NUMERICAL ANALYSIS OF INTERNAL STABILITY OF ANCHORED SHEET PILE WALL WITH DIFFERENT BACKFILLS

A DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE AWARD OF THE DEGREE

OF

MASTER OF TECHNOLOGY

IN

GEOTECHNICAL ENGINEERING

SUBMITTED BY: -

HEMANT KUMAR

2K17/GTE/09

UNDER THE SUPERVISION OF

PROF. A.K. GUPTA

DEPARTMENT OF CIVIL ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY

(FORMELY DELHI COLLEGE OF ENGINEERING)

Bawana Road, Delhi-110042

AUGUST 2020

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi -110042

CANDIDATE'S DECLARATION

I, HEMANT KUMAR, Roll No. 2K17/GTE/09 student of M. Tech (Geotechnical Engineering), hereby declare that the Major project II titled **"NUMERICAL ANALYSIS OF INTERNAL STABILITY OF ANCHORED SHEET PILE WALL WITH DIFFERENT BACKFILLS**" which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associate ship, Fellowship or other similar title of recognition.

Place: NEW DELHI HEMANT KUMAR

Date: 31 AUGUST, 2020

DEPARTMENT OF CIVIL ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi-110042

CERTIFICATE

I hereby certify that the Major project II titled "**NUMERICAL ANALYSIS OF INTERNAL STABILITY OF ANCHORED SHEET PILE WALL WITH DIFFERENT BACKFILLS**" which is submitted by HEMANT KUMAR 2K17/GTE/09, Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: NEW DELHI

Date: 31 AUGUST, 2020

Dr. A.K. GUPTA

PROFESSOR , SUPERVISOR
DEPARTMENT OF CIVIL ENGG
DTU, DELHI 110044

ABSTRACT

In this project the numerical investigation using the finite method is done to study the failure mechanism of anchored sheet pile wall with extensible reinforcements with different backfills models. The details of the numerical approach are given in the literature review. The high strength steel is used in the form of face of the sheet pile wall. Alternatively, we can also provide strength to the sheet pile wall by providing anchors and geogrids. It can also be shown that improvement in the capacity of the sheet pile wall can be done by change in the properties of the backfill materials. In this report more emphasis is given on the study of properties of backfill materials. The methods used in the design of anchored sheet pile walls are free earth support method and fixed earth support methods. Due to the simplicity, the free earth support is widely used method. These conventional support methods use Rankine's active and passive earth pressures which are related to the Mohr- coulomb failure criterion. Rankine's earth pressures are based on the rotation and translation of wall as a rigid body. But the anchored sheet pile walls are far from being a rigid body as they are relatively flexible walls. Also, the anchor in the sheet pile wall creates a stress concentration in the surrounding backfill soil at the anchor level which is basically due to restricted wall movements, which is not considered in the conventional methods of design. Therefore analysis of anchored sheet pile wall using FEM method is more desirable. A study by Bjerrum et al. by finite element method (FEM) also showed the stress concentration at the anchor level.

Finite element models of different backfill soils models are simulated and analyzed along with variation in reinforcement spacing, reinforcement length and reinforcement stiffness. The $\emptyset - c$ reduction procedure, a technique based on shear strength parameter reduction , is used to calculate or simulate the failure conditions. The results of $\emptyset - c$ reduction analysis are used for design purpose of anchored sheet pile walls. In particular, shear strain is used to identify failure surfaces. Inference of the results shows that, for both the backfills i.e. cohesive and granular, the potential failure surface acts like a direct sliding mode. Analysis of both the types of backfills is done and the required failure plane and failure type is determined by the numerical method, also the type of backfill most suitable for the sheet pile wall is concluded.

ACKNOWLEDGEMENT

It gives me immense pleasure in expressing my gratitude to all those people who supported me and have their contribution in making this major project possible. I would like to express my gratitude to the mentor as well as our head of department who gave me the golden opportunity to do this wonderful project on the topic "**NUMERICAL ANALYSIS OF INTERNAL STABILITY OF ANCHORED SHEET PILE WALL WITH DIFFERENT BACKFILLS**"

I express my profound gratitude and indebtedness to **DR. A.K. GUPTA, Professor,** Department of civil Engineering, Delhi Technological University, New Delhi, for introducing the present topic and for his inspiring guidance, constructive criticism and valuable suggestions throughout this project work and helping me in undertaking this project and for being there whenever I needed his assistance.

I also express my gratitude and indebtedness to **PROF. NIRENDRA DEV**, **Head of department,** Department of civil engineering, Delhi Technological University, New Delhi for their astute guidance, constant encouragement and sincere support for this project work. I would also express my gratitude to all the professors of the Department of civil Engineering, Delhi Technological University, New Delhi for their astute guidance and sincere support for this project work.

I am immensely grateful to all those who have helped me making this project better, by providing me their valuable comments and guidance.

Last but not least, my sincere thanks to all my friends & seniors who have patiently extended all sorts of help for accomplishing this undertaking.

HEMANT KUMAR

2K17/GTE/09

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF GRAPHS

CHAPTER1
INTRODUCTION

1.1. GENERAL

Sheet pile wall with reinforced soil is a compound composition which is created by the interconnection of soil with metallic or polymer reinforcements. The main characteristics of the reinforcement layers inside the soil is to enhance the tensile resistance of the soil frame by using friction created across the reinforcement surface and develops passive resistance in the direction opposite to the wall displacement. The average shear stress taken by the soil is decreased, whereas the average normal stress is enhanced on the failure surface. The traditional design of segmental retaining wall or sheet pile wall structures is normally done according to limit equilibrium analysis but practice should also done to design the wall by doing a numerical analysis.

For resisting the lateral pressure of soil and if there is elevation in ground and to prevent the slope, retaining wall and sheet pile wall are constructed to prevent them against failing. There are many ways by which we make the soil slope stable i.e. by construction of gravity wall, cantilever wall, pile wall, anchored wall, soil nailing. Sheet pile wall is constructed by installing concrete pile, timber pile and steel pile and using geogrids and geosynthetics fixed at one end of the wall and to other end geogrids or geotextiles of different properties are used according to the need of the design model. Also we use different backfill materials such as sand backfill and clay backfill, in the sheet pile wall models.

