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INFLUENCE OF METALLIC STRIP REINFORCEMENT LENGTH AND RETAINED SOIL PROPERTIES ON THE REINFORCED EARTH WALLS STABILITY

Ong Chun Ee*

School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru,Johor, Malaysia

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*Corresponding author
chuneeong@graduate.utm.my

Abstract

Reinforced earth (RE) walls work as gravity-retaining structures which these composite structures rely on the self-weight of the reinforced soil mass to resist lateral loads from earth pressure, surcharges from vehicles, earthquakes, and water pressure. The type of compacted backfill material at the reinforced zone and reinforcement length that was designed and constructed has a capability to form a reinforced-soil mass that provides sufficient self-weight to stabilize the overall retaining structure. The stability of the reinforcement-soil interface and the strength of the reinforcement provide the internal stability of the structure, which allows the RE wall to act as a unit and be able to sustain significant loading and deformation where the wall stability was highly depending on the type of backfill soil properties and the reinforcement strip length. Therefore, in this research, the safety factor of the RE wall was analyzed by using a different type of soil properties i.e., silt and clayey soil with a different of reinforcement length using finite element modelling PLAXIS 2D and PLAXIS 3D approach. Both numerical modelling results shows that the effects of clayey soil as a backfill material at the reinforced zone gives higher wall deformation compared to silt soil. Besides that, this analysis also shows that the reinforcement length, L_R has a significant impact on the wall deformation; as the reinforcement strip length increased, the wall deformation significantly reduced. The finding this research shown that numerical modelling PLAXIS 2D gives conservative design as it gives higher value of wall deformation and lower safety factor compared to PLAXIS 3D.

Keywords: *reinforced earth wall, reinforcement strip, backfill material, PLAXIS 2D and PLAXIS 3D*

1.0 INTRODUCTION

Henri Vidal, 1960 was a French architect and engineer invented reinforced earth walls which consists of retained soil, metallic steel strip reinforcements and precast concrete wall panels and was known as the first Mechanically Stabilized Earth (MSE) walls system. Over past decades, RE walls was well known and used in the worldwide includes in Malaysia as the flexible vertical retaining wall structures because the friction between soil and reinforcement materials and the connection between the precast concrete wall panels and reinforcement materials allows it for earth retention and load support in infrastructure projects with a less construction cost and time beside it has a high tolerance to differential settlement compared to conventional reinforced concrete retaining walls. However, the excessive differential settlement between the precast concrete wall panels and metallic steel strip reinforcements can affected to the stability and serviceability of the RE walls if there is a significant increase of the tensile stress on the reinforcements strip. These excessive differential settlements can be due to the unexpected ground movements such as induced by nearby excavations, volume change of expansive soils and consolidations of underlying soils. Many studies shows that the differential settlement between adjacent precast concrete wall panels can induced to the disjointing, dislocation, cracking, pop-outs and distress of the wall panels.

The conceptual of RE walls was by placing reinforcement materials such as geosynthetics, geogrids and metallic steel strips to reinforcing the backfilling materials which tensile strength and stiffness is used to ensure the internal stability of the wall. Several aspects of RE walls behavior can be identified based on the fundamental aspects such as pull-out tests and analyze the impact of corrosion on the metallic steel strip reinforcement such as loss of thickness, stiffness and strength, but it was much challenging to performed an accuracy simulation by using finite elements to determine the interactions between the backfilling material, reinforcement strip and the facing wall panels.

1.1 Problem Statement

RE walls stability was highly depending on the backfill material at the reinforced zone and reinforcement length. Soil properties used as a backfill material in the reinforced zone of the RE wall where the performance of the walls mainly required a high quality of backfill materials such as a well-graded granular fill material which has a high friction characteristic much preferred for a better drainage, better durability to the reinforcing strip. As per AASHTO guideline, the backfill material soil properties at the reinforced zone should has a limitation of %fines and plasticity index (PI) 15% and 6% respectively. Backfilling with the marginal material such as high fines grained soil content of high plasticity and expansive soil and poor drainage surrounding the RE walls can cause excessive wall movement or even failure due to the high rates of deformation arises on the wall. However, due to the limitation of selected backfill of good quality granular material on site, the marginal material could also be used as a backfill in the reinforced zone for a substantial construction cost saving. Therefore, this research is to determine lack information of the soil plasticity index value that may give a minimum safety factor of the RE walls (FOS=1.5). The proposed marginal material suitable to be used as a cost-efficient alternative where sufficient quantity of well-graded granular soil was not available locally that may provide most economical design and better environmental condition. A knowledge of the effects backfilling material properties and the interaction with metallic steel strip reinforcement length was very important to take into the account consideration for a sustainability and the performance of the RE wall stability that may determine thoroughly.

1.2 Aim and Objectives of Research

The aim of this research was to study the effects of backfill material soil properties at reinforced zone and metallic steel strip reinforcement length on internal stability of reinforced earth walls.

The objectives of this research was as bellows:

(a) To determine the influence of soil properties ie plasticity index, soil cohesion and soil friction angle on walls deformation by using finite element method modelling PLAXIS 2D and PLAXIS 3D.

(b) To determine the influence of metallic steel strip reinforcement length on the wall deformation and safety factor of the RE walls using PLAXIS 2D and PLAXIS 3D.

(c) To compare the outcomes results within PLAXIS 2D and PLAXIS 3D and validate numerical modelling tool that provides most conservative design for the reinforced earth walls stability.

1.3 Scope of Study

The scope of study in this research was to determine the uncertainties effects of backfilling soil properties and reinforcement length on the reinforced earth walls stability by using finite element numerical tools PLAXIS 2D and PLAXIS 3D. In this research, the limitation of this study was to analyze the effects of different soil properties ie soil friction angle, soil cohesion and plasticity index that used as a backfill material at reinforced zone on the RE walls internal stability. The values of these soil properties obtained from the laboratory test where the soil sample obtained from two difference site; Kajang and Port Dickson ie silt and clayey soil respectively. In addition, the effects of metallic strip steel reinforcement length various at 0.5H, 0.7H and 0.9H on the walls deformation and safety factor of the walls was analyze using numerical tools PLAXIS 2D and PLAXIS 3D. The RE walls height, H will be in the range of 13m, 10m and 6m.

This research was an addition effects to the internal stability of the retaining wall that should taking into consideration in the system reliability analysis of the reinforced earth walls beside of the effects corrosion induced thickness metal losses and reduce of strength in the reinforcement steel tensile. The reinforced earth walls studied in this research was comprised of metallic reinforcing strip connected to the flexible precast concrete wall panels.

2.0 LITERATURE REVIEW

A reinforced earth walls with rectangular cross section was constructed by alternating layers of compacted granular soil and metallic steel ties which are distributed at convenient horizontal and vertical intervals. Placing the reinforcement in regions of tensile strains and in particular on orientations coinciding with the direction of principal tensile strains, this will cause the reinforcement to inhibit the development of tensile stresses in that region of the soil and also increase the shearing characteristics of the backfill material.

The RE walls mechanism failure can be within or outside the reinforced zone which the slip surface passes through the reinforced zone and the unreinforced soils (Morrison, 2006) as in Figure 1. The most critical path to take consideration in the reinforced earth walls structures was external, internal stability and within the precast concrete wall panel. The external mechanism failure was defined by slip surfaces that pass outside the reinforced soil zone while internal stability was due to the tension rupture and pull-out due to the reinforcing strip. The modes of internal stability can be determined by using empirically derived relationships that would be used to estimate stress states within the soil ground and reinforcing strip while the facing failure (deformation of the precast concrete wall panel) can be minimize through controlling the quality of backfill material in the reinforced zone.

