of Damansara Uptown Retail Project

The soil investigation result from the case study is used to plot the soil strata for geometry input in the PLAXIS 7.2. The data from monitoring equipment on site will be used to compare with the analysis result.

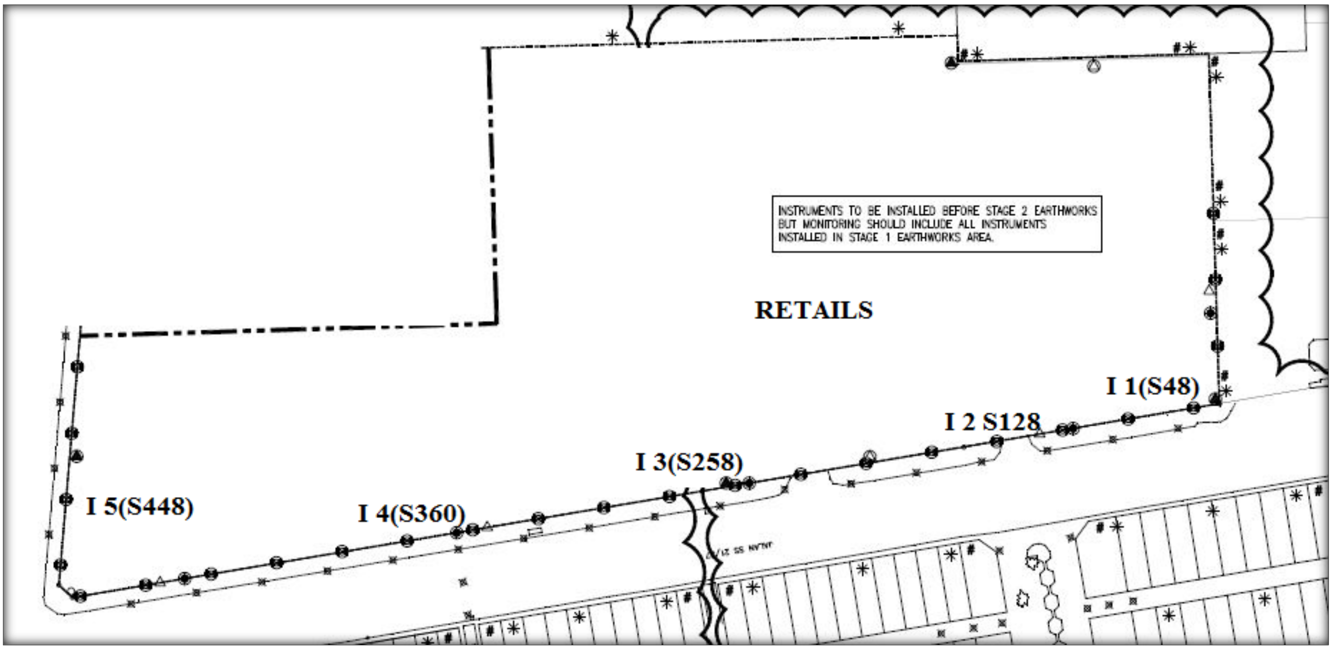



Figure 6: location of inclinometer for phase 1(retail area)

| LEGEND | INSTRUMENT | EXISTING INSTRUMENTS AT RESIDENTIAL | EXISTING INSTRUMENTS AT RETAILS | NEW INSTRUMENTS AT RETAILS | PROVISIONAL |
|---|---|---|---|---|---|
| # | TILTMETER | 3 | 9 | 10 | - |
| ✳ | BUILDING SETTLEMENT MARKER | 10 | 31 | 8 | 6 |
| ⊠ | GROUNG SETTLEMENT MARKER | 18 | 24 | 12 | 6 |
| ⊕ | INCLINOMETER | 6 | 6 | - | - |
| △ | WATER STANDPIPE | 3 | 2 | 2 | 2 |
| ⊚ | EXISTING STANDPIPE | 3 | 2 | - | - |
| ● | EXISTING PIEZOMETER | 1 | 1 | 3 | |

table 2: total of instrument use for monitoring purpose

## 3.1 Soil interpretation

### 3.1.1 Soil stratification

Soil investigation for mixed development in Damansara Uptown consist of 35 boreholes. Due to large excavation area, this project will focus only at location that has been label in the figure 7. Based on several borehole data, soil stratification can be classified as below:

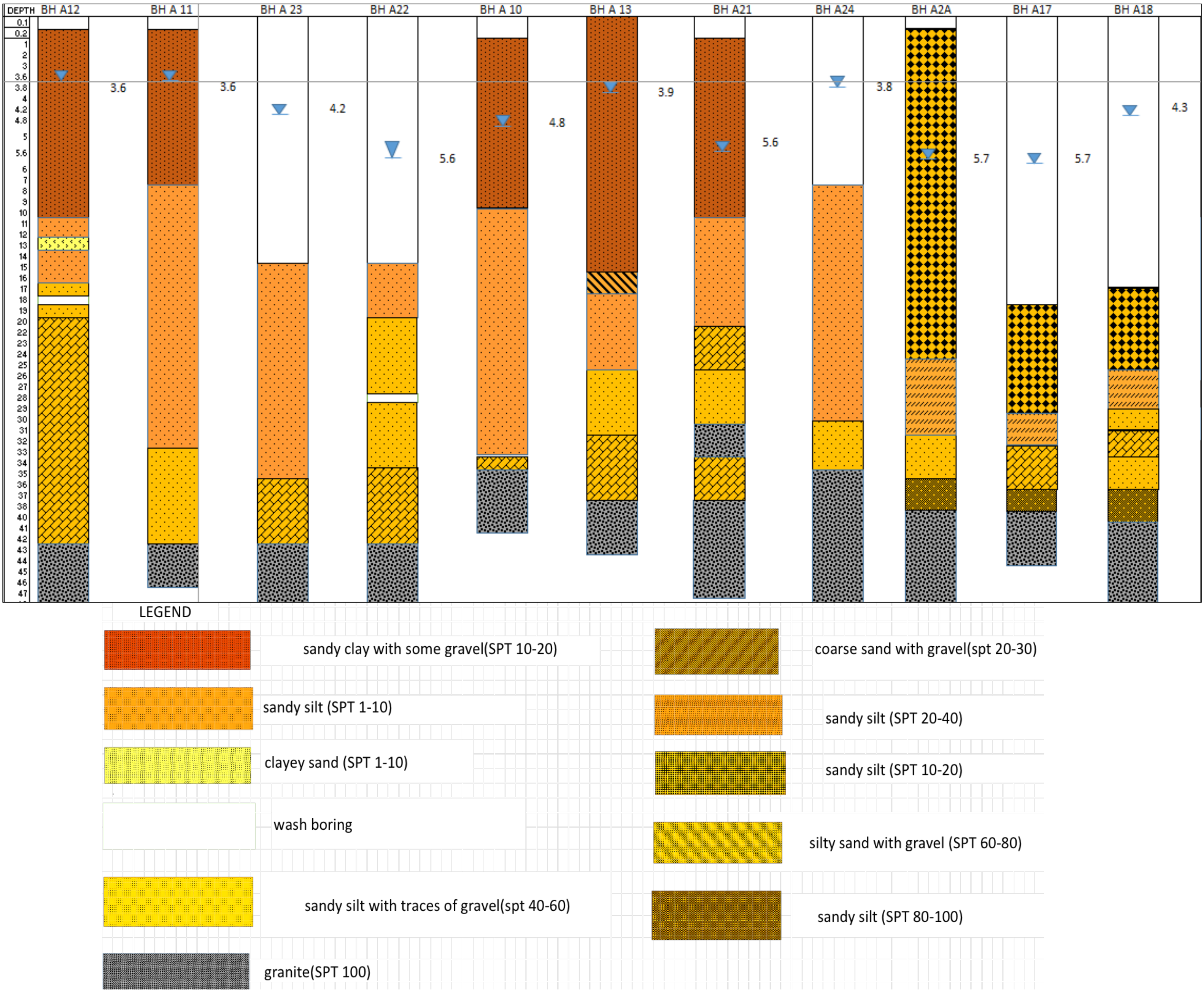



Figure 7 : soil stratigraphy

| STRATUM | SPT(N) | THICKNESS(m) | TOP LEVEL (mOD) |
|---|---|---|---|
| sandy silt | 0-10 | 9.5 to 14 | 0 to -16.5 |
| sandy silt | 10-20 | 8 to 21 | -16.5 to -19 |
| sandy silt | 20-40 | 1.5 to 3 | -24 to -29 |
| silty sand | 40-60 | 2 to 12.5 | -29 to -31 |
| silty sand | 60-80 | 1.5 to 12.5 | -30.5 to -38.5 |
| silty sand | 80-100 | 4 to 12 | -35 to -40 |
| granite | | 7 to 9 | -40 to -54.6 |

Table 3 : Summary of soil stratigraphy

### 3.1.2 Ground water level

The groundwater level measured from site is in between -1.9 mOD to -5.7 mOD. For design purposes, the average ground water level is taken at -3.0mOD.