1.2 PRESENT STUDY ELEMENTS

R.H. chen and Y.M. chiu had made the experimental analysis on geotextiles reinforced structures or sheet pile walls to examine the effect of the geogrids and their failure mechanism under surcharge conditions. The main elements in the test involved are facing type of structure or wall type, type of surcharge and the type of reinforcement material used in the experiment. As a result numerical evaluation is completed with the use of the software program Plaxis 2d.

Plaxis 2d is a finite element analysis software in which engineering problems in the field of geotechnical engineering and design are solved. It constitutes of a computer program package for finite element calculation of stresses, strains of structure and foundation, etc.

So, as it is a 2D software all the models are to be constructed in the two dimensional point of view and certainly the analysis can be done according to the required data input. Plaxis 2d has an advantage over other finite difference software as it done the analysis of the structure by creating finite element mesh and calculating stress and strain of the model at different nodes and stress strain points.

Plaxis 2d software is generally used for analysis of soil and rock in which different soil models can be considered and their respective properties are entered and analysis is done for respective models and cases.

The program automatically identifies clusters based on the input geometry lines. Inside the particular cluster the soil has homogeneous properties. In the 2D analysis, the triangular elements have three stress points and six nodes. At the nodes, displacements are calculated, whereas the stresses in each element are calculated at the stress points. The element stiffness matrix is analyzed by numerical (Gaussian) integration using the three stress points.

This analysis is done in two phases: -

- The first phase involves the construction process
- And the second phase involves the determination of the failure condition of the structure by Ø- c reduction technique.

The shear strength parameters, coefficient of friction (tan Ø) and cohesion (c) , are continuously reduced by dividing by a reduction factor $\sum_{\mathrm{Msf}}$ at a given stage in the analysis. The safety factor is then defined as the value of $\sum_{\mathrm{Msf}}$,where for a number of successive continuous reductions the difference between successive $\sum_{\mathrm{Msf}}$ becomes very small. The shear strain increments are analyzed at every node of the model after each calculation step. Concentrated incremental shear strain zones are considered as the potential failure planes. Evaluating the incremental shear strains zone at the end of the Ø – c reduction phase presents the idea about the failure mechanism and the failure plane in spite the fact that the displacement value obtained in the calculation have no realistic meaning.

Several different techniques have been proposed to investigate the actual failure mechanisms in reinforced soil retaining structures. In these techniques, the investigated system parameters are changed to establish a failure.

One of the techniques is the shear strength reduction technique proposed by Matsui and san (1988). In this technique, cohesion (c) and coefficient of friction tanØ are gradually reduced by dividing them by a common shear strength reduction ratio (R) . The failure mechanism of a cut slope is analyzed by using a shear strain failure criterion (strain based failure judgement method). Simultaneously, shear failure occurs when the calculated shear strain exceeds the limit shear strain (i.e. 1%).

A similar technique was used by san et al, who examined gradually reducing k_o in subsequent runs from its empirical value (k_o= 1-sin Ø) until failure occurred using the strain based failure judgement method.

Recently a numerical investigation was conducted by Leshchinsky and Vulova (2001) on reinforced soil walls using the finite difference method. They concluded that as the spacing of the reinforcement decreases, the possibility of development of an active failure surface within the reinforced zone decreases. Also, the required reinforcement strength (at working conditions) is nearly half the value obtained by conventional design.

1.3 OBJECTIVES AND SCOPE OF THE PRESENT WORK: -

The main objective of the project is to analyze the internal stability of the anchored sheet pile wall with different backfill soil models. The sheet pile walls has equipped with different reinforcement parameters which also has been analyzed. Different backfills soil models (i.e granular and cohesive soil models) analysis has been done for finding out the best suited backfill material.

The main scope of the present work is: -

- To generate models of sheet pile structures along with different factors including anchors and geogrid parameters and different backfill soil models.
- Numerical analysis of the above models using the software Plaxis 2d and interpretation of results.
- By analyzing the above models, the best anchors and geogrids parameters and best backfill soil model has been found out.
- To encourage the use of poorly draining backfills (i.e. marginal soil, native soil or cohesive soils) as backfill material where purely-draining soils were not readily available. Experimental studies on native soils have shown that these soils could be used if necessary forethought steps were taken (Benjamin et al. 2007).
- In regions where clean backfill material has difficult to obtain or expensive, the use of native soil or marginal soils can be an advantage by using geosynthetic-reinforced sheet pile walls.

The different models indicated below are: -

1. Anchored sheet pile wall consisting of “sand” as backfill material with “anchors and geogrids as reinforcing parameters”.
2. Anchored sheet pile wall consisting of “sand” as backfill material and “without anchors and geogrids as reinforcing parameters”.
3. Anchored sheet pile wall consisting of “clay” as backfill material “with anchors and geogrids as reinforcing parameters”.
4. Anchored sheet pile wall consisting of “clay” as backfill material “without anchors and geogrids as reinforcing parameters”.

1.4 RESEARCH OBJECTIVE

In conventional design, the backfill material is automatically supposed to be a purely clean granular material but with reinforcement parameters stability of any backfill can be increased. The project objective is to analyze the stability of the sheet pile wall in different soil backfills i.e. clayey and granular backfills. By analyzing the different backfills soil models, the best backfill soil would be used for making the embankments.

1. To generate different models of sheet pile wall structure with varying reinforcement parameters.
2. The project also includes the study of anchors and geogrids in different soil models.
3. Numerical analysis of the above models using the software plaxis 2d and assessment of the results.
4. By analyzing the above models, the most effective anchors and geogrids variation parameters and most stable backfill soil models (i.e. granular or cohesive soil models) has to be find out.

.