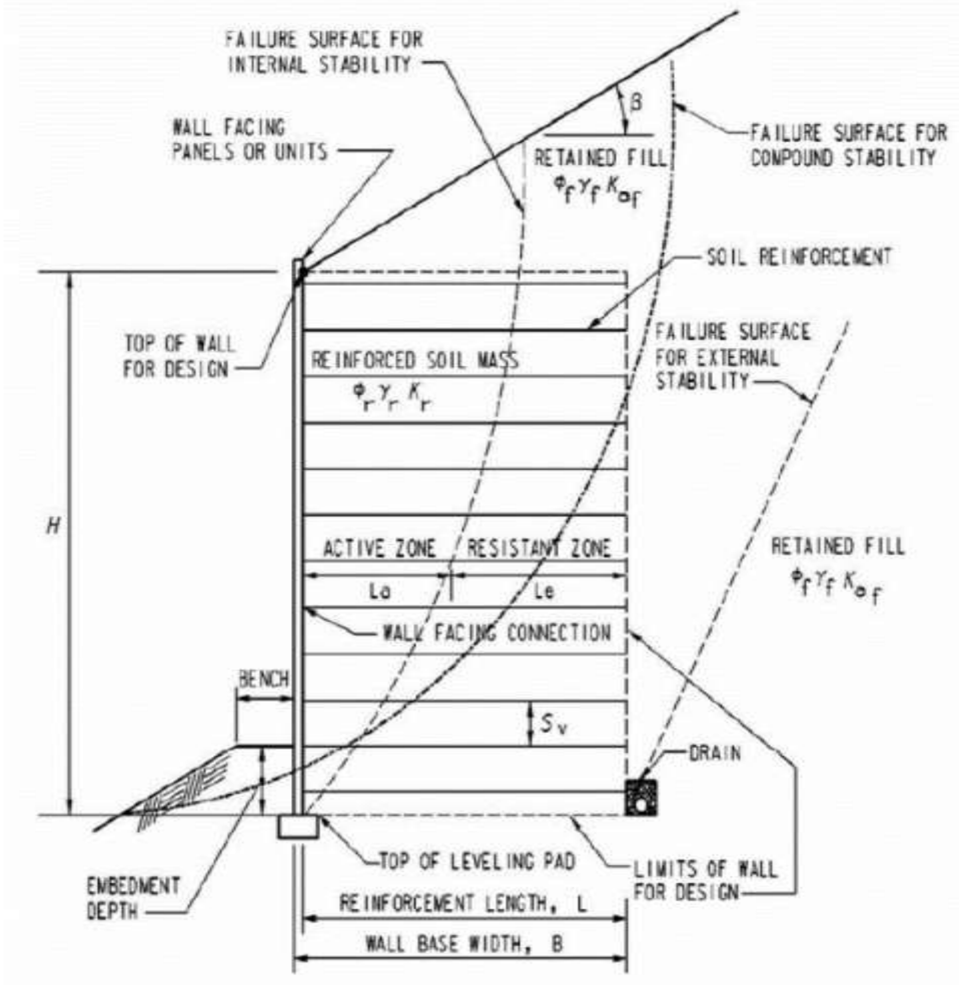

Figure 1 Typical design of reinforcement earth wall element

The reinforced earth walls stability analysis can be done either by using a Limit Equilibrium Method (LEM) such as GeoStudio or Strength Reduction Method (SRM) incorporated in the Finite Element Method (FEM) such as PLAXIS or Finite Differential Method (FDM) such as FLAC^{2d}. The FEM or FDM can be used to provide information such as deformation of the precast concrete wall structure. General equation to analyze the reinforced earth walls stability factor was as below:

$$\text{Factor of Safety} = \frac{r\,(c, \varphi, T)}{d} \tag{1}$$

where d = disturbance

r = resistance;

c = cohesion of the soil

ϕ = friction angle of the soil

T = tensile strength of the reinforcements

2.1 Fundamental Design Approach Of Reinforced Earth Wall

The fundamental of RE wall was to transfer the stresses from the soil to every single reinforcing strip. Lee et al. and Bolton and Choudhurv assume that each strip has to support the skin (face) against failure which the soil exerts an active pressure, while Schlosser and Vidal assume that the reinforcement maintains the active earth pressure *(Ka)* in the soil. Both lead to the same force *(T)* in the reinforcement. The tensile force per unit length of the wall developed at any depth, T determined as per equation below:

T = active earth pressure at depth z x area of the facing wall supported by ties reinforcement

$$T = K_a.\sigma_v.S_h.S_v \tag{2}$$

where S_v = vertical spacing between the reinforcement strip.

S_h = horizontal spacing between the reinforcement strip.

σ_v = vertical stress caused by overburden stresses from the soil.

After the tensile force in the strip was determined, there will be two (2) modes of failures that may occur. Firstly, the force may exceed the breaking stress of the reinforcement and this is called the tension failure. Secondly, it may not be possible for sufficient friction to occur between the strip and the soil to generate the force required, and failure occurs with strip pulling out which was known as pull-out failure.

$$\text{Factor safety against tie breaking, } FS_{(B)} = \frac{\text{yield strength each tie}}{\text{maximum force in any tie}}$$

$$FS_{(B)} = \frac{(w)\ (t)\ (f_y)}{T} \quad (3)$$

where w = reinforcement strip width
t = reinforcement strip thickness
f_y = yield stress of the reinforcement strip

$$\text{Factor safety against pull-out, } FS_{pull} = \frac{\text{Maximum friction force for a tie at depth z}}{T_i}$$

$$FS_{pull} = \frac{2 \times l_e\ \sigma_v \tan \phi_r}{T_i} \quad (4)$$

where $T_i = S_i \times \sigma_H$
S_i = thickness of the reinforcement strip
l_e = effective length of reinforcement strip
σ_v = vertical stresses at a given depth of soil
σ_H = horizontal earth pressure at the middle layer of the soil
ϕ_r= friction angle between soil and the strip reinforcement.

From Equation (3)

$$l_e = \frac{FS_{pull}\ T_i}{2 \times \sigma_v \tan \phi_r} \quad (5)$$

And at any depth

$$l_a = (H - z) \tan (45 - \phi/2) \quad (6)$$

Therefore, total length of reinforcement

$$L = l_e + l_a \quad (7)$$

2.2 Reinforced Earth Walls Backfill Material

The RE walls are design where its stability was mainly depending on the interaction between the reinforcement strips and the soil. A well graded granular fill material which has a high friction characteristic much preferred for a better drainage, better durability to the reinforcing strip and eventually also provide a less spacing between the reinforcement strip. Besides that, it will also benefit to have an advantage on the placement and compaction during the construction, therefore it will increase the rate of wall erection (save construction time) and improved the tolerance for wall alignment verticality.

Base on the guideline AASHTO design criteria, the allowable fines content (ie passing sieve #200) for the backfilling reinforced earth walls was limited to 15% and the plastic index < 6. The selected fill materials are to minimize the potential metal loss of the reinforcing strip and exceed the minimum strength requirement (Armin and William, 2010).

2.3 The Effects of Extreme Infiltration on Marginal Backfill Material

The effects of extreme infiltration from the rainfall on marginal backfill (ie high fines content and PI > 6) for the RE walls must be known because a high matric suction can be developed due to low permeability in the soil. Without the proper drainage system surrounding the RE walls structure, there will be potential increase of the degree saturation of the backfill material that may lead to the excessive pore water pressure and matric suction changes over the time, where this condition may induce to soil masses stability including reinforced and unreinforced soil structures (Farshid and Faraz, 2017).

The active earth pressure will increase the reinforcement load in this marginal backfill due to increase of pore water pressure in the soil. The increase in positive pore-water pressure will decrease the soil matric suction and decrease soil shear strength that can significantly increase the soil-reinforcement interface strength and reduce the load mobilized in the reinforcement (Vahedifard, 2016). These corresponding decrease in effective stress will also lead to a decrease in the pull-out resistance (Hatami and Esmaili, 2015). Besides that, past studies have shown that the RE walls will distress in the unsaturated soil condition due to the varying moisture content conditions where these was due to the matric suction was regarded as a redundancy factor and was ignored in the conventional design (Koerner, Valentine 2013). Therefore, if not overcome this change may affect to the integrity of the reinforced earth walls that may lead to instability.

2.4 Causes of Reinforced Earth Walls Deformation

RE wall which was backfilled with the marginal materials will within the reinforced zone will resulting to a poor drainage and may causes to the excessive wall movement or even a failure to the wall structure. (Narejo and Ramsey, 2001) stated that the performance of the RE wall was much dependent on the provision of the drainage in the RE wall where a comprehensive drainage and filtration plan should be in the design in order to provide a choice of drainage and filtration system in the RE wall. (Scarborough, 2005) has a case study on the MSE wall failure located at Virginia where the failure of the wall was due to the poor drainage. An additional pressure was built behind the wall facing due to the lack of drainage inside the RE wall. Based on the finding, the others factors contribute to the wall failure was also due to the inconsistent compaction of backfilling soils and the use clayey material as a backfilling material within the reinforced zone. (Leshchinsky, 2005) in his research stated that the use of high fine content backfilling material can generate a perched water zone which can causes an additional pore water pressure on the wall facing that may contribute to a large deformation of the wall or failure of the wall structure.

In RE wall design, there was no limitation of the wall height but a special attention should be provided to the specification of the backfill soil, corrosion and degradation of the reinforcement, drainage requirement and construction damage (Elias, 2001). The RE wall may be failed due to the poor backfilling material (marginal backfill material), insufficient length and strength of the reinforcement, insufficient provision of drainage, sudden drawdown of the ground water level and also weak foundation soil (Leshchinsky and Han, 2004).

2.5 Case Study of Reinforced Earth Walls Failure

Case study 1 : A reinforced earth wall supporting a 10.7-m high earthwork adjacent to a highway bridge on National Highway, NH-6 near Kolkata (India) was failed on 9th February 2006 as visualized in Figure 2. These case history was presented by A.Sengupta, 2012 after the reinforced earth wall was failed due to the over estimation of the foundation clay layers strength and underestimation of the self-weight of the backfilling materials. The numerical analyses were carried out and resulting that by consolidating a foundation clay layer to gain in shear strength, the factor of safety of the wall can be achieved theoretically. To expedite the consolidation and drainage process of the foundation clay layers, the prefabricated vertical drains (PVD) were used.

Figure 2 Failure of the RE wall at National Highway, NH-6 near Kolkata, India (A.Sengupta, 2012)

Case study 2 : Due to the misaligned Mechanically Stabilized Earth (MSE) wall, the geotechnical investigations was carried out to evaluate the performance of the wall. This wall was a part of the approach to the railway over bridge in Hyderabad-Bangalore highway in India was presented by TG. Sitharam and A.Hedge, 2018. The MSE wall was constructed at the height of 13.85 m and was misaligned verticality. The proposed remedial works was to dismantle and reconstruct the MSE wall. However, through the geotechnical investigation from the field test and numerical simulation, the structure integrity of the wall was not affected and can be retained with a minor remedial works. The major cause of the misalignment was due to the poor monitoring during the installation of the precast wall panel. After the remedial works, the wall has opened to the public and sustained with heavy traffic loads for the past 5 years without any significant developing additional misalignment or cracks. This case study was also similar to one of the developments in Malaysia at Nilai, Negeri Sembilan where the wall height was approximately to 7.3m as shown in Figure 3. The misalignment wall was dismantling and reconstruct the wall at 2m from the ground level to minimize the tolerance of the wall verticality.