### **3.1.3** Result of laboratory test

The result of undisturbed samples from the borehole log will be used to calculate the soil parameter input for PLAXIS analysis.

FORMULA USE:

**Degree of saturation, Se= w*Gs**

w = moisture content

Gs= specific gravity

**Unit weight , $\gamma$ =**

**Unsaturated unit weight , $\gamma_{unsaturated} = [( Gs*\gamma_w ) / (1+e)]$**

$\gamma_{w=}$ unit weight of water = 9.81

Gs= specific gravity

e = void ratio

**Saturated unit weight , $\gamma_{saturated} = [ (Gs+e) / (1+e)]* \gamma_w$**

$\gamma_{w=}$ unit weight of water = 9.81

Gs= specific gravity

e = void ratio

For the initial Young Modulus of each layer, correlation between Es with standard penetration values proposed by (Bowles,1997) for silt , sandy silt or clayey silt is used.

$$Es= 0.3\ N + 1.8\ (Mpa)$$

For granite, the value of young modulus , E is taken from the result of uniaxial compression test for rock from the case study .Summary of the laboratory test result and calculation are shown in the table below: -

| | Average thickness (m) | Unit weight,γ (Kn/m³) | γ w (kN/m²) | degree of saturation, Se[%] | moisture content[%] | specific gravity,Gs | void ratio,e | γ unsat (kN/m²) | γ sat (kN/m²) | c(kN/m²) | Ø[°] | ψ[°] | young modulus , E (Kn/m²) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| sandy silt | 12.000 | 29.788 | 9.810 | 97.43 | 23.96 | 4.066 | 0.660 | 24.031 | 27.931083 | 14 | 25.5 | 0 | 3300 |
| sandy silt | 12.000 | 21.508 | 9.810 | 95.200 | 30.670 | 3.104 | 0.850 | 16.460 | 20.966942 | 13 | 25.5 | 0 | 6300 |
| sandy silt | 2.500 | 42.416 | 9.810 | 94.500 | 17.190 | 5.497 | 0.490 | 36.194 | 39.420281 | 14 | 27 | 0 | 10800 |
| silty sand | 5.500 | 22.083 | 9.810 | 94.26 | 29.67 | 3.177 | 0.830 | 17.031 | 21.47986 | 14 | 25 | 0 | 16800 |
| silty sand | 2.000 | 25.927 | 9.810 | 92.590 | 25.210 | 3.673 | 0.740 | 20.707 | 24.878774 | 14 | 28 | 0 | 22800 |
| silty sand | 7.000 | 19.821 | 9.810 | 89.430 | 30.370 | 2.945 | 0.900 | 15.204 | 19.850702 | 13 | 24.5 | 0 | 28800 |
| granite | 8.000 | 0.000 | 9.810 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | (25-65.7) E+6 |

## 3.2 Analysis using Finite Element PLAXIS 7.2

Analysis of retaining wall by the finite-element method is by using Plaxis version 7.2 software. The analysis consists of different stages of excavation. The Mohr-Coulomb model was selected in this analysis. Modeling in Plaxis will be in three stages and as follows:

### 3.2.1 Geometry and input (preprocessing)

#### 3.2.1.1 Geometry of the model

The model consists of 7 layer of soil based on the soil stratigraphy obtain from the borehole data. The soil parameter of each layer of soil are assign based on the laboratory result and the retaining wall based on data that has been calculated at 4.2.2.

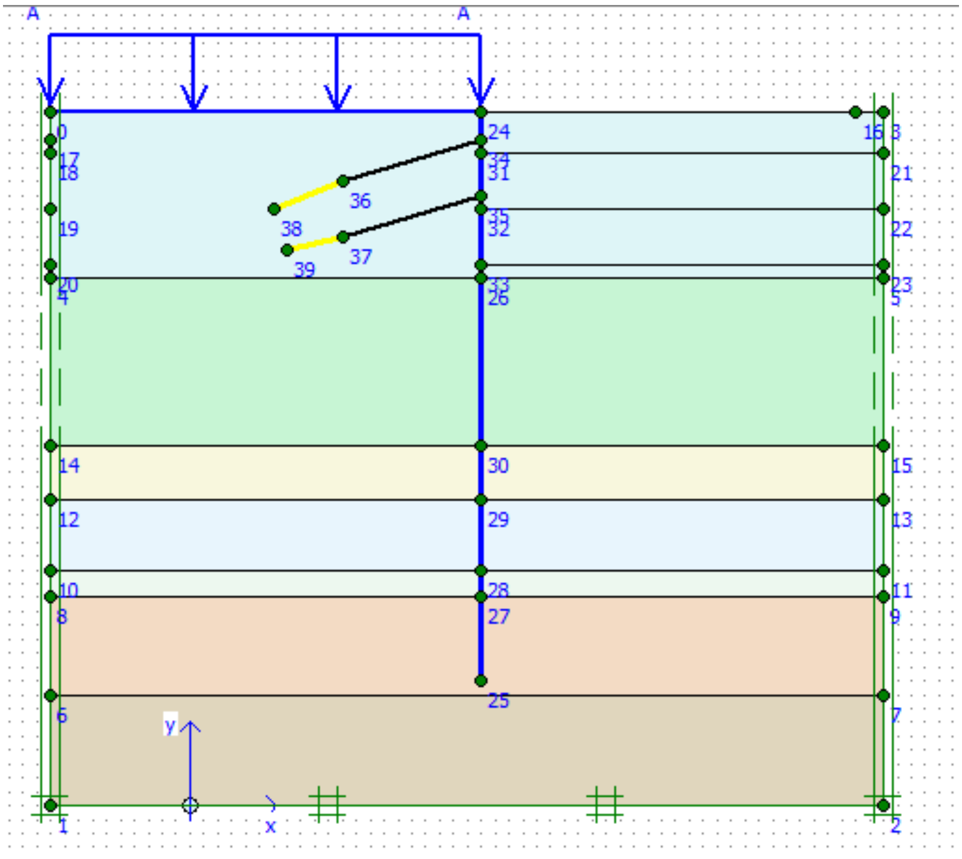


Figure 8 : Geometry of the soil model

### 3.2.1.2 Define the material properties

#### 3.2.1.2.1 Soil properties

For the first design, the soil properties will be based on Mohr Coulumb model with undrained behaviour of soil. The initial Young Modulus is calculated based on the correlation made by (Bowles,1997) for silty sand. For Young Modulus of granite, the value taken from the uniaxial compression test for rock. The unsaturated and saturated unit weight are taken from the result and calculation that have been calculated at 3.1.3.