CHAPTER 2
REVIEW OF LITERATURE AND SCOPE

2.1 INTRODUCTION

This chapter describes the detailed review of literature performed towards highlighting the need of anchored sheet pile walls in various geotechnical purposes. A brief literature about different geotechnical properties of granular and cohesive backfills is discussed.

2.2 GEO REINFORCED MODELS

Geosynthetic-reinforced models and soils (GRS) are those which uses geotextiles as reinforcement. These models along with sheet pile walls or retaining wall have been used extensively for highway infrastructure and provide some advantages over traditional retaining walls, including generally lower cost, rapid construction, and good performance under static and seismic loading. In recent years, GRS walls also have been developed as bridge abutments with loads applied directly to the top of the reinforced soil mass using a shallow footing. This concept offers significant cost savings in comparison to conventional pile-supported designs and can reduce differential settlements between the bridge and approach embankments.

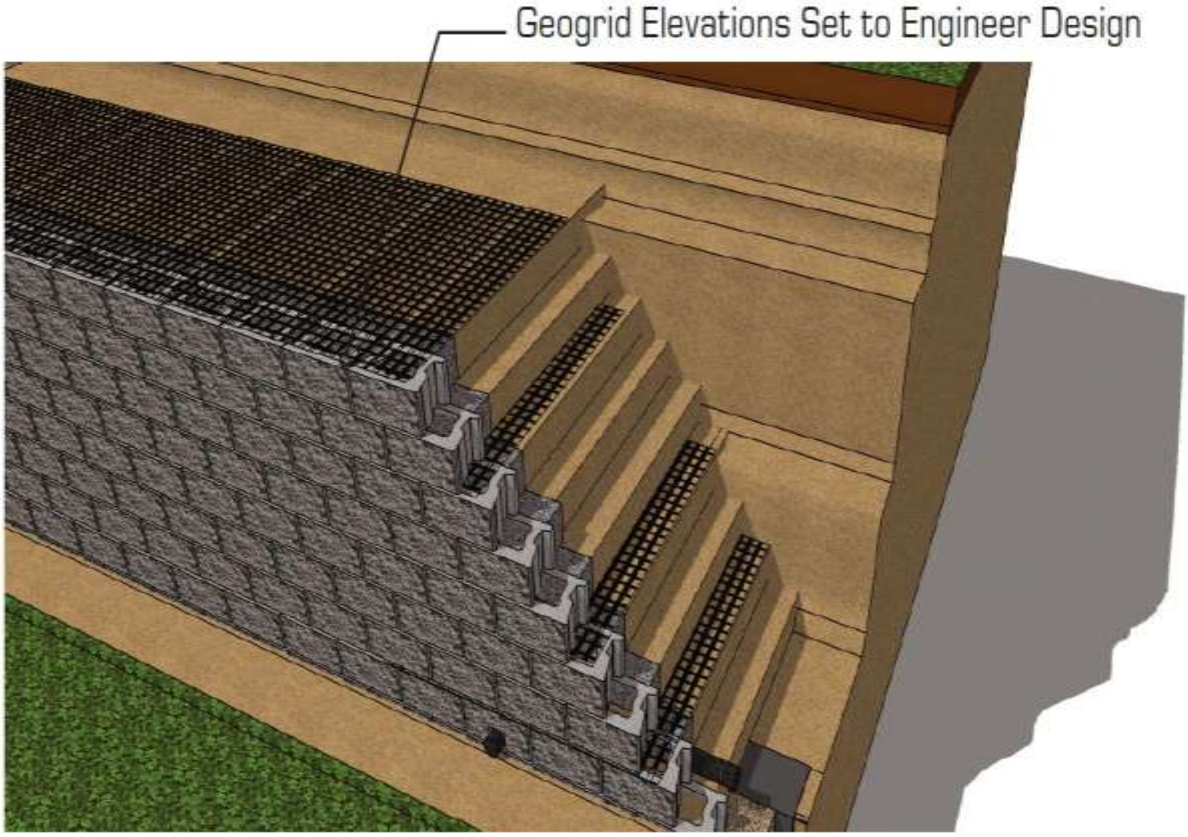


Fig 2.1: Geogrid used in earth structures

2.3 DIFFERENT TYPES OF BACKFILLS

Granular Backfill - "Granular soil" means gravel, sand, or silt (coarse grained soil) with little or no clay content. Granular soil has no cohesive strength. Some moist granular soils exhibit apparent cohesion. Granular soil cannot be moulded when moist and crumbles easily when dry.

Cohesive backfill - Cohesive soil means clay (fine grained soil), or soil with a high clay content, which has cohesive strength. Cohesive soil does not crumble, can be excavated with vertical side slopes, and is plastic when moist. Cohesive soil is hard to break up when dry, and exhibits significant cohesion when submerged.

2.4 REINFORCED SOIL STRUCTURES: BEHAVIOUR, ANALYSIS AND DESIGN

The behavior of reinforced soil structures depends on three of its basic components: soil, reinforcement type and their interaction characteristics. Among these, backfill soil and its engineering behavior governs internal stress distribution, pullout resistance and failure surface envelope (Federal Highway Administration, FHWA 2001). Based on the engineering properties and its interaction with reinforcement and drainage properties, granular soils are ideally suited for reinforced soil sheet pile and retaining wall structures (FHWA 2001, BS8006 2010).

Major functions of the reinforcement members in geo reinforced structures are to sustain tensile loads and deformation, if any developed in the fill. The reinforcements are classified as extensible reinforcement like polymer products and inextensible reinforcements like metallic mat and strip etc. In case of the inextensible reinforcement, deformation of reinforcement is much less than soil deformation. Different types of facing components in retaining and sheet pile wall are being used, basically to prevent the soil to slide away from soil layers and the rows of reinforcement, and also to contribute in stability of the structure by maintaining reinforcement members to function together.