Figure 3 Dismantling and reconstruct the top panel 2m from the finished floor level to reduce the difference of verticality wall panels.

3.0 METHODOLOGY

Site investigation was conducted through a borehole for collection of disturbed samples and undisturbed samples for a laboratory test. Two sites were identified i.e at Kajang and Port Dickson mainly silt and clayey soil respectively in order to have different type of soil. The location of minimum 3 numbers of bore holes were carried out for each site as per the indication inside the drawing. The site investigation works was done accordingly to the BS 5930: 1999 and BS 1377:1990. The purpose of this sample is to determine the soil properties and soil water content through laboratory test.

3.1 Field Exploration

The borehole was formed by using wash boring method with a multi-speed rotary boring machine, YME D90R (skid mounted) as visualized in Figure 4. The borehole was line with NW size casing (I.D of 76.0mm and O.D of 89.0mm) and HW size casing (I.D of 101.0mm and O.D of 115.0mm) to prevent the collapse of the borehole wall. SPT was carried out at every change of soil stratum or at every 1.50m interval driving a 50mm diameter split spoon into the soil by using a 65kg hammer at a height falling of 760mm. The penetration of 150mm with the numbers of blows was recorded as a seating blow and subsequently the next 300mm penetration with the numbers of blows was recorded as the N value (or the blow count) of the soil strata encountered.

3.2 Sampling for Laboratory Testing

Disturbed soil samples were obtained at every change of soil stratum or at intervals 1.5m. The disturbed sample were extracted from the split-spoon sampler, which was driven into the soil in conjunction with SPT.

Undisturbed (UD) soil samples were obtained for soft to very soft soil layer. The UD was collected by using thin-walled tube or piston tube and were advanced by means hydraulic fluid. The UD soil samples obtained were clearly labelled, trimmed at both end and sealed with non-shrinkage microcrystalline wax to prevent the change in moisture content. The test to be carry out is Triaxial Compression Test for Unconsolidated Undrained (UU) and Consolidated Undrained (CU) test and One Dimensional Consolidation Test to obtained the soil properties.

Figure 4 Field exploration by using deep rotary boring machine

3.3 Soil Properties

In this research, the soil properties were divided into two different zones ie reinforced soil zone and foundation soil zone in the model. Mohr–Coulomb model for drained condition was used to represent the soil in these numerical modelling. The reasons of choosing Mohr–Coulomb model was because the soil properties such as E and υ for soil elasticity, cohesion and friction angle for soil plasticity can be obtained from the triaxial compression testing that can be used to represent soil compared to a more complicated models such as hardening soil model that required a series of soil parameters. The effects of reinforcing strip on suppress dilation of backfilling cannot be simulated by assuming the dilation angle, ψ equal to zero (Sadok and Djabri, 2014). From the bore logs report, it was shown that the ground water table observation for Kajang and Port Dickson site was 15.2m and 17.7m respectively from the original ground level. Thus, in this study ground water table was assumed to be below the foundation soil level in this analysis.

Table 1 and Table 2 shows the soil properties for the Kajang and Port Dickson site respectively

Table 1 Soil properties of reinforced earth wall (Mohr Coulomb model for drained condition obtained from laboratory test for Kajang's Site (BH 3)

Type of Soil Properties	**Unit**	**Retained soil and reinforced soil zone**	**Foundation soil zone**
γ_{unsat}	kN/m^3	17	17
γ_{sat}	kN/m^3	21	21
Soil elasticity, *E*	kN/m^2	10,000	10,000
Poisson ratio, υ	-	0.3	0.3
Void ratio, e		0.6	0.6
Cohesion, c_{ref}	kN/m^2	13	13
Friction angle, ϕ	degrees	27	27
Dilation angle, ψ	degrees	0	0

Table 2 Soil properties of reinforced earth wall (Mohr Coulomb model for drained condition obtained from laboratory test for Port Dickson's Site (BH 1)

Type of Soil Properties	**Unit**	**Retained soil and reinforced soil zone**	**Foundation soil zone**
γ_{unsat}	kN/m^3	13	13
γ_{sat}	kN/m^3	19.3	19.3
Soil elasticity, *E*	kN/m^2	3,000	3,000
Poisson ratio, υ	-	0.3	0.3
Void ratio, e	-	1.07	1.07
Cohesion, c_{ref}	kN/m^2	20	20
Friction angle, ϕ	degrees	13	13
Dilation angle, ψ	degrees	0	0

3.4 Material Properties of Precast Concrete Wall Panel and Reinforcing Strip

A square precast concrete wall panel facing was are modelled by using plates of 1.50 m side and 0.15 m thickness of facing panels. In the PLAXIS input, the concrete panels properties that required in the analysis was elastic stiffness (*EA*), flexural rigidity (*EI*), unit weight (γ_c), Poisson ratio (υ) and the weight of the concrete panel facing (w_c). The reinforcing strip can only sustain a tensile force without bending stiffness; the material property of reinforcement will be elastic axial stiffness (*EA*). Thus, value of *EA* for metallic steel strip reinforcement Grade 65 to be assumed 210,000 kN/m with the thickness of 4mm (I.P Damains and A. Josa, 2020). Table 3 shows the tabulation of the materials properties used in this research.

Table 3 Material properties of the reinforced earth wall

Type of Material Properties	**Unit**	**Concrete Wall Panel**	**Metallic Steel Strip Reinforcement**
Elastic Stiffness, *EA*	kN/m	4109	210,000
Flexural Rigidity, *EI*	kN/m²/m	7.7	-
Unit weight, γ_c	kN/m³	24	-
Weight of concrete panel, w_c	kN/m/m	8.1	-
Poisson ratio, υ	-	0.15	-
Reinforcement strip spacing, *l*	m	-	1.0
Thickness	m	0.15	0.004

3.5 Numerical Modelling

Numerical modelling can be valuable tools in the prediction slope stability analysis. In this research, the effect soil properties and reinforcement strip length on the slope stability was analyzed by using the PLAXIS 2D and PLAXIS 3D software. Plane strain model with 15 nodes and 10 nodes triangular elements was integrated in the PLAXIS 2D and PLAXIS 3D software respectively in the stages replicating the actual field construction, i.e, placement of soil in lifts along with concrete wall facing and metallic reinforcement strip layers. The concrete wall facing segment was modelled as a plate element with elastic behavior. The soil properties were modelled as a Mohr-Coulomb model and the reinforcement layers were simulated using node-to-node anchor elements which available in both PLAXIS 2D and PLAXIS 3D. Interface elements with suitable strength reduction factors were used to create boundaries between the dissimilar materials used in the model.

This research has a limitation that only consideration of soil properties such as soil friction angle, soil cohesion and soil plasticity index value synchronize in the numerical modelling software PLAXIS 2D and PLAXIS 3D to justify the influence of these soil parameters on the safety factor and deformation of the RE wall with various of reinforcing strip length range from L_R = 0.5H, 0.7H and 0.9H, where H is the heights of the wall. The methodology creation of RE wall geometry using this numerical modeling was presented in Figure 5.

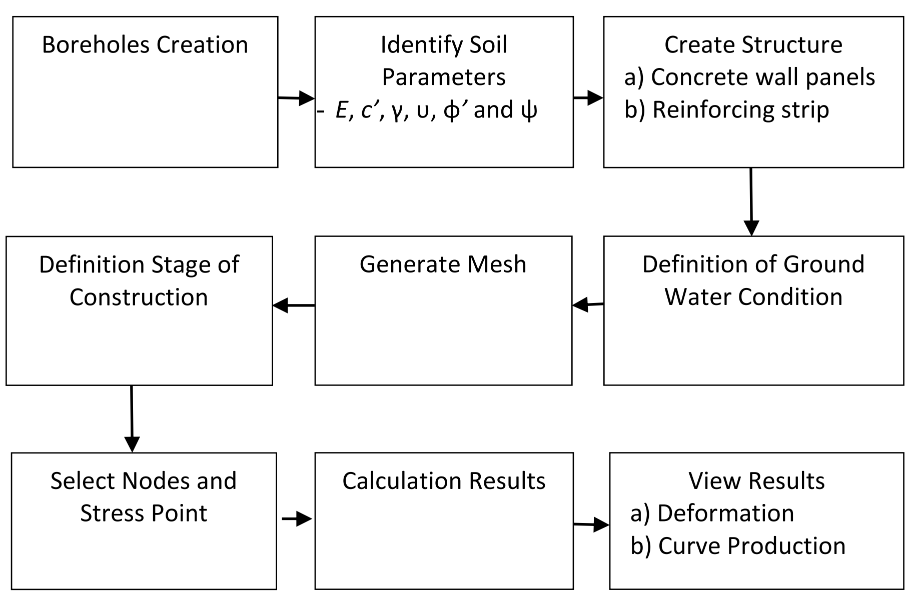

Figure 5 Work flow PLAXIS 2D and PLAXIS 3D

After setting up the geometry of the model in the PLAXIS 2D and PLAXIS 3D, there was two stages been proposed in the stage of construction in this research:

(a) Phase 1 – Plastic analysis (calculation of wall deformation)

(b) Phase 2 – Phi-c reduction analysis (calculation of factor safety)

4.0 RESULTS

4.1 Numerical Modelling Using PLAXIS 2D

A two-dimensional plane strain model with 15 nodes triangular elements integrated in the PLAXIS 2D software is used. During the automatic generation of mesh, clusters are divided into triangular elements by the program. The element stiffness matrix is evaluated by numerical integration using Gauss points. During the finite element calculation, total displacements are calculated at the nodes and stresses are calculated at the Gauss points.