For the analysis, young modulus of the sandy silt are vary until the deformation of the retaining wall have almost the same result as inclinometer 5.

| STRATUM | SPT(N) | Initial Young modulus, Es (Kn/m²) | 10% increase from initial ,Young modulus, Es (Kn/m²) | 20% ,Young modulus, Es (Kn/m²) | 30%, Young modulus, Es (Kn/m²) |
|---|---|---|---|---|---|
| sandy silt | 0-10 | 3300 | 3630 | 3960 | 4290 |
| sandy silt | 10-20 | 6300 | 6930 | 7560 | 8190 |
| sandy silt | 20-40 | 10800 | 11880 | 12960 | 14040 |
| silty sand | 40-60 | 16800 | 18480 | 20160 | 21840 |
| silty sand | 60-80 | 22800 | 25080 | 27360 | 29640 |
| silty sand | 80-100 | 28800 | 31680 | 34560 | 37440 |
| granite | | 25 E+6 | 25 E+6 | 25 E+6 | 25 E+6 |

For the second analysis using hardening soil model, the soil properties will be based on design guideline given from the consultant at site. The following minimum design criteria must be satisfied for the alternative design. The design value used for design should not exceed the following values or range:-

| Material | Effective Cohesion, c' (kPa) | Effective Friction Angle, $\phi'$ ($^o$) |
|---|---|---|
| **Sandy CLAY SPT-N < 20** | 2 | 28 |
| **Sandy SILT SPT-N < 20** | 2 | 30 |
| **Sandy SILT SPT-N > 20** | 2 | 32 |

| Subsoil Layers | Effective Young's Modulus, E' (Kn/$m^2$) | Unloading/ Reloading Stiffness, $E'_{ur}{}^{ref}$ (Kn/$m^2$) |
|---|---|---|
| **Soil layer with 5 < SPT-N < 10** | 8,600 to 15,600 | 25,800 to 46,800 |
| **Soil layer with 10 ≤ SPT-N < 20** | 17,300 to 33,000 | 51,900 to 99,000 |
| **Soil layer with 20 ≤ SPT-N < 30** | 34,700 to 50,400 | 104,100 to 151,200 |
| **Soil layer with 30 ≤SPT-N < 50** | 52,100 to 85,200 | 156,300 to 255,600 |
| **Soil layer with SPT-N ≥ 50** | 86,900 | 260,700 |

**In the PLAXIS Material Models Manual 2010 the default setting used in PLAXIS for $E_{50}^{ref}$ is $E_{ur}^{ref}$ equal to $3E_{50}^{ref}$**

| Subsoil Layers | E' (Kn/m$^2$) | $E_{50}^{ref}$ (Kn/m$^2$) | $E'_{ur}{}^{ref}$ (Kn/m$^2$) |
|---|---|---|---|
| **Soil layer with 5 < SPT-N < 10** | 8,600 to 15,600 | 8600 to 15600 | 25,800 to 46,800 |
| **Soil layer with 10 ≤ SPT-N < 20** | 17,300 to 33,000 | 17300 to 33000 | 51,900 to 99,000 |
| **Soil layer with 20 ≤ SPT-N < 30** | 34,700 to 50,400 | 34700 to 50400 | 104,100 to 151,200 |
| **Soil layer with 30 ≤SPT-N < 50** | 52,100 to 85,200 | 52100 to 85200 | 156,300 to 255,600 |
| **Soil layer with SPT-N ≥ 50** | 86,900 | 86900 | 260,700 |

#### **3.2.1.3** RETAINING WALL

A basement wall was constructed ,consists 1000mm diameter secant hard soft pile wall with maximum spacing of 765mm centers. The minimum design toe level is -28.5 mOD. The site layout is as figure below.

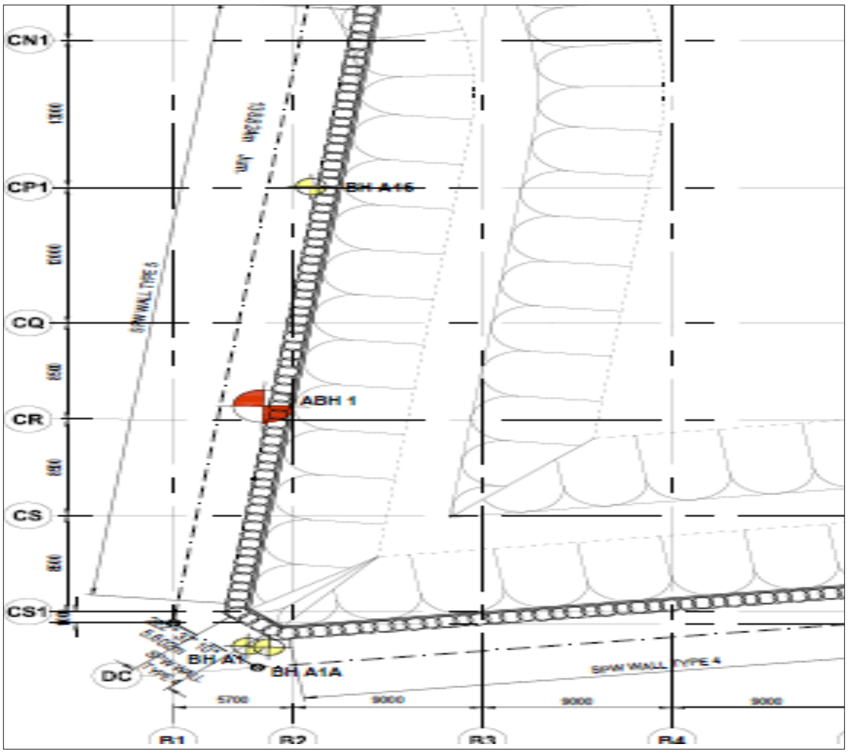



*Figure 9: site layout of secant pile wall type 5*

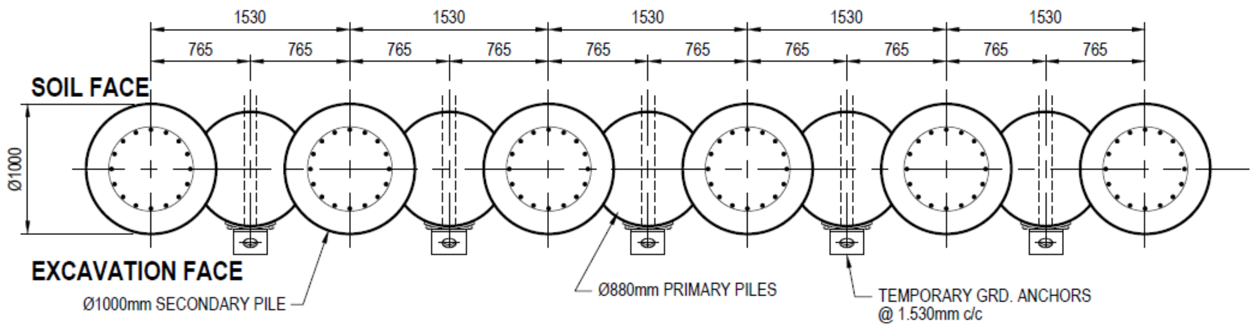



Figure 10 : Detail of secant pile wall type 5

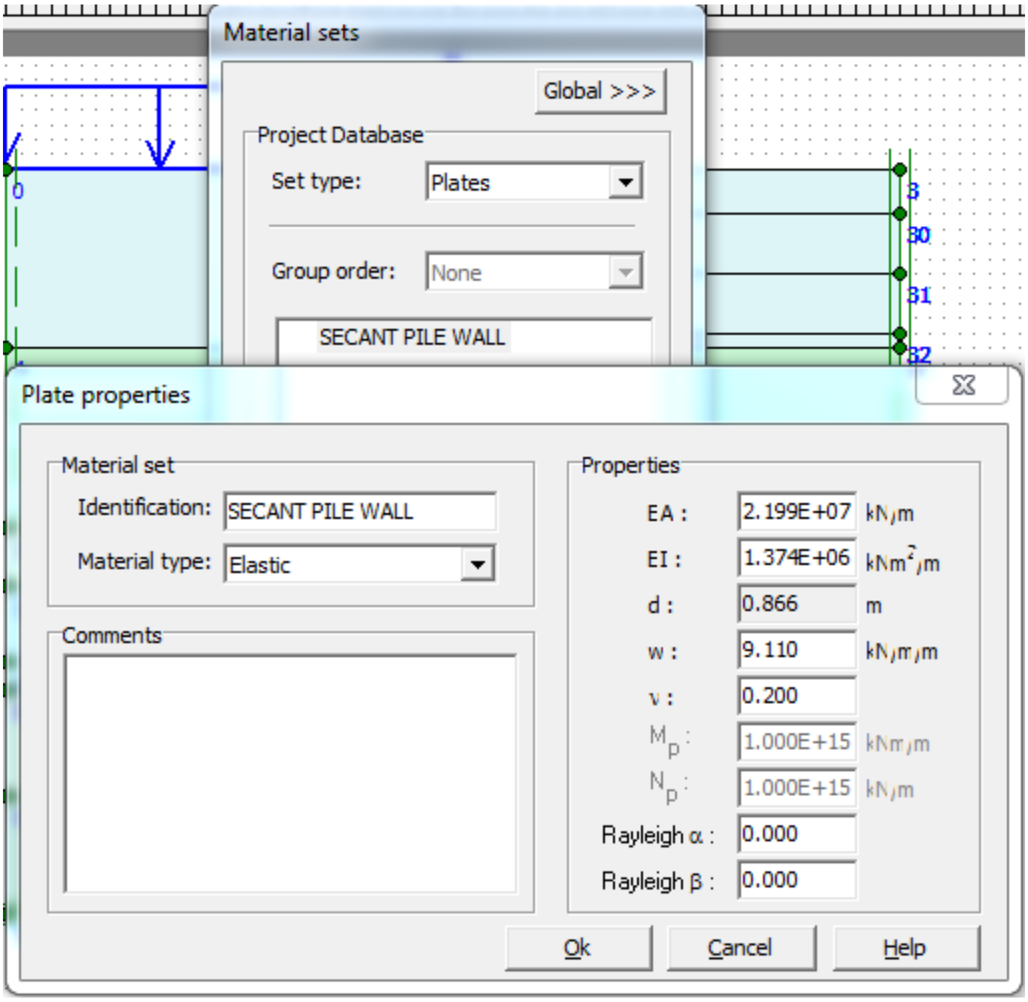



Figure 11 : input for retaining wall

FORMULA USE:

### 3.2.1.4 Properties per pile

Bending stiffness, EI=

I=Moment of inertia = $(\pi r^4/4)$

E= Young modulus of the wall material

axial stiffness ,EA =

E = Young modulus of the wall material

A = cross sectional area = $\pi r^2$

Weight of the plate, W= $\gamma_{concrete}$ * d

According to BS 8110 :1997 clause 4.1.8.1 characteristic strength of concrete, concrete grade C35 and C40 are recommended. ACI- 318 code suggested that for normal weight concrete , the young modulus of the concrete can be calculated by using Ec= 4700√fc'(Weng, Yen, & Wang, 2007).Calculated Ec= 4700√35N/mm$^2$= 27.805 Kn/mm$^2$ ≈ 28+6 Kn/m$^2$ . The diameter of hard soft pile is 1000mm. For the specific weight of the concrete, $\gamma_{concrete}$ = 24 kn/m$^3$

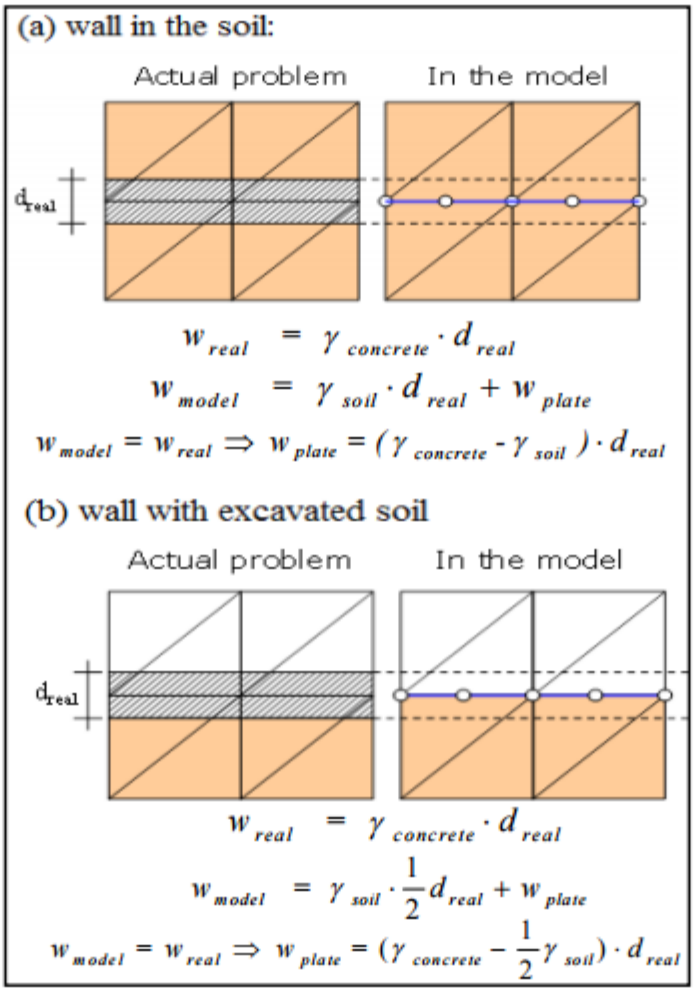
EI= (28+6 Kn/m$^2$)*(π*0.5 m$^4$/4) = 1.37446e+6 kn/m$^2$

EA= (28e+6 Kn/m$^2$)*( π* 0.5m$^2$) = 21.991e+6 Kn/m$^2$

Weight = 24 Kn/m$^3$*(1m)= 24 Kn/m$^2$

### 3.2.1.5 Plate properties

$W_{plate} = W_{real} – W_{soil}$ (Brinkgreeve& Shen. 2011)




Therefore, W plate = ($\gamma_{concrete\ -1/2}\gamma_{soil}$ )* area *d

W plate = (24-(29.79/2) Kn/$m^3$) *( π* 0.5$m^2$) *1=7.1516Kn

#### 3.2.1.6 Ground anchor

Due to geotechnical or geometrical requirements, few anchors for walls or for tiedown structures are less than 9 m long with an angle 20$^{o}$ installed (Sabatini et al., 1999). Standard diameter of strand anchor is 12.9 mm with an average value elastic modulus equal to 195 Kn/mm$^2$. For one strand, the stiffness EA is: -

EA= 195 Kn/mm$^2$ x ($\pi$* 6.45$^2$) = 2.5486 x 10$^4$ Kn

Assume the strand use equal to 10, EA= 195Kn/mm$^2$ x(10* $\pi$* 6.45$^2$)= 2.5486x10$^5$ kN

The grout material properties are as follows: the maximum diameter of grout is 160mm ; cross sectional area of the grout = 20,106 mm2, the average compressive strength of the grout = 20 MPa, the tensile strength of the grout = 2.0 MPa, the tensile strain failure = 1.0 x 10 $^4$ by ( Neville ,1996) and the average elastic modulus of the grout = 2.1 x 10$^7$ kN/m2 obtained from the following formula(Kim, Park, & Kim, 2007):

Ec= 4:73 $\sqrt{}$ $f_{ck}$

where Ec is expressed in GPa and fck in MPa, as reported by (Neville ,1996)