In reinforced soil structure design, soil reinforcement interaction is an important factor, which governs by the composite behavior of soil and reinforcement. The soil reinforcement interactions are controlled by two interactions mechanism namely pullout of reinforcement from soil (pullout mechanism) and soil sliding over the reinforcement (direct shear mechanism). Internal stability of reinforced soil models will be contributed by strength of geosynthetics generally tensile strength and length of reinforcement required to prevent pullout (FHWA 2001). The pullout resistance offered by reinforcement is due to frictional force developed between soil and reinforcement in the reinforced soil which depends on interaction properties.

Different agencies developed design guidelines for reinforced soil models. They are Federal Highway Administration (FHWA 2001 AND 2010), British Standard (BS 8006 2010) and National Concrete Masonary Association (NCMA 1997 and 1998) etc.

Design of reinforced soil sheet pile and retaining walls involves external stability and internal stability considerations. External stability issues consider sliding and overturning of the structure as a monolithic block, bearing capacity of the foundation soil against increased normal pressure near the toe, and a potential deep seated failure surface.
External design or stability ensures that the reinforced block provides enough gravity resistance against the external forces. Internal stability aspects verify geosynthetic performance against tensile stresses or forces and pullout failure. We generally estimate anticipated reinforcement forces i.e. tensile and pullout forces along with the geometry of the reinforcement and potential sliding surface or failure envelope by limit equilibrium analysis. But numerical analysis results are reliable more close to the practical condition.

Bathurst, R.J. et al. (1993) reported a paper on case study which described the design and construction of a 3m high geogrid reinforced wall model comprising 520sq.m of face area which was constructed to support a sloped backfill.

William P. Dawkins (2001) HQ, Department of the Navy, Rowe (1952, 1957), Bowles (1977), and U.S. Steel Corp present curves of bending moment reduction coefficients to be applied to the bending moment calculated by the classical Free Earth Method of anchored wall design to account for sheet-pile flexibility.

The principal differences in the two sets of curves are:

a. Rowe (1952) and Bowles (1977) give curves for “loose” sand and “dense” sand which account for the height of the wall and are implicitly restricted as to position of the anchor with respect to the height of the wall.

b. “Design Manual 7.2” (Headquarters, Department of the Navy 1982) and U.S. Steel Corporation (1975) present only a single curve for each of “medium compact and coarse grained soils” and indicate no limitations on system configuration.

Kristian Krabbenhoft and Lars Damkilde (2002). limit analysis has been used for decades in civil and mechanical engineering practice as a means of analysing structures of materials with reasonable accuracy. Such materials can be described as being rigid and perfectly plastic includes hard steel, concrete and soils. This problem is relevant when determining e.g. the necessary external pressure in modeling problems, which arises when evaluating the bearing capacity of reinforced soil or the stability of slopes which includes retaining wall and sheet pile walls.

Hemanta Hazarika et al. (2007) mention in their study that Scrapped tire-derived materials, such as tire chips and tire shreds, can be categorized as three dimensional geosynthetic. Introduces recent Japanese experience in geotechnical related applications of geosynthetic that focus mainly on tire chips and tire sheds. Three specific applications of tire chips and tire shreds are introduced here. They are: (1) tire shreds to improve drainage; (2) sand-mixed tire chips to mitigate earthquake damage; and (3) tire chips mixed with cement treated clay to improve toughness and ductility. The developed techniques related to these applications, verification through model testing, as well as element testing and the field applications are presented.

Guler, E. (2007). discussed the analysis of wall models with different types of backfills. The models used by the Guler are diagrammed below. Two instrumented full-scale geosynthetic reinforced test walls (Wall 1, Wall 2) were modeled using the same finite element code as used in this study. All the walls were 3.6 m high with a target facing batter of 88 degree to the vertical. They had a maximum 6 m of backfill. The first wall was constructed with 2.52 m long biaxial polypropylene geogrid, and each reinforcement layer had 0.6 m vertical spacing and has granular material as backfill material.
The second wall was identical to the first one except that the backfill material of the second wall has cohesive material instead of granular material.

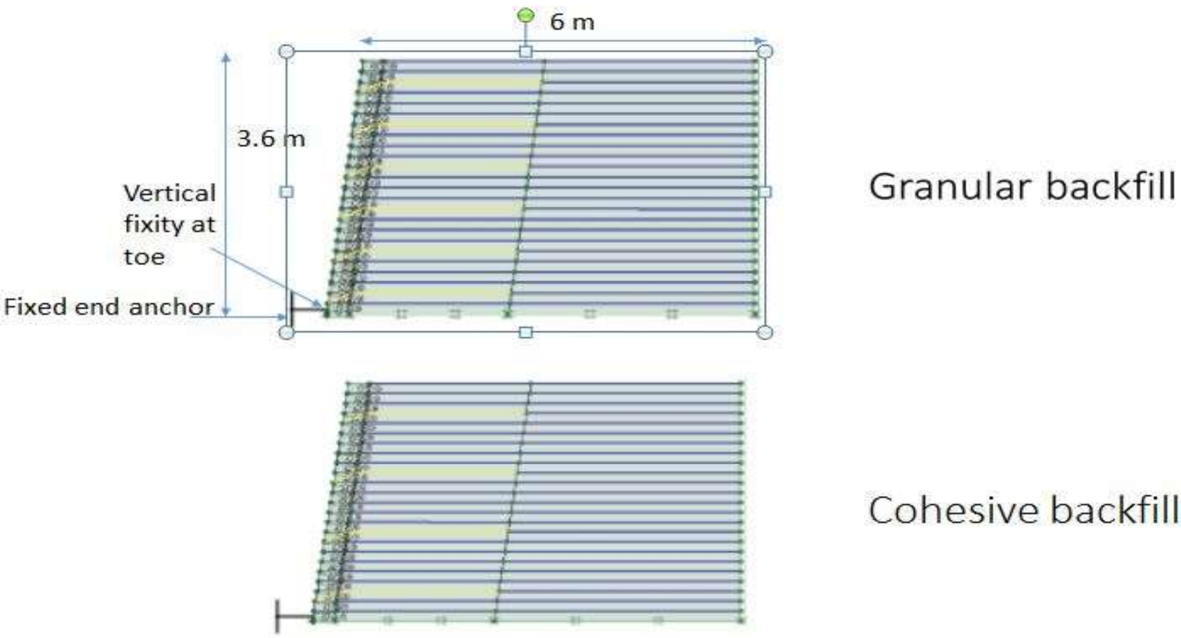


Fig 2.2: Soil reinforcement with different backfills

All modular facing units were solid masonry blocks with a continuous concrete shear key. The blocks, each weighing 196 N, were 300 mm long, 150 mm high and 200 mm wide. From the above model the plane strain compression hardening model for granular and cohesive Soil is determined as shown in below figure 2.3 (ref paper E. Guler, 2007).