4.1.1 Effects of Soil Properties On Total Displacement of the Reinforced Earth Wall for A Silt and Clay Soil as a Backfill Material

Precast concrete wall panels deformation was influence by the soil properties of backfill material besides of surcharge loading and different type of the reinforcement used for the reinforced earth walls. Past researcher has shown that clayey soil has higher impact to deformation of the wall which clay has low permeability that induced more earth pressure on the precast wall panels compared to a silt soil (Anand and Solanki, 2018). Figure 6 and Figure 7 show the total horizontal displacement for a 13m heights of RE wall with the backfill material of silt soil and clay soil respectively with the reinforcing trip length, L_R/H = 0.7.

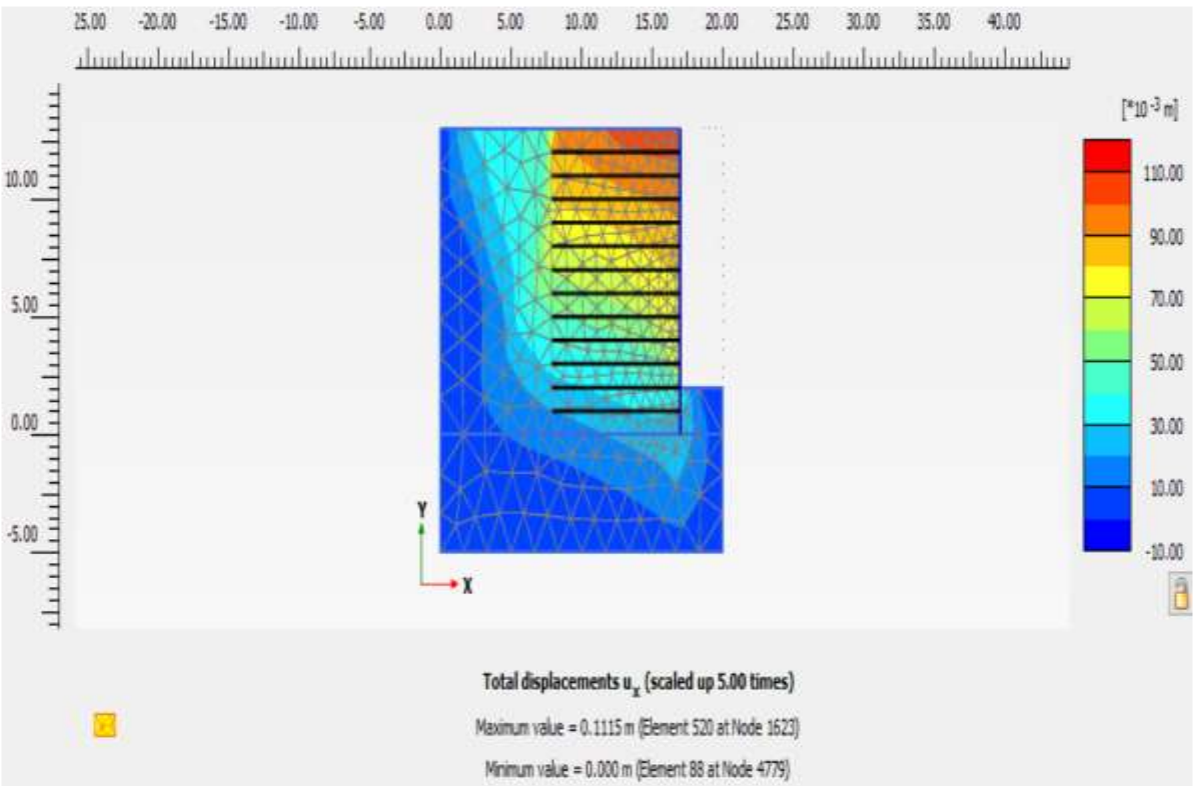

Figure 6 Horizontal displacement due to silt soil as a backfill material

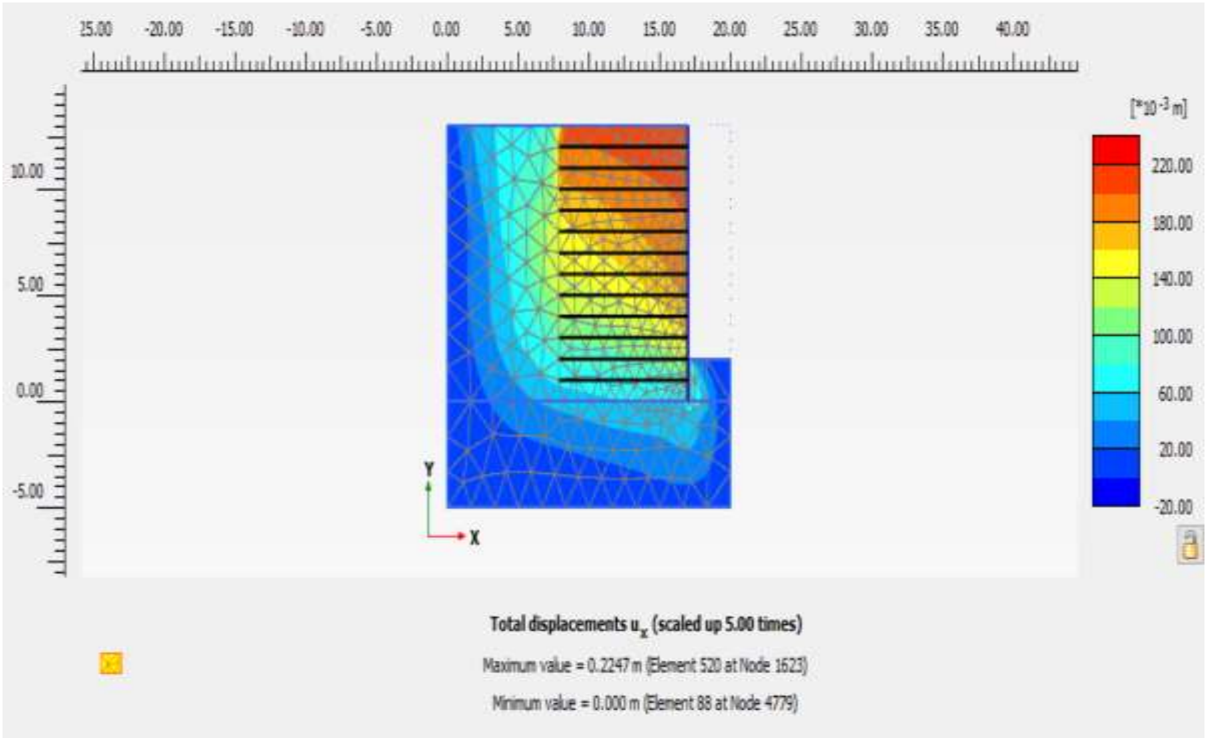

Figure 7 Horizontal displacement due to clay soil as a backfill material

Figure 8 and Figure 9 displays the total vertical displacement for a 13m heights of RE wall with the backfill material of silt soil and clay soil respectively with the reinforcing trip length, $L_R/H = 0.7$.