EA= 2.1 x 10$^7$ kN/m2 x 20,106 mm2= 4.25x 10$^{12}$ kN

### 3.2.2 Calculation stage (solving)

3.2.2.1 Generate the meshes

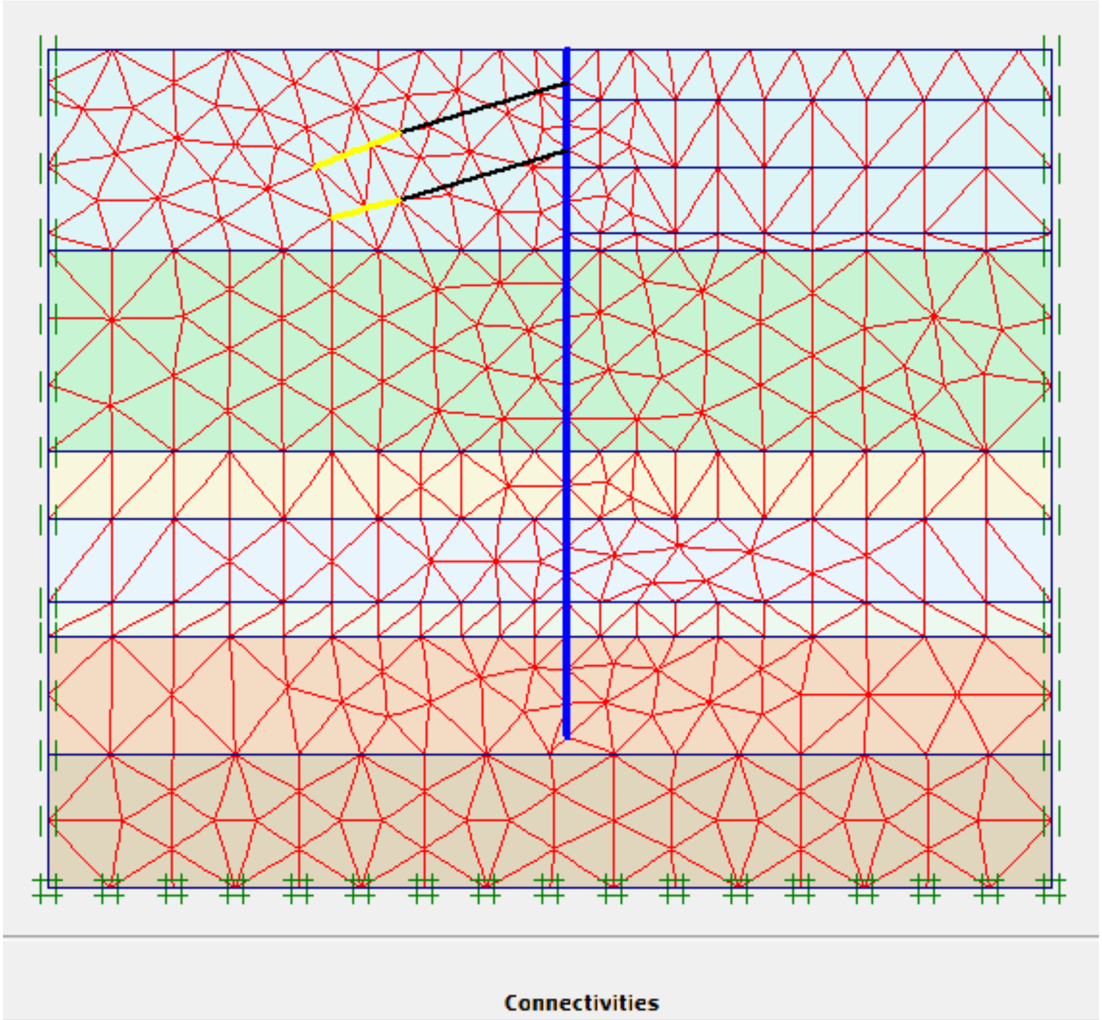



Figure 12 : Mesh Condition

### 3.2.2.2 Define the initial stress ( initial soil stress and phreatic level)

**Phreatic level**

Phreatic level indicates the direction of groundwater movement in unconfined aquifer and phreatic surface indicates the location of pore water pressure is under atmospheric condition.

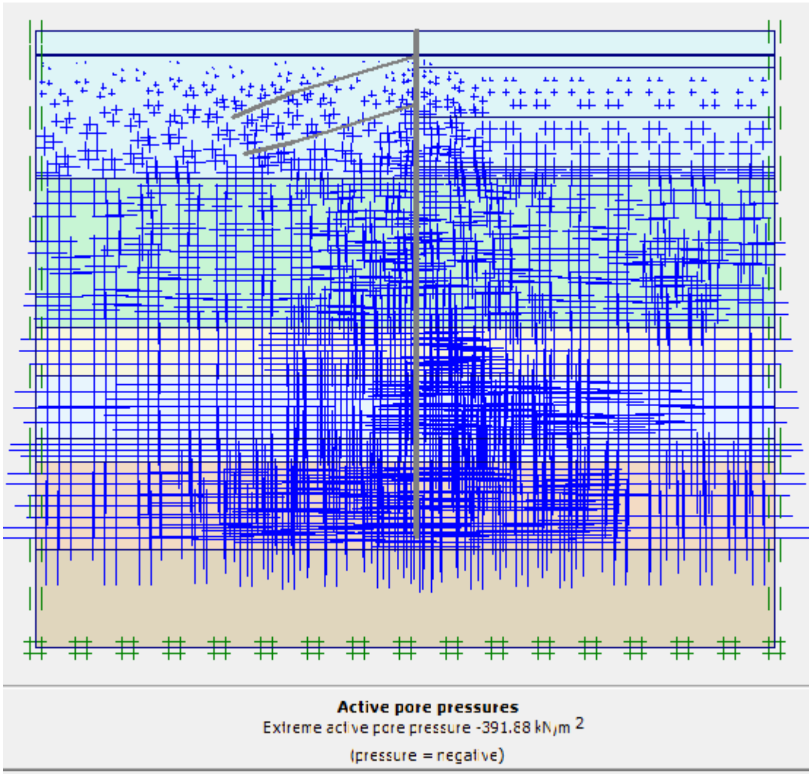



Figure 13 : negative pore pressure

The higher the negative pore pressure, the higher the effective stress. Increasing in negative pore pressure will increase the available shear strength and effective stress within the soil mass that indirectly improve the stability of the slope. Figure below show the effective stress of the soil.

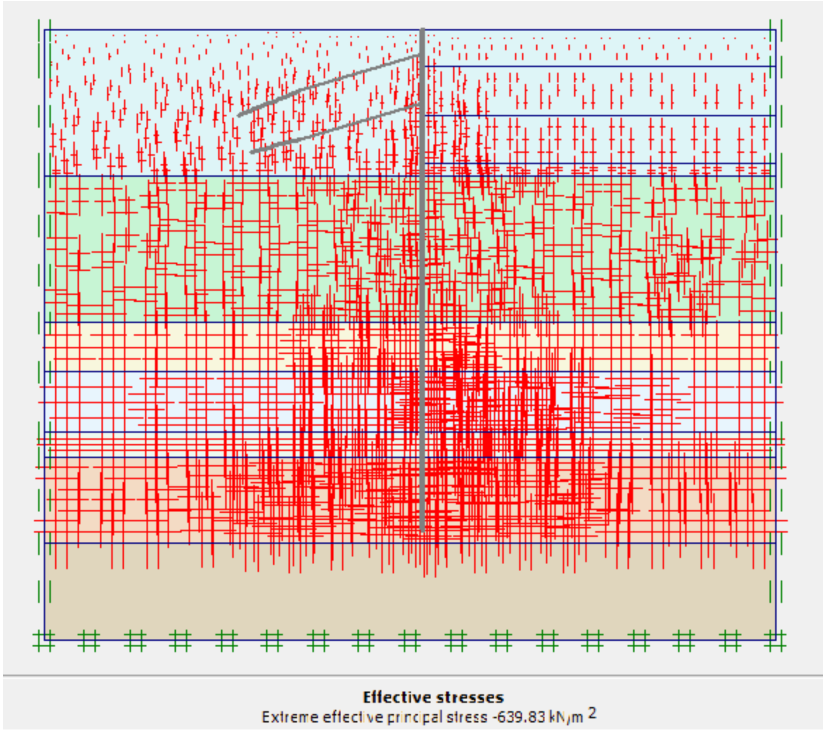
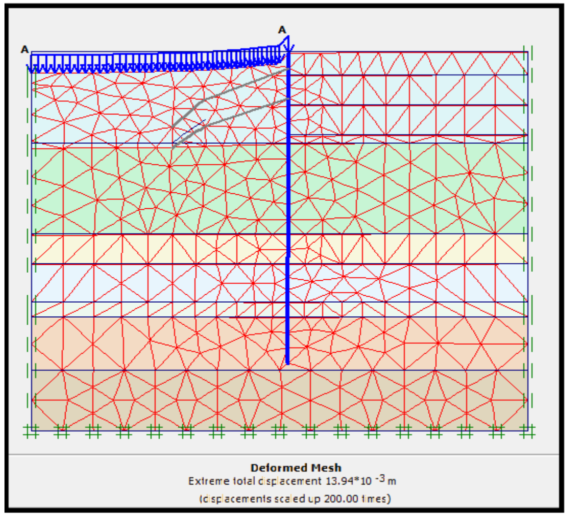


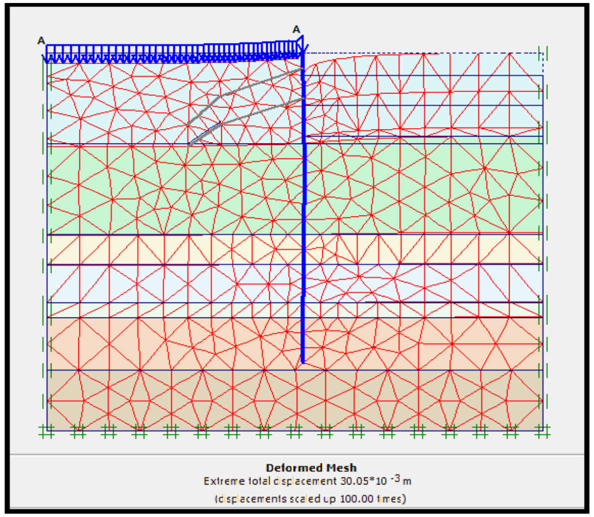
Figure 14 : effective stresses of the soil equal to -639.49kN/m$^2$

Calaculation of the retaining wall deformatin will be based on the construction sequece .