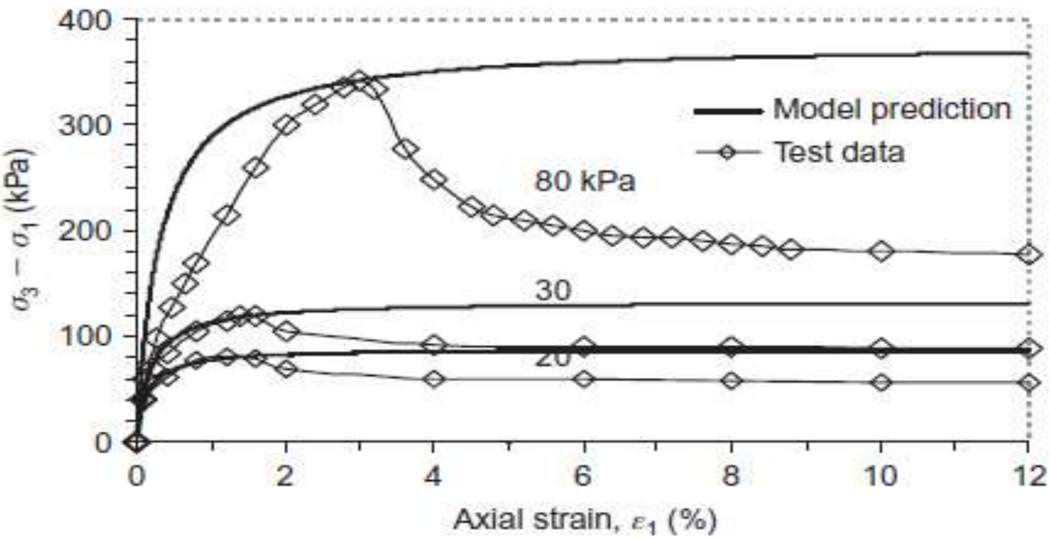


Fig.2.3: Plain Strain Compression test analysis for Hardening Soil model for Granular and Cohesive Soil (E. Guler, 2007)

Hornsey, W. P. et al. (2009) mine owners and operators are presented today with a diverse range of geosynthetic products which all appear to provide similar benefits. Key factors in selecting geosynthetic for use in the mining industry include construction and operational durability issues such as slope stability, puncture resistance and resistance to weathering; but also their chemical resistance when they come into contact with the extreme liquors present on many mining operations and processes.

Chen, R.H. and Chiu, Y.M. (2008) published a paper which described the deformation and settlement of the backfill and concluded that both got increased with increasing angle and magnitude of surcharge.

Liu, C. N. et al. (2009) in order to study the interface shear strength of soil against geosynthetic they have conducted a series of large scale direct shear tests with different soils (sand, gravel and laterite) against PET-yarn geogrids of various tensile strengths, percent open area and aperture patterns. First, the appropriateness of different set-ups of a lower shearing box is examined in this study. It reveals that a lower box which is filled with the test soil and is of the same size as the upper box is more suitable for testing the soil/geogrid interface. The test results show that the soil/PET-yarn geotextile interface has significantly lower shear strength than soil strength.

Yang, G. et al. (2009) have carried out the monitoring during construction of a cast-in-situ concrete-rigid facing geogrid reinforced soil wall model in the Gan (Zhou)-Long (Yan) railway main line of China. The monitoring included the vertical foundation pressure and lateral earth pressure of the reinforced soil wall facing, the tensile strain in the reinforcement and the horizontal deformation of the facing. The vertical foundation pressure of reinforced soil wall is non-linear along the reinforcement length, and the maximum value is at the middle of the reinforcement length, moreover the value reduces gradually at top and bottom.

Anubhav and Basudhar, P. K. (2010) since, the performance of geosynthetic reinforced soil structures depends also on the characteristics and behavior of the interface between soil and geosynthetic, they studied on that. They conducted a direct shear test to study the shear force–displacement behavior at the soil–geotextile interface using two differently textured woven geotextiles.

Omer Bilgin (2010) the construction of sheet pile walls may involve either excavation of soils in front or backfilling of soils behind the wall. These construction procedures generate different loading conditions in the soil and therefore different wall behavior should also be expected. The conventional methods, which are based on limit equilibrium approach, commonly used in the design of anchored sheet pile walls do not consider the method of construction. However, continuum mechanics numerical methods, such as finite element method, make it possible to the analyses and design of sheet pile walls. The effect of wall construction type for varying soil conditions and wall heights were investigated using finite element modeling and analysis. The influence of construction method on soil behavior, wall deformations, wall bending moments, and anchor forces were investigated. The study results indicate that walls constructed by backfill method yield significantly higher bending moments and wall deformations.

Nicolas, F. (2011) et al. prepared a paper to determine the internal behavior of a mechanically stabilized earth wall in which the reinforcement of the wall is given with 3 different strips by considering 3 individual models and the results obtained from them are studied and compared.

Indraratna, B. et al. (2011) have focused on the interface between ballast and geogrid copes with fouling by coal fines. They have investigated the stress-displacement behavior of fresh and fouled ballast, and geogrid reinforced ballast through a series of large-scale direct shear tests.