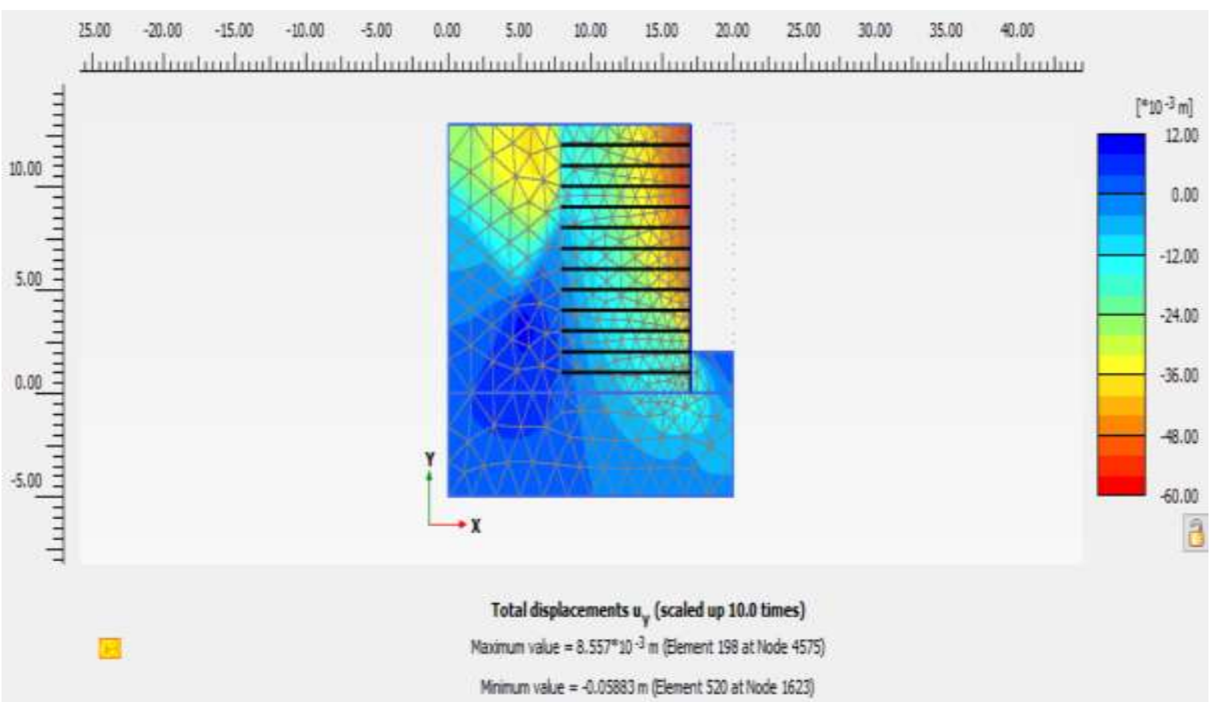

Figure 8 Vertical displacement due to silt soil as a backfill material

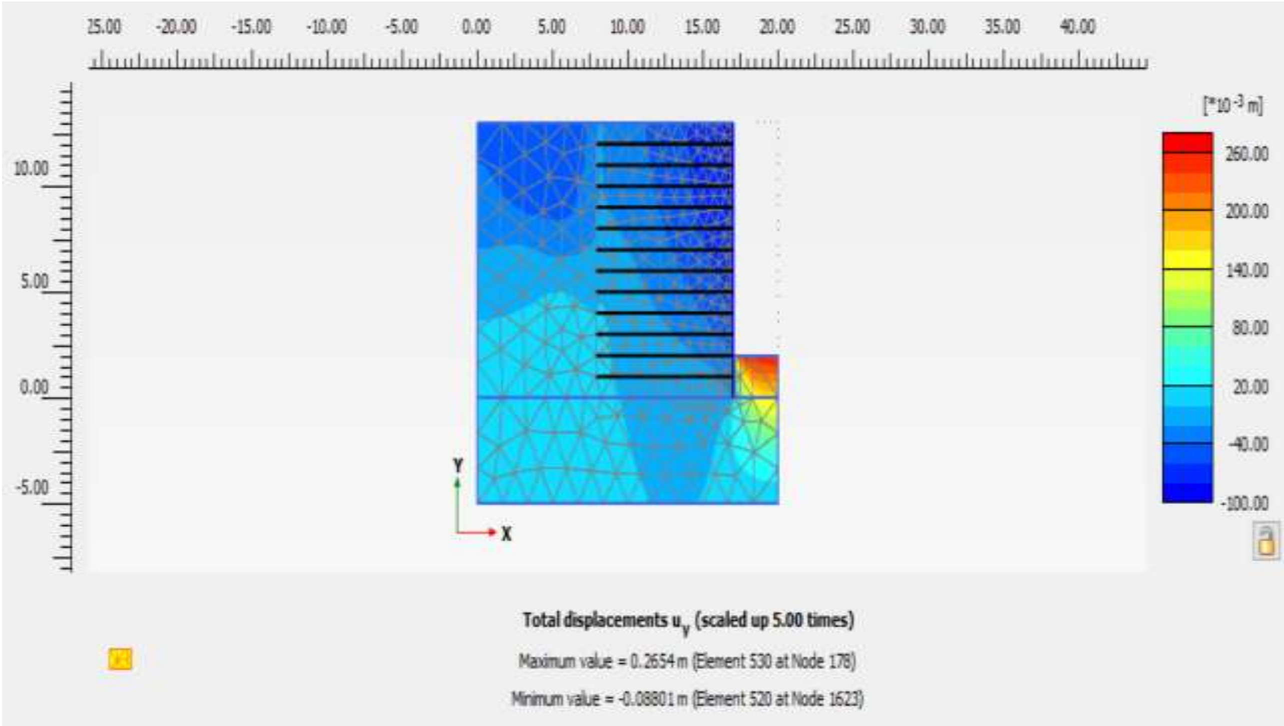

Figure 9 Vertical displacement due to clay soil as a backfill material

4.1.1.1 Relationship Between RE Wall Heights On Total Horizontal and Vertical Displacement of Reinforced Earth Wall for A Silt and Clay Soil as a Backfill Material.

From the chart in the Figure 10 and Figure 11 shows that both horizontal and vertical displacement was much influence with the different of soil properties used as a backfill material in the reinforced zone. It can be seen that silt soil has a lower wall deformation compared to clay soil. This is may be because of that clayey soil known as an expensive soil attribute to swelling and shrinkage due to the volume changes in the soil compared to silt soil. The potential volume change occurs may be due to the initial moisture content and void ratio which clayey soil has a higher void ratio and moisture content compared to silt soil. In this case study, clayey soil has a higher void ratio value of 1.07 compared to 0.6 (silt soil). Thus, these excessive volume changes in the soil can attribute to ground movements which can gives a significant impact to the wall displacement. By providing an adequate drainage system surrounding the RE wall, the potential increase degree saturation of the backfill material and excess pore water pressure behind the wall can be reduce and thus these will increase RE wall stability.

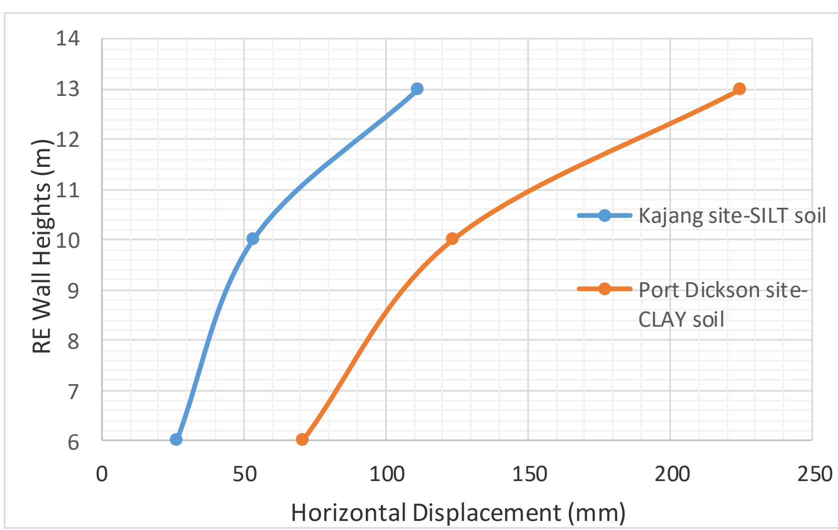

Figure 10 Horizontal displacement based on the wall heights 13m

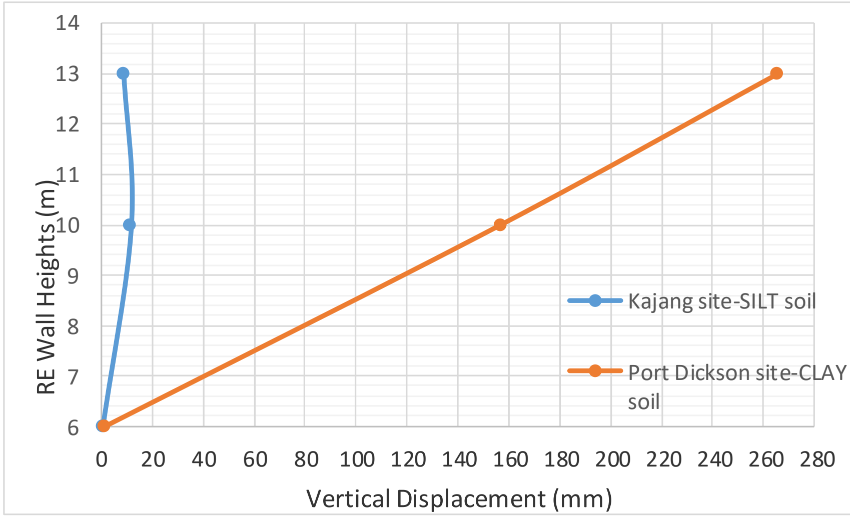

Figure 11 Vertical displacement based on the wall heights 13m

4.1.1.2 Effects of Soil Plasticity Index On Vertical Displacement of Reinforced Earth Wall

From the above analysis, it is shown that silt soil which contained slightly high plasticity index (PI = 11) will effect lower vertical displacement of the reinforced earth wall compared to the clayey soil which contained high plasticity index, (PI = 38) as visualized in Figure 12. This analysis was based on 13m wall heights with the various of reinforcement length range from 0.5H to 0.9H.

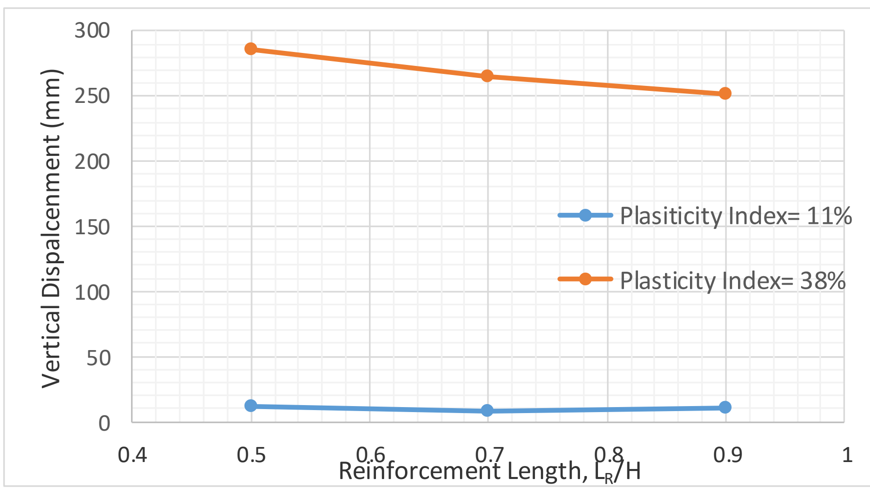

Figure 12 Effects soil plasticity index on vertical displacement, U_y of the reinforced earth wall

4.1.1.3 Effects of Soil Friction Angle On Wall Deformation of Reinforced Earth Walls

From the analysis, the wall deformation was highly influences with the soil friction angle. In this study, an increase of friction angle at 50% (13^o to 27^o) has a significant impact increased wall deformation. This was due to the reduced of lateral earth pressure coefficient of increased friction angle of the soil. Thus, it can be summarized that the higher friction angle soil with the longer reinforcement strip length will be decreasing the wall deformation as plotted in Figure 13.