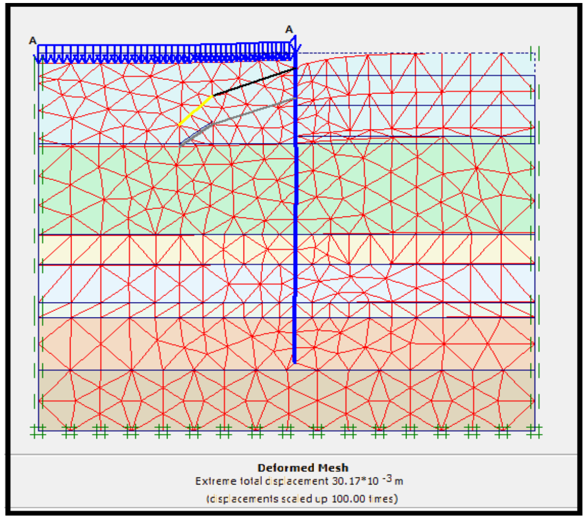
CONSTRUCTION SEQUENCE



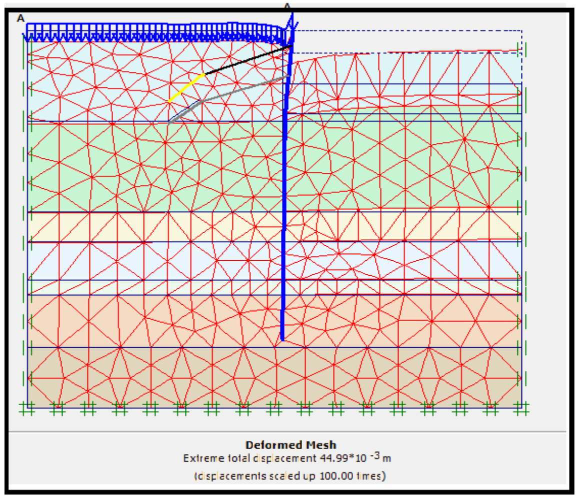

**1) Secant pile wall installation**



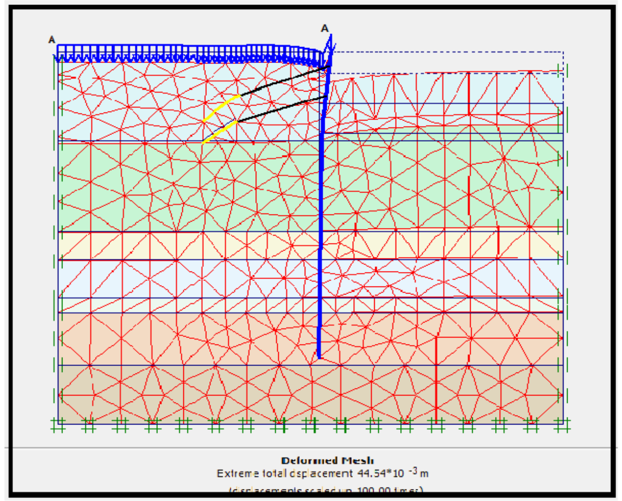

**2) First excavation to approximately -3.0 m**



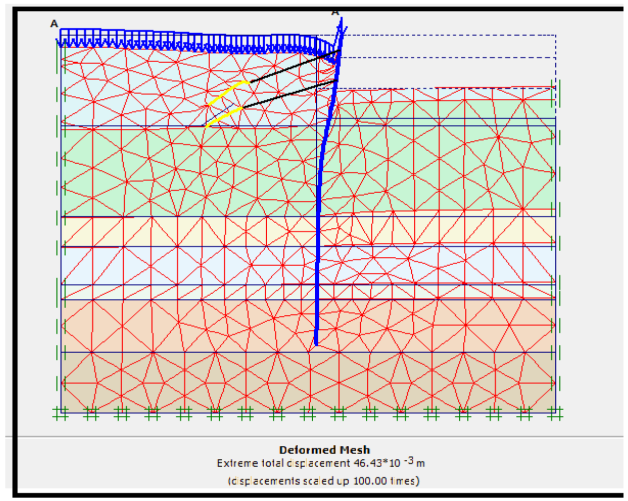

**3) installtion of ground anchor at -2.1 m**




**4) Second excavation to -6.5 m**




**5) Installation of ground anchor at -5.5 m**




**6) Third excavation to approximately -11.75 m**

In construction, flow of the activities is one of the main important aspects to be taken seriously because it involves costing, designing, safety, etc. For this project, the assumed construction sequence of excavation for the construction of the retaining wall as follows:

- Stage 1 : Secant Pile Wall Installation
- Stage 2 : First excavation to approximately -3.0 mOD
- Stage 3 : Installation of ground anchor at -2.1 mOD
- Stage 4 : Second excavation to approximately -6.5 mOD
- Stage 5 : Installation of second temporary support at -5.5mOD
- Stage 6 : Third excavation to approximately -11.75 mOD

| Identification | Phase no. | Start from | Calculation | Loading input | Time | Water | F |
|---|---|---|---|---|---|---|---|
| Initial phase | 0 | 0 | N/A | N/A | 0.00 ... | 0 | [illegible] |
| installation of sec... | 1 | 0 | Plastic | Staged construction | 0.00 ... | 1 | [illegible] |
| excavation (3 m) | 2 | 1 | Plastic | Staged construction | 0.00 ... | 2 | [illegible] |
| ground anchor in... | 3 | 2 | Plastic | Staged construction | 0.00 ... | 3 | [illegible] |
| excavation (6.5 m) | 4 | 3 | Plastic | Staged construction | 0.00 ... | 4 | [illegible] |
| ground anchor | 5 | 4 | Plastic | Staged construction | 0.00 ... | 5 | [illegible] |
| excavation (11.7... | 6 | 5 | Plastic | Staged construction | 0.00 ... | 6 | [illegible] |

### 3.3 Grantt chart and key milestone of project

The table show the project Gantt chart and key milestone of this project to ensure the project run smoothly within the time frame.

FYP 1

| AVTIVITIES | W1 | W2 | W3 | W4 | W5 | W6 | W7 | W8 | W9 | W10 | W11 | W12 | W13 | W14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| selection of project title | | | | | | | | | | | | | | |
| preliminary research work and literature review | | | | | | | | | | | | | | |
| submission of extended proposal (first draft) | | | | | | | | | | | | | | |
| submission of extended proposal (final draft) | | | | | | | | | | | | | | |
| research methodology | | | | | | | | | | | | | | |
| preparation for proposal defense | | | | | | | | | | | | | | |
| proposal defense | | | | | | | | | | | | | | |
| submission of interim draft report | | | | | | | | | | | | | | |
| submission of interim report | | | | | | | | | | | | | | |

gantt chart key milestone

Table 4 : Gantt chart and key milestone of FYP1

FYP 2

4.4.2 Project Gantt chart (FYP 2)

| No. | Detail/Week | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Interpretation of database | | | | | | | | | | | | | | |
| 2. | PLAXIS 7.2 simulation | | | | | | | | | | | | | | |
| 3. | Comparison simulation result with inclinometer | | | | | | | | | | | | | | |
| 4. | Data Analysis | | | | | | | | | | | | | | |
| 5. | Pre-SEDEX | | | | | | | | | | | | | | |
| 6 | Viva | | | | | | | | | | | | | | |

Table 5: Gantt chart and Key Milestone for FYP2

# CHAPTER 4

# 4 RESULT AND DISCUSSION

Analysis has been done in Chapter 3. The result of the analysis will be as follows:

I. Horizontal wall deflection under different level of excavation
II. Comparison horizontal wall deflection soil coefficient (PLAXIS 7.2) with inclinometer.
III. Comparison between Mohr coulomb model, Hardening Soil model and inclinometer.