Liu, J. et al. (2011) have focused on the problem of static liquefaction of sand. Using a ring shear apparatus, they have explored the possibility of fiber reinforcement as a new method to improve the liquefaction resistance of sand. In order to understand the effect of the fiber content and sand density on the static liquefaction behavior of fiber-reinforced sand, a series of undrained ring-shear tests which was developed at the Disaster Prevention Research Institute (DPRI), Kyoto University were carried out on saturated samples with different fiber content and sand density, and the test results and mechanisms of fiber reinforcement were then analyzed.

Colin JFP Jones et al. (2011) gave the applications of geosynthetics related to civil engineering and environmental industries and are well established as providing filtration, separation, reinforcement, and drainage and acting as barriers. In practical conventional geosynthetic materials have a passive role, e.g. barriers stop the passage of liquids;

reinforcement provides tensile resistance and drains provide a passage for water. New applications for geosynthetics can be identified if the geosynthetic can provide an active role, initiating chemical or physical change to the soil matrix in which it is installed as well as providing the established functions.

Maheshwari, B. K. et al. (2012) have studied on liquefaction resistance of Solani sand reinforced with geogrid sheet, geosynthetic fiber and natural coir fiber and reported the results. They were carried out the tests on shake table (vibration table) with sand samples prepared at a relative density of 25%, with and without reinforcements. Synthetic geogrid sheets were used in three different combinations comprising of three layers, four layers, and five layers.

Omer Bilgin (2012) Steel sheet pile walls are being widely used in civil engineering projects as excavation support systems, cofferdams, cutoff walls under dams, slope stabilization, waterfront structures, and floodwalls. Sheet pile walls used to provide lateral earth support can be either cantilever or anchored depending on the wall height. Based on the function of the wall, the characteristics of the foundation soils, and the proximity of the wall to existing structures, sheet pile wall can usually be cantilever for heights less than 3–4.5 m. Anchors are used for higher walls or when the lateral wall deformations need to be restricted.

Omer bilgin (2012) have studied on conventional methods used for the design of anchored sheet pile walls which is based on the lateral force and moment equilibrium of active and passive earth pressures and anchor force. Although it has been known for decades that the stress concentration occurs around the anchor level because of the restricted wall movements. A parametric study using conventional and numerical methods was performed to investigate the behavior of single-level anchored sheet pile walls, and the lateral earth pressures, wall bending moments, and anchor forces were analyzed. The study results indicate that the conventional methods for the cases studied overestimate the wall bending moments, whereas the anchor forces are underestimated. This study suggests the analysis of anchored sheet pile wall with numerical methods instead of conventional methods should be done. New lateral earth pressure coefficients that consider the effect of stress concentration around the anchor level were developed and proposed to be used in the design of single-level anchored pile wall. Thus this new earth pressure parameter provides more practical result.

Naveen Kumar and Arindam Dey (2014) The paper reports the finite element (FE) study to assess the behavior of a flexible sheet pile wall. The effect of excavation and backfilling process on the behavior of the sheet pile wall have been thoroughly investigated and the results are presented in terms of the wall deformations and bending moments, developed anchor forces, and the earth pressures developed on both active and passive side of the wall. It has been observed that the sheet pile wall systems in the dewatered excavation cases are failing before the desired excavation depth, and hence, forms a crucial part of the analysis. It has been observed that anchor forces generated in the backfill case with loose sandy soil, had relatively higher values. The finite element modeling gave a good idea about the stress strain developed, strength mobilization, development of slip surface and failure pattern of the soil wall system through diagrams of earth pressure developed, relative shear stress, formation of plastic points and incremental deviatoric strains.

Mohamed Faizur Rahaman Khazi and Mahammood Vazeer (2016) The anchored sheet pile wall is analyzed by Finite Element method, FEM and SAP2000. The method uses soil spring models for soil structure interaction (SSI) and sheet pile is modeled as beam element and the embedded part of the pile as a beam on Winkler foundation. The method is validated with the examples available in literature. The method is used for the case study of the failure of WQ-7 berth of Visakhapatnam Port which failed immediately after construction during post 2004 Indian Ocean tsunami. Seismic and non-seismic loading conditions are considered in the analysis along with the effect of liquefaction. In the investigation during the analysis it is found that the failure of the structures is not due to liquefaction rather may be due to basal heave failure on account of inadequate pile penetration and mud flow.

Dina A. Emarah and Safwat A. Seleem (2017) the walls of sheet piles are widely used as a part of numerous structural designing activities, for example earth retaining structures, braced cuts, cofferdams, and continuous walls of waterfront structures . Different types of sheet piles are used for these targets, such as steel and precast concrete. Steel sheet piles have higher resistance against the high stresses which are produced when they drove into stiff soils. They divided according to height to cantilever and anchored sheet piles. The anchored sheet piles are recommended for walls of height exceed 6 m. By using anchor rods, the required penetration depth and the cross sectional area of the sheet piles were decreased. Many researchers studied the sheet pile wall behaviour and stability. Also, they used the finite element method (FEM) for many types of retaining walls subjected to different loading conditions. Many of following parameters were required for the design of sheet pile walls, such as lateral pressures and forces that acting on the sheet pile wall, penetration depth as well as stresses in the anchor and geogrids.

CHAPTER 3
NUMERICAL MODELING

Numerical modeling techniques are powerful tools that have been used to study the behavior of various structures under variety of loading conditions. Numerical models are particularly advantageous in situations where the prototype structures are too big to be tested in laboratory. Even if they can be tested using small scale models, it is difficult to analyze various behavioral aspects owing to the limitation associated with the instrumentation and tediousness in repeating the laboratory tests for variety of parametric variations. Numerical studies on GRS walls have been started in early nineties and becoming more popular due to advent of increasing computational facilities. The response of numerical model depends on the selection of constitutive relations for different materials involved in the model and their parameters. The reinforced soil sheet pile wall comprises of soil, reinforcement elements and structural facing elements. These materials are dissimilar and proper interface behavior between them shall also be considered for proper simulation and analysis. Brief description of the numerical program, and implementation of soil constitutive models and their properties are presented in this chapter.