4.1.1.4 Effects of Soil Cohesion On Wall Deformation of Reinforced Earth Walls

From the analysis, it's clear that the wall deformation was highly influences with the soil cohesion value. It can be summarized that the higher cohesion soil will gives a higher to the wall deformation and the relationship as plotted in Figure 14. Therefore, in a normal practice of the construction reinforced earth wall in Malaysia, the cohesionless soil (c = 0kPa) as a backfill material at the reinforced zone. The benefits using cohesionless soil was it do not increase earth pressure behind the facing wall that may increasing total displacement of the wall and this may cause distress to the wall.

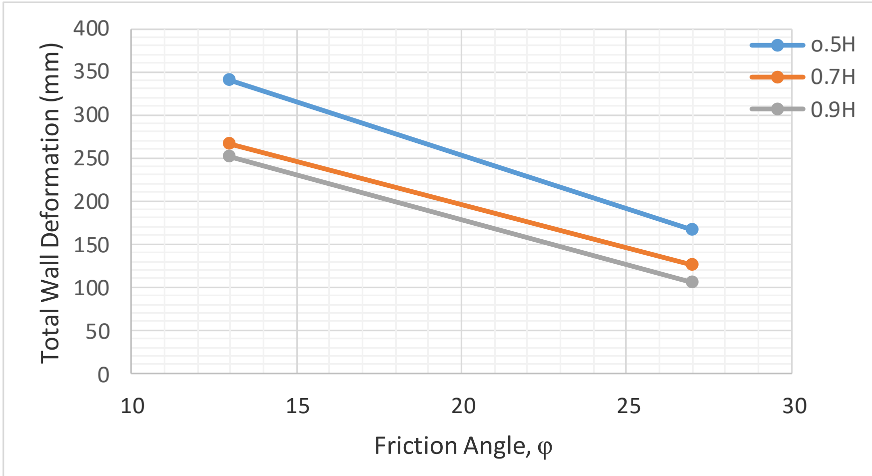

Figure 13 Effects soil friction angle on wall deformation

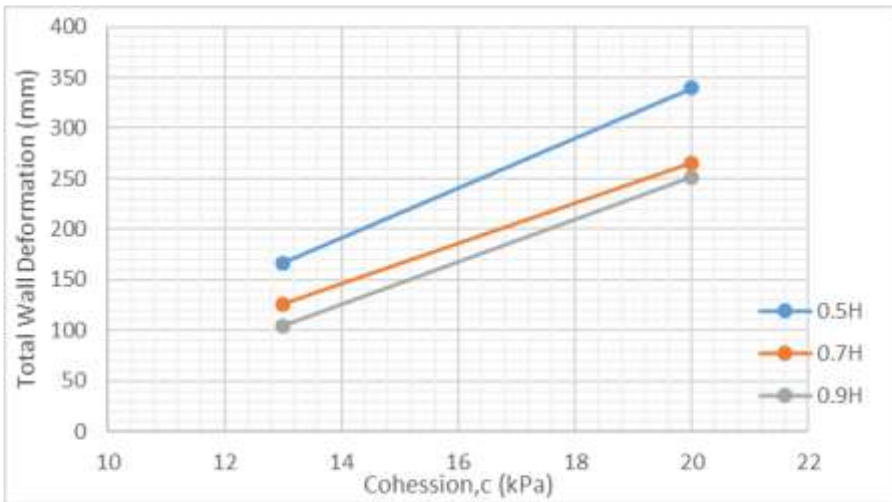

Figure 14 Effects soil cohesion on wall deformation

4.1.2 Effects of Reinforcing Strip Length On Precast Wall Panel Deformation

The reinforcing strip length was the main factor design that must take into the consideration during the reinforced earth walls design as it affected to the displacement of the precast wall panels. As the length of reinforcing strip was increased, there will be a possibility of reducing the total wall deformation as shown in figure below. In FHWA design restricted a guideline that the reinforcement length, L_R for the reinforced earth wall should be at 0.7H or minimum 2.5m while structures with the sloping surcharge backfills need a longer reinforcement for stability at the range of 0.8 H to 1.1 H where H is the design of the wall height.

Figure 15 and Figure 16 represent the value total displacement precast concrete wall panel based on the soil properties obtained from the Kajang's site (silt soil) and Port Dickson site (clay soil) respectively. The deformed reinforced earth wall model shows the predicted total displacements provide a good visualization the possibility of the failure criteria.

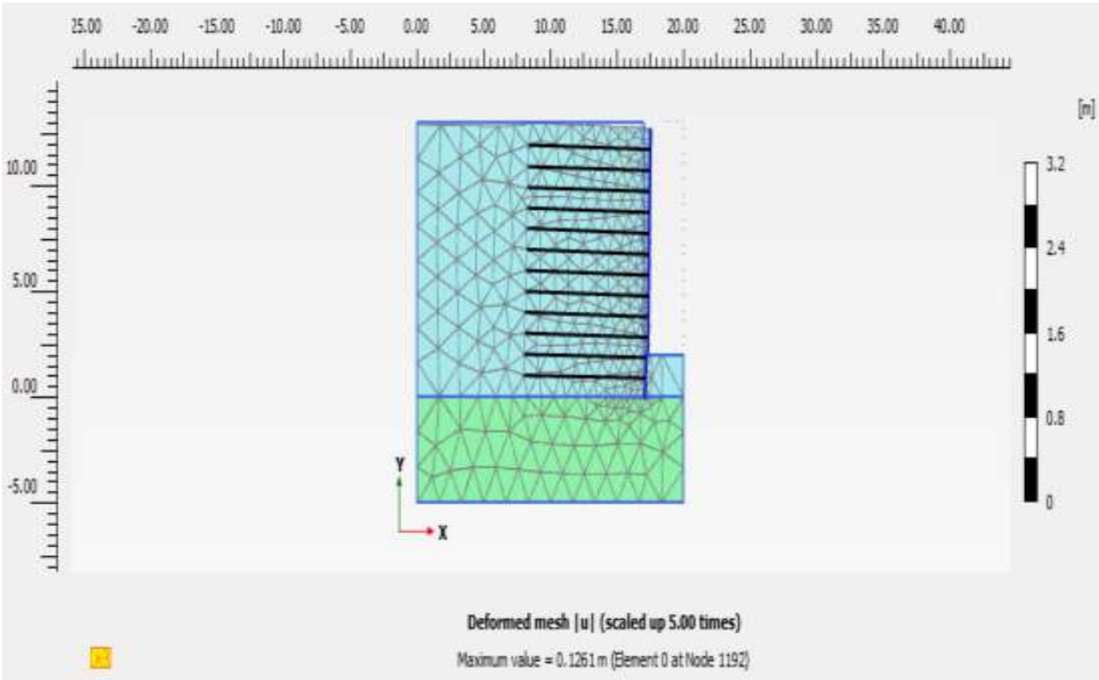

Figure 15 Deformed mesh with total displacement for a 13m wall heights with a reinforcing strip length $L_R/H = 0.7$ (silt soil)

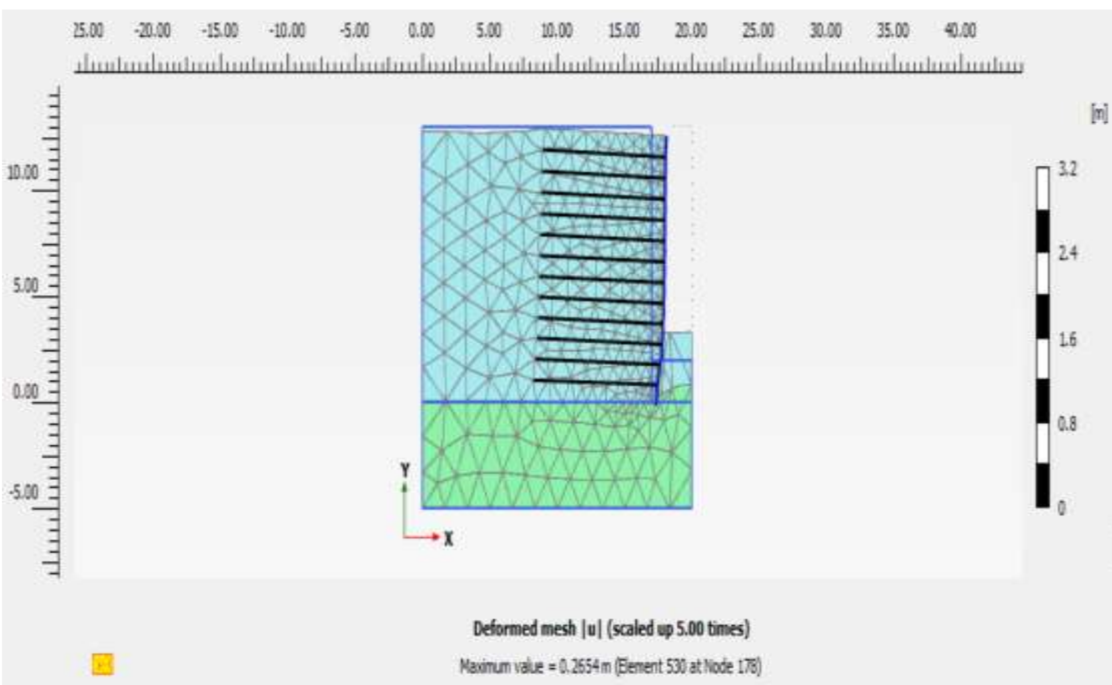

Figure 16 Deformed mesh with total displacement for a 13m wall heights with a reinforcing strip length $L_R/H = 0.7$ (clay soil)

4.1.2.1 Relationship Between Reinforcing Strip Length On The Precast Wall Panel Deformation

From the results shown in PLAXIS 2D, the length of the reinforcement strip increases, the total displacement of the wall decreases for both silt and clay soil. It also shown that higher wall has more impact to the increase value of total displacement that may need longer reinforcement to stabilize the wall. These results of analysis were visualizing as in the graph Figure 17.