Table below show the value of Young Modulus use to analyse the horizontal deflection of retaining wall and compared with the inclinometer.

| STRATUM | SPT (N) | Young modulus, | 10% ,Young modulus, | 20% ,Young modulus, | 30%, Young modulus, | 50%Young modulus, | 100%Young modulus, | 150%Young modulus, | 200% Young modulus, | 250% Young modulus, | 300% Young modulus, | 350% Young modulus, | 450% Young modulus, | 550% Young modulu |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Es (Kn/m²) | Es (Kn/m²) | Es (Kn/m²) | Es (Kn/m²) | Es (Kn/m²) | Es (Kn/m²) | Es (Kn/m²) | Es (Kn/m²) | Es (Kn/m²) | Es (Kn/m²) | Es (Kn/m²) | Es (Kn/m²) | Es (Kn/ |
| sandy silt | 0-10 | 3300 | 3630 | 3960 | 4290 | 4950 | 6600 | 8250 | 9900 | 11550 | 13200 | 14850 | 18150 | 21450 |
| sandy silt | 10-20 | 6300 | 6930 | 7560 | 8190 | 9450 | 12600 | 15750 | 18900 | 22050 | 25200 | 28350 | 34650 | 40950 |
| sandy silt | 20-40 | 10800 | 11880 | 12960 | 14040 | 16200 | 21600 | 27000 | 32400 | 37800 | 43200 | 48600 | 59400 | 70200 |
| silty sand | 40-60 | 16800 | 18480 | 20160 | 21840 | 25200 | 33600 | 42000 | 50400 | 58800 | 67200 | 75600 | 92400 | 109200 |
| silty sand | 60-80 | 22800 | 25080 | 27360 | 29640 | 34200 | 45600 | 57000 | 68400 | 79800 | 91200 | 102600 | 125400 | 148200 |
| silty sand | 80-100 | 28800 | 31680 | 34560 | 37440 | 43200 | 57600 | 72000 | 86400 | 100800 | 115200 | 129600 | 158400 | 187200 |
| granite | | 25 E+6 | 25 E+6 | 25 E+6 | 25 E+6 | 25 E+6 | 25 E+6 | 25 E+6 | 25 E+6 | 25 E+6 | 25 E+6 | 25 E+6 | 25 E+6 | 25 E+6 |

Soil stiffness within the design range suggest by the consultant

Unloading/ Reloading Stiffness, $E'^{ref}_{ur}$ (Kn/m$^2$) using value 350% increment from initial young modulus.

## 4.1 Horizontal wall deflection under different level of excavation

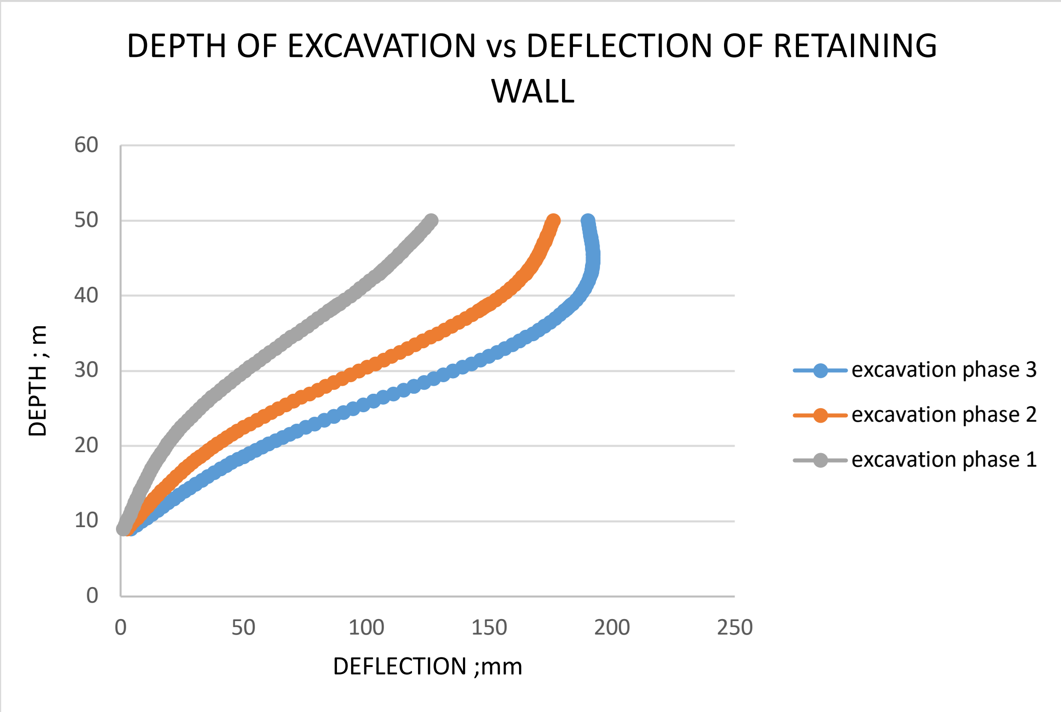



Figure 15 : horizontal wall deflection by PLAXIS 7.2

Figure 15 show the horizontal wall deflection from first level excavation until third level excavation. Plaxis v7.2 (finite-element method) showed that the deeper the excavation level, the movement of the wall is towards the excavation side. The maximum horizontal deflection occurred near the excavation level.

## 4.2 Comparison between the predicted wall deflection under different soil stiffness (PLAXIS 7.2) with inclinometer.

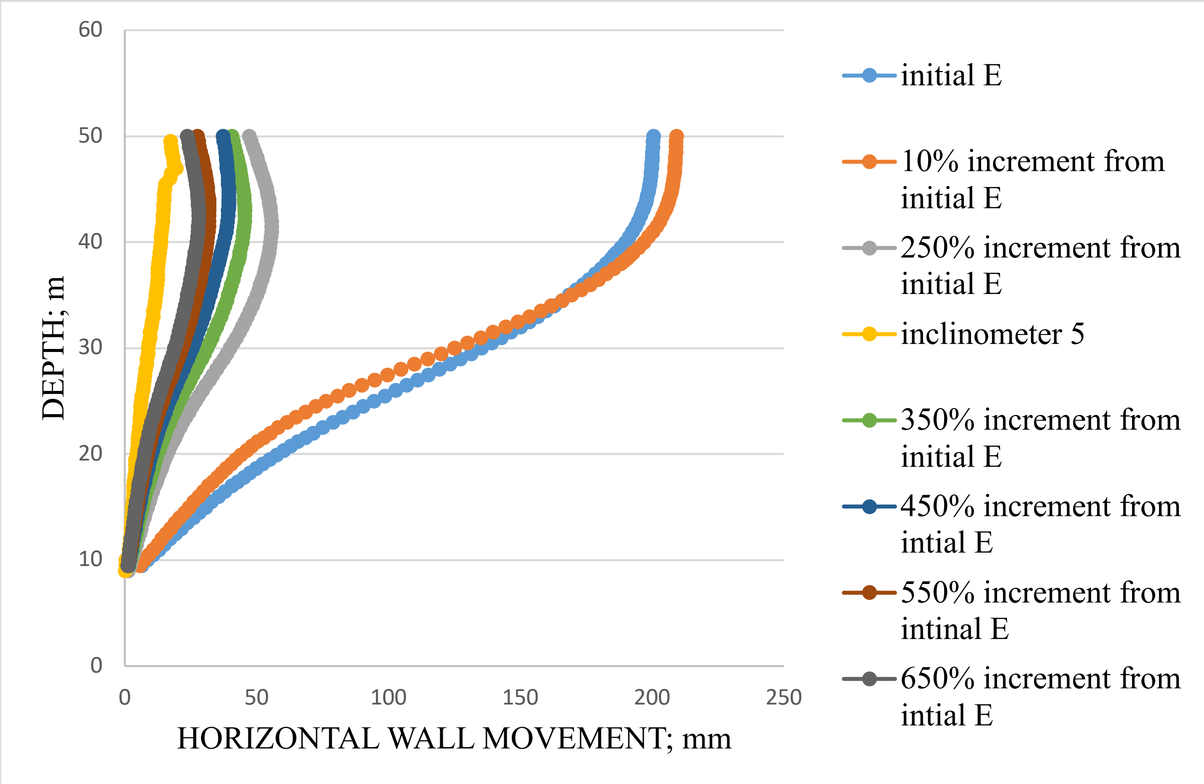



Figure 16 : Horizontal wall deflection with undrained soil properties

Figure 16 show comparison between the horizontal deflection of secant pile wall by PLAXIS 7.2 and inclinometer from case study. Undrained soil properties used for this simulation. The soil stiffness that have almost the same value of horizontal defelction with inclinometer is:-

| STRATUM | SPT(N) | 650% increment from inital soil stiffness,E |
|---|---|---|
| | | Es (Kn/m²) |
| sandy silt | 0-10 | 49500 |
| sandy silt | 10 -20 | 94500 |
| sandy silt | 20-40 | 162000 |
| silty sand | 40-60 | 252000 |
| silty sand | 60-80 | 342000 |
| silty sand | 80-100 | 432000 |
| granite | | 25 E+6 |