The numerical analysis of reinforced soil sheet pile walls for this parametric study was carried out using the computer program Plaxis. In this finite element program, a two dimensional plane-strain model is used.

A geometrical model in this program is a representation consisting of points, lines and clusters. The program automatically recognizes clusters based on the input geometry lines. Within the cluster the soil properties are homogeneous.

In the 2D analyses, the triangular elements have three stress points and six nodes. Displacements are calculated at the nodes, whereas the stresses in each element are calculated at the stress points. The element stiffness matrix is evaluated by numerical (Gaussian) integration using the three stress points.

The analysis was conducted in two phases: the first phase represents the construction process, and the second phase is the determination of the failure conditions of the structure by Φ –c reduction (Matsui and San 1988).

The shear strength parameters, coefficient of friction (tan Φ) and cohesion (c), are incrementally reduced by dividing them by a reduction factor ∑ Msf at a given stage in the analysis:

$$\sum \text{Msf} = \frac{\tan\emptyset_{\text{input}}}{\tan\emptyset_{\text{reduced}}} = \frac{c_{\text{input}}}{c_{\text{reduced}}}$$

∅ input = initial friction angle of the soil.

∅ reduced = friction angle of the soil after reduction.

c input = initial cohesion of the soil.

c reduced = cohesion of the soil after reduction.

The safety factor is then defined as the value of ∑ Msf, where for a number of successive incremental reductions the difference between successive ∑ Msf becomes very small. The shear strain increments after each calculation step are calculated at every node of the model. Concentrated incremental shear strain zones are considered as the potential failure planes. Evaluating the incremental shear strains at the end of the ∅ –c reduction phase gives a good idea about the failure mechanism despite the fact that the displacement values obtained have no physical meaning according to Brinkgreve and Vermeer 1998.

3.1 MATERIAL MODELS FOR NUMERICAL SIMULATION

Modeling the reinforced soil sheet pile wall comprises of backfill soil, facing and reinforcement and interface elements between dissimilar materials. Various components of numerical models of steel and concrete sheet pile walls, reinforced with geosynthetics with their modeling parameters are discussed in the following sections.

3.1.1 BACKFILL SOIL

Static and dynamic behavior of any soil in numerical analyses is governed by the choice of appropriate soil constitutive model. Different researchers simulated the behavior of backfill soils with different constitutive models. For example, Mohr- Coulomb shear criteria, modified generalized plasticity model, geologic cap model, and time dependent generalized plasticity model. The numerical model studies by Huang et al. (2009) and Zarnani and Bathurst (2011) showed that numerical models of reinforced soil walls, with simpler constitutive model are adequate to predict the static behavior and also its hysteretic behavior during cyclic loading.

In present study, the static behavior of soil is simulated with elasto-plastic Mohr Coulomb material, coded with stress dependent hyperbolic soil modulus proposed by Duncan et al. (1980). Dynamic behavior is simulated as non-linear and hysteretic constitutive soil model follows the Masing rule (Masing 1926).

3.1.2 GEOSYNTHETIC REINFORCEMENT

Geosynthetic reinforcement members are planner products manufactured from polymeric materials. The main function of reinforcement member within the soil is to reinforce the backfill soil by developing tensile force in it. The reinforcements are simulated as structural elements in numerical simulations of reinforced soil wall.

Different researchers adopted different methods to model the reinforcement members. In this present study, the geosynthetic reinforcement is modeled using the geogrid structural element available in plaxis. The geogrid elements are three nodded shell elements used to model flexible membrane that resist tensile stresses as membrane but do not resist any bending loading or moment.

3.1.3 INTERFACE ELEMENT

An interface element enables proper interaction between dissimilar materials. Karpurapu and Bathurst (1995) modeled the interface between reinforcement layer and soil as a zero thickness element. The shear strength and stiffness behavior between the soil and reinforcement are modeled as stick-slip formulation following Mohr Coulomb failure criterion.

The interface between backfill soil and flexible sheet pile wall controls the relative movement between them. The relative interface movement is controlled by interface normal stiffness (k_n) and shear stiffness (k_s).

The interface behavior of geogrid is represented numerically at each geogrid node by a rigid attachment in normal direction and spring-slider in the tangent plane to the geogrid surface. The orientation of the spring-slider changes in response to the shear displacement between geogrid and neighboring soil elements. The shear behavior of the geogrid-soil interface is cohesive and frictional in nature and is controlled by effective confining stress σ_m and coupling spring properties: (i) stiffness per unit area *k* (ii) cohesive strength *c* (iii) friction angle Ø.

3.1.4 SOIL-REINFORCEMENT INTERACTION

The soil-reinforcement interaction is one of the major influencing parameters governing the performance of reinforced soil sheet pile wall model. In a GRS model, the wall (facing) movement mobilizes interface shear stress between soil and reinforcement. Further, this leads to tensile stress mobilization within the reinforcement (geosynthetic), which supports the facing structure or sheet pile to keep the model stable. It mobilizes pullout mechanism which defines by degree of movement and counteracted or resisted by confining stress. In general, soil-reinforcement interaction behavior/parameters can be determined experimentally by either direct shear tests or pullout test.