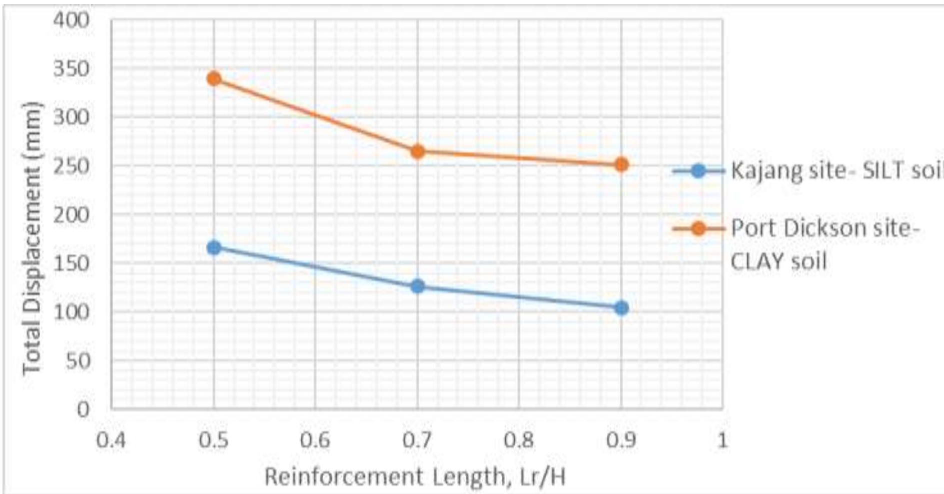

Figure 17 Total displacement of reinforced earth wall at a different reinforcement strip lengths for a 13m wall heights wall

4.2 Numerical Modelling Using PLAXIS 3D

Part of the objective this research was to develop a 3D Finite Element Method model to simulate the wall deformation of a typical reinforced earth wall heights, H = 13m and was constructed with a various metallic steel strips length (L_R/H = 0.5, 0.7 and 0.9) and with a various range of soil properties obtained from the site investigation and laboratory testing. Thus, a three-dimensional model with 10 nodes triangle elements integrated in the PLAXIS 3D software was used in this analysis.

Figure 18 and Figure 19 shows the analysis results of total displacement precast concrete wall panel based on the soil properties obtained from the Kajang's site (silt soil) and Port Dickson site (clay soil) respectively using numerical modelling PLAXIS 3D.

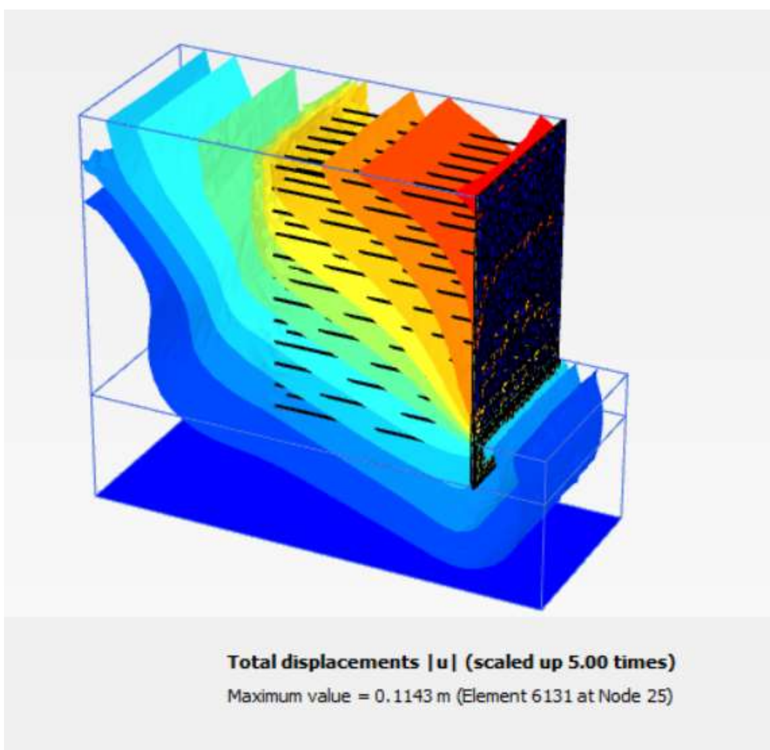

Figure 18 Deformed mesh with total displacement for a 13m wall heights with a reinforcing strip length L_R/H = 0.7 (silt soil)

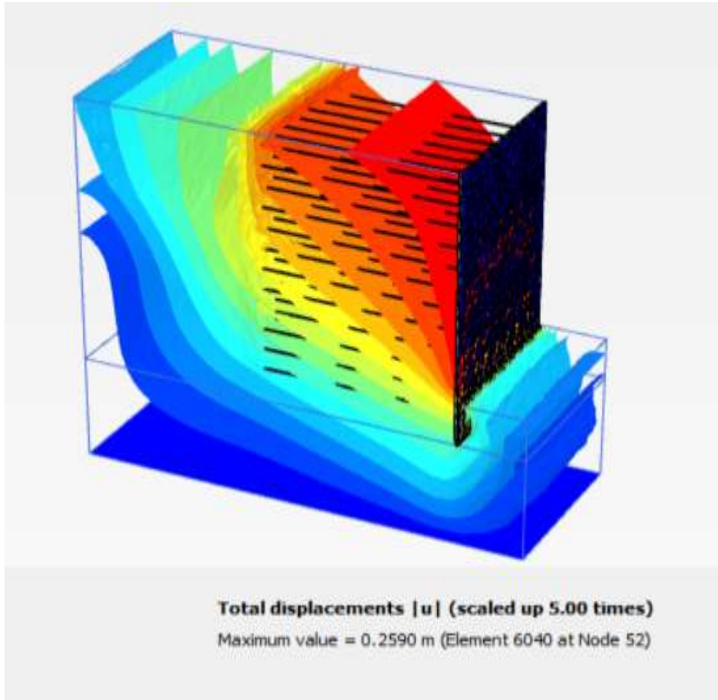

Figure 19 Deformed mesh with total displacement for a 13m wall heights with a reinforcing strip length L_R/H = 0.7 (clay soil)

4.2.1 Comparison Analysis Results Between PLAXIS 2D AND PLAXIS 3D

Through the analysis PLAXIS 2D AND PLAXIS 3D, the end results of the total displacement for PLAXIS 3D was lower compared to the PLAXIS 2D for both sites as visualized in the Figure 20 and Figure 21. Therefore, this results will influence to the factor safety of the wall which PLAXIS 3D will gives a higher value of factor safety compared to PLAXIS 2D as shown in Figure 22 and Figure 23.

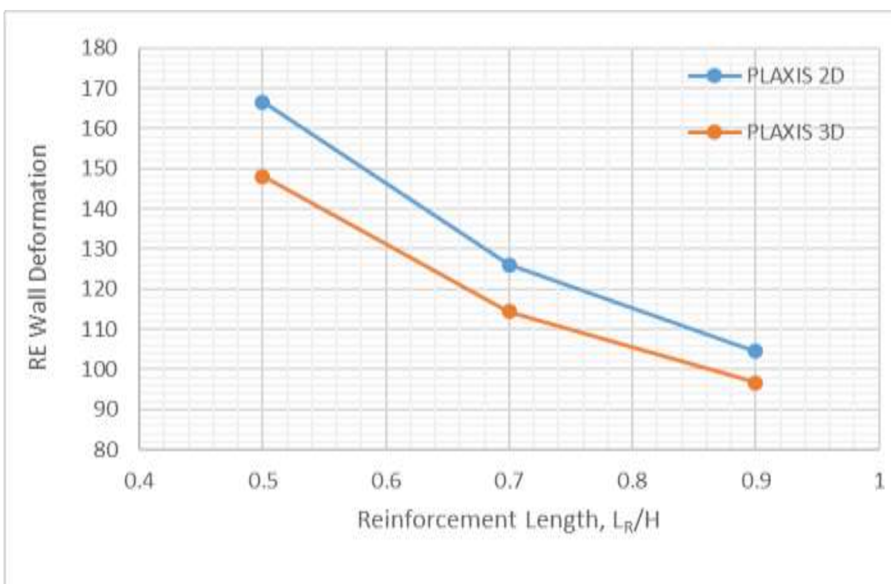

Figure 20 Comparison wall deformation analysis by PLAXIS 2D and PLAXIS 3D for Kajang site - silt soil