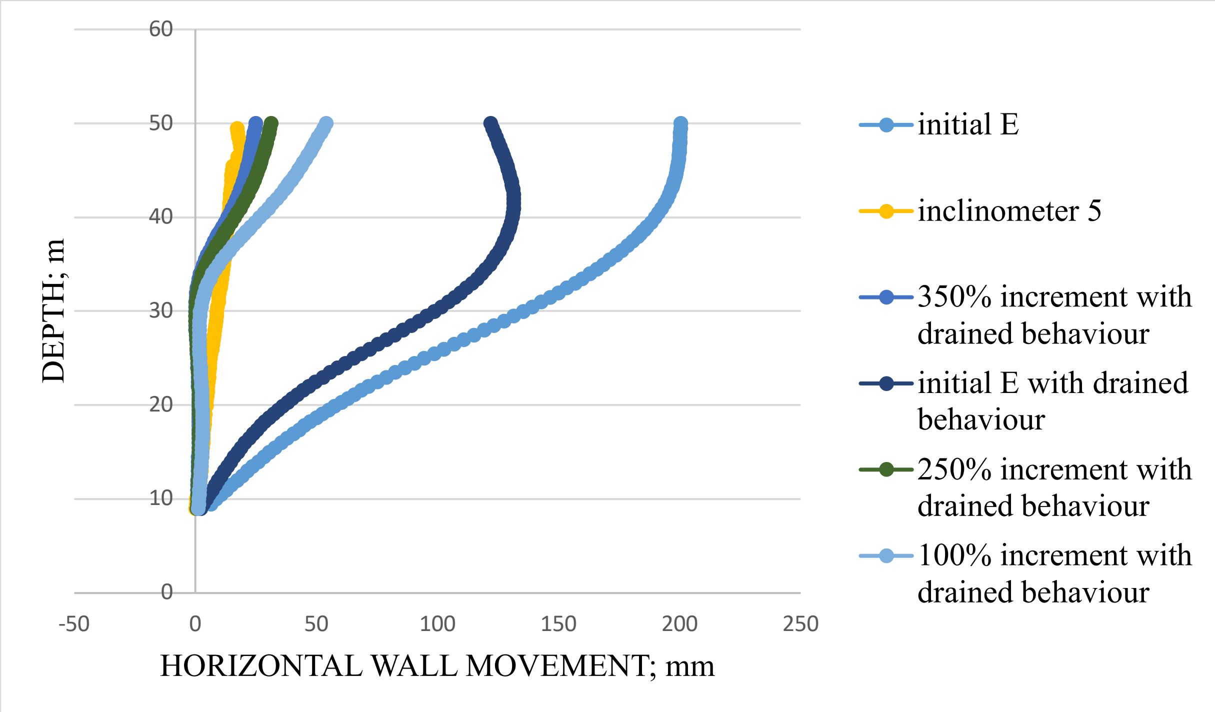



Figure 17 : Horizontal deflection with drained soil properties

Figure 17 show the horizontal deflection of secant pile wall with drained soil properties. The soil stiffness that has almost the same value with inclinometer is:-

| STRATUM | SPT(N) | 350% increment from initial soil stiffness,E |
|---|---|---|
| | | Es (Kn/m²) |
| sandy silt | 0-10 | 51975 |
| sandy silt | Okt-20 | 99225 |
| sandy silt | 20-40 | 170100 |
| silty sand | 40-60 | 264600 |
| silty sand | 60-80 | 359100 |
| silty sand | 80-100 | 453600 |
| granite | | 25 E+6 |

The horizontal wall deflection for this soil properties smaller compare with undrained soil properties. The undrained condition has higher value because of the total pressure exerted on the wall include the pore water pressure.

## 4.3 Comparison between Mohr coulomb model, Hardening soil model and inclinometer.

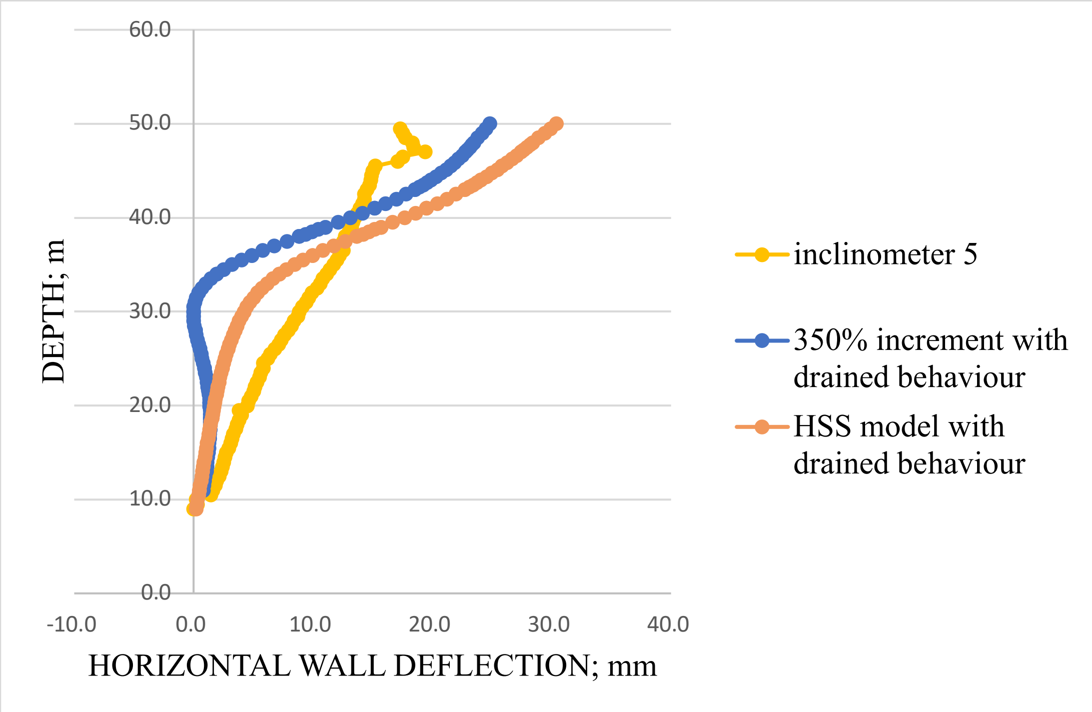



Figure 18 : Comparison between HSS model, Mohr Coulomb Model and inclinometer

To validate the preciseness of data, the result from Mohr Coulomb model was compare with the inclinometer and Hardening soil model. The input soil properties for this analysis are limited based on the design guideline by the consultant of case study. The result show that with the same value of soil stiffness has the deflection of Hardening soil model are more reliable compared with Mohr Coulomb model starting at depth 40 meter. This is because, different model has different consideration. Mohr Coulomb model includes limited number of features of soil behavior while Hardening soil model stimulate the behavior of different types of soil when subject to primary deviatoric loading, compression and elastic unloading / reloading.

# CHAPTER 5

# 5 CONCLUSION AND RECOMMENDATION

As a conclusion, this study provides a basic analysis of lateral earth pressure acting on braced excavation wall. The prediction of the wall deflection is important to prevent retaining wall failure and contribute to a safe retaining wall design. By using PLAXIS 7.2, horizontal wall deflection under different level of excavation can be predicted. The deeper the depth of excavation, the higher the horizontal deflection of secant pile wall. Undrained and drained condition of soil give a big impact in the deflection of secant pile wall.

To increase the preciseness of data, Hardening soil model has been used. The horizontal deflection from this model is compared with Mohr Coulomb model and inclinometer. However, the data obtained still not accurate when we compared the result with inclinometer reading from the case study. PLAXIS v7.2 analysis is done in 2D while the inclinometer measurement in 3D. The analysis also ignored the effects of corner wall supports and effects from the foundation of adjacent buildings.

For further studies, the analysis of this project can be done using three- dimensional analysis to establish more accurate result. Analysis using different constitutive model is also recommended for further studies.

# CHAPTER 6

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