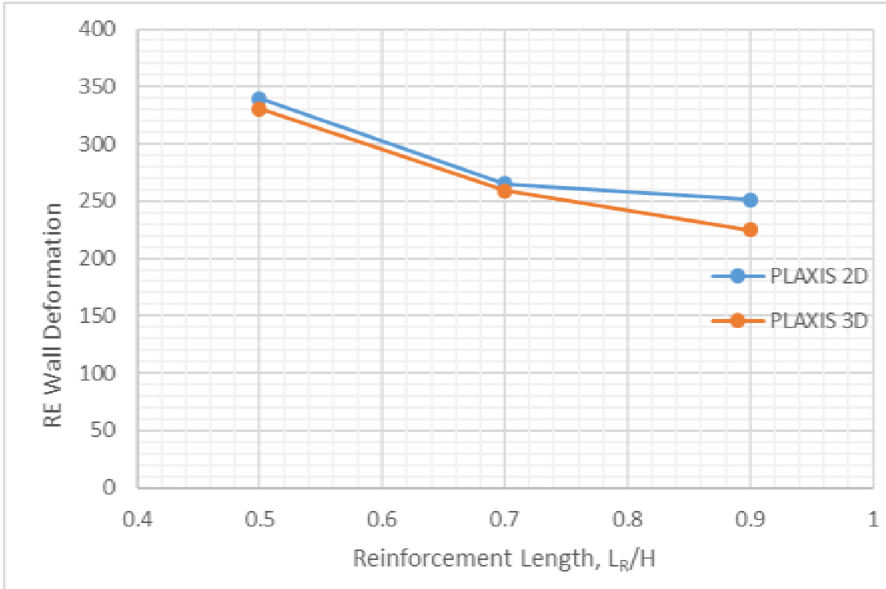

Figure 21 Comparison wall deformation analysis by PLAXIS 2D and PLAXIS 3D for Port Dickson site - clay soil

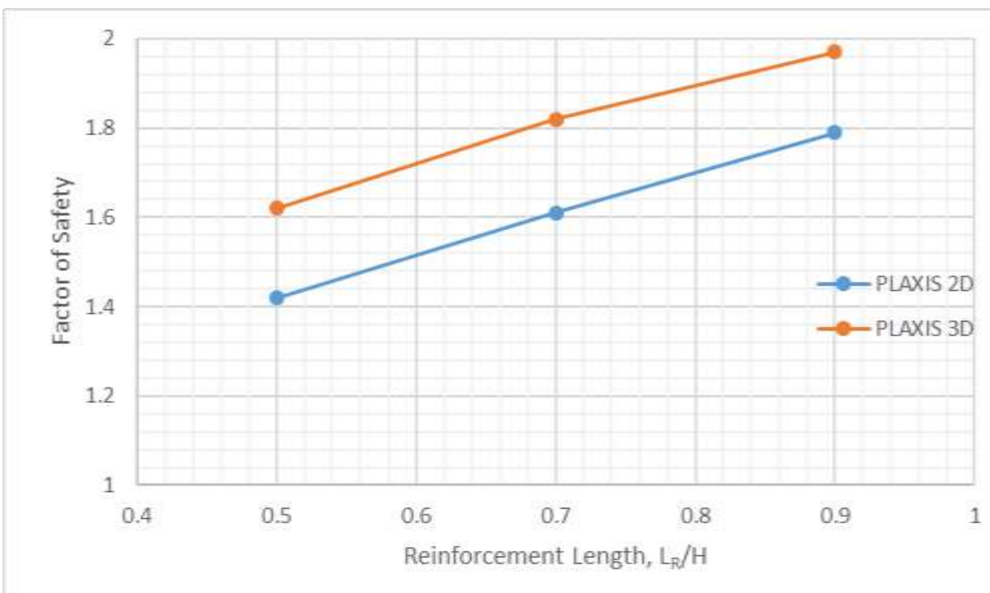

Figure 22 Comparison factor of safety analysis by PLAXIS 2D and PLAXIS 3D for Kajang site- silt soil

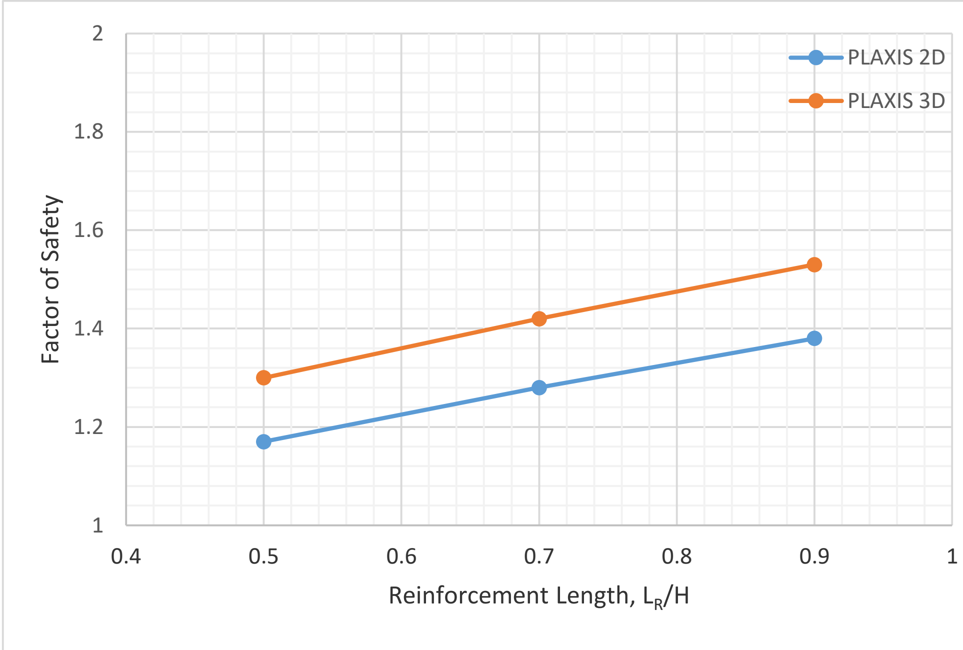

Figure 23 Comparison factor of safety analysis by PLAXIS 2D and PLAXIS 3D for Port Dickson site - clay soil

5.0 DISCUSSION

Based on the results obtained from the analysis by using a finite element method PLAXIS 2D and PLAXIS 3D, we can summarize as bellows:

(a) FHWA approached that minimum reinforcement strip length would be 0.7H where H was the height of the RE wall, but in some restricted area and space constraint, the reinforcement length with 0.5H could also provide the minimum factor of safety of the wall. It was always possible to use reinforcement lengths less than 0.7H as specified in the design guideline if lower factor of safety was allowed but attention should be given to wall deformations as the wall deformation will be increased as the reinforcement length was reduced.

(b) In this research by using PLAXIS 2D with the wall heights of 13m with silt soil as a backfill material in the reinforce zone, the calculated factor of safety, FOS = 1.42 was closed to the design factor of safety recommended by FHWA the design standards must be greater or equal to 1.5 for internal stability of the reinforced retaining structures. However, the reinforced zone area should be design with an adequate of drainage system within the wall area to maintain a low water content in the poorly draining fill that may causes excess pore water pressure and lead to RE walls failure.

(c) From the analysis by using PLAXIS 2D with the wall heights of 13m by using clayey soil as a backfill material in the reinforce zone, it was shown that the calculated factor of safety was 1.38 and 1.17 with the reinforcement strip length 0.9H and 0.5H respectively. This shows that clayey soil with the high plasticity index and considered as an expansive soil contribute the results of lower factor of safety of the reinforced earth walls.

(d) From this research, PLAXIS 2D gives a lower factor of safety compared to PLAXIS 3D. With the higher factor of safety given by PLAXIS 3D model, it can be argued that PLAXIS 3D was over estimation (lower value of total displacement). The differences might be due to reinforcement layers are in 3D surface in the PLAXIS 3D modelling while the reinforcement layers are in the horizontal direction only in PLAXIS 2D.

6.0 CONCLUSION

From this research, PLAXIS 2D gives a lower factor of safety compared to PLAXIS 3D. Therefore, there will be an argument that PLAXIS 3D giving an over estimation results (lower value of total displacement and higher factor of safety) given in the PLAXIS 3D model.

In terms of selection type of backfill material in the reinforced zone, cohesive soil with the high plasticity index (clayey soil) was not suitable to be used as a backfill material at the reinforced zone. The supporting reason is during the analysis in this research was assume the ground water level was below the foundation soil level (FS=1.38). But in the reality, with the infiltration rate of rainwater into the soil will increase the lateral earth pressure behind the facing wall. Thus; it will increase the wall deformation and decrease the factor safety of the wall which there will be a possibility factor of safety will be less than 1.0.

7.0 RECOMMENDATION

In this research, the internal stability of the reinforced earth wall has been studied and analyze by using finite element numerical tools PLAXIS 2D and PLAXIS 3D software. The finality of this research is to find the most dangerous (unfavorable) overall failure model of the reinforced earth walls. A detailed study by varying the reinforced wall geometries at the difference height, reinforcing strip length and soil parameters (cohesion, friction angle and soil plasticity index) was carried out though the numerical analysis. A comparative analysis of these results will be able let us to justify most conservative model that gives a minimum factor of safety (most critical). Therefore, numerical modelling PLAXIS 2D was most conservative model to be used in the design of reinforced retaining walls.

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