CHAPTER 4
FORMULATION OF THE PROBLEM

4.1. INTRODUCTION

4.1.1. Line diagram of problem:-

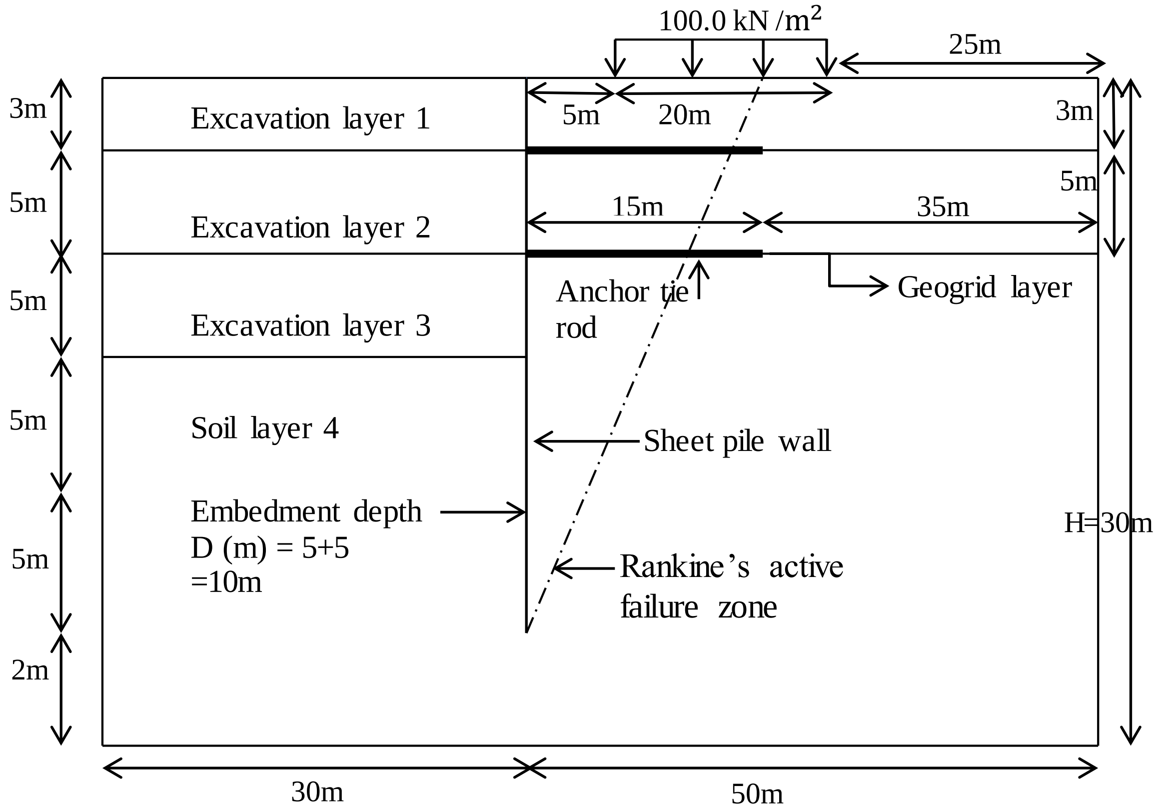


Fig.4.1: Typical wall section of the anchored sheet pile wall

4.1.2 Brief of the problem :-

In the given problem of the sheet pile wall, the three layers of the soil has been excavated sequentially and the model along with sheet pile wall contains different soils backfills such as sand and clay are analyzed. Also backfill of the soil contains surcharge load of 100kN/m² which resembles the live load on the backfill. Therefore analysis of the sheet pile wall is done for the different backfill with respect to the factor of safety of the sheet pile section with numerical analysis.

4.2. STEPS INVOLVED FOR GENERATION OF RETAINING WALL MODEL

Step 1: In the project properties and dimensions in the x and y direction are entered, in this case dimensions are entered as 80m and 30m respectively. So beyond this, model cannot be extended.

Step 2: Coordinates of the sheet pile wall are known so that we can easily make it at the time of modelling. As modelling is in 2D, so two dimensional coordinates are to be known.

Step 3: In the model generation, we have 3 elements that are generated which consists of elements as one element is volumes consisting of soil, one element is geogrid with anchors and other element is surface load that applied on the top surface of the wall.

Step 4: At the sheet pile wall, the soil namely are the sand soil and clay soil. In the given ribbon "create the boundary of the soil cluster by drawing a rectangle area of 80m x 30m and fill the soil cluster with required soil type such as sand soil or clay soil. Choose the properties of the clay soil or sand soil according to the specific properties or given as per our problems so that we get a required soil cluster.

Step 5: Now to assign the soil, material set option is used in the ribbon, a new material set dialog box is opened and the properties of the soil such as material model, modulus of elasticity, poisons ration, cohesion and angle of internal friction, angle of dilation and the interface value are entered as per the required model of the soil.

Step 6: Now a surface load is created at the top of the wall assigning the required value in the downward direction. After assigning the required surface load, we would go for the creation of mesh generation in the window, we go to generate mesh option in the ribbon and mesh is generated using medium coarseness or global coarseness in the model.

Step 7: In the Mesh mode, "generate mesh" option is selected and appropriate mesh is generated. After generation of the mesh to view mesh, "view mesh" option is selected and refinement of the mesh is done near the sheet pile wall and near the geogrid layers.

Step 8: As the water level is present at the great depth in the model, the water levels modes in the initial conditions is skipped and proceed to generation of initial stresses option where we generate initial stresses in the model by deactivating the surface load and the sheet pile wall and taking ∑M weight =1.0 so that the whole soil mass is considered in the generation of initial stresses in the model.

Step 9: Now we proceed to the calculation stage, by clicking on the save as project dialog box to save the data according to the project name.

By taking ∑M weight =1.0 , a calculation dialog box is opened with initial phase as default.

Step 10: So by doing this, generation of the model, generation of the mesh and phase initialization are done. So we will define different phases in the calculation mode such as phase1, phase2, phase 3, phase4, phase5, phase6, etc. and all the phases executed after the initial phase in the chronological order.

Step 11: After the calculation of the model or stage construction has finished we can see the output of the result using "view output" in which the result according to the phases done can be known such as displacements, stresses, strains, factor of safety, etc. Review of the project can be done from the obtained result.

Step 12: Similarly steps 1 to 11 are repeated for the different sheet pile wall models. The obtained results from the walls are collected and analyzed.

Based on the above steps, many models are generated which include: sheet pile wall of different backfills such as clay and sand backfills, in addition with condition of different surcharge load. Also analysis is done on the sheet pile wall with different backfills with and without anchors and geogrids elements and analyze the stability of the sheet pile structure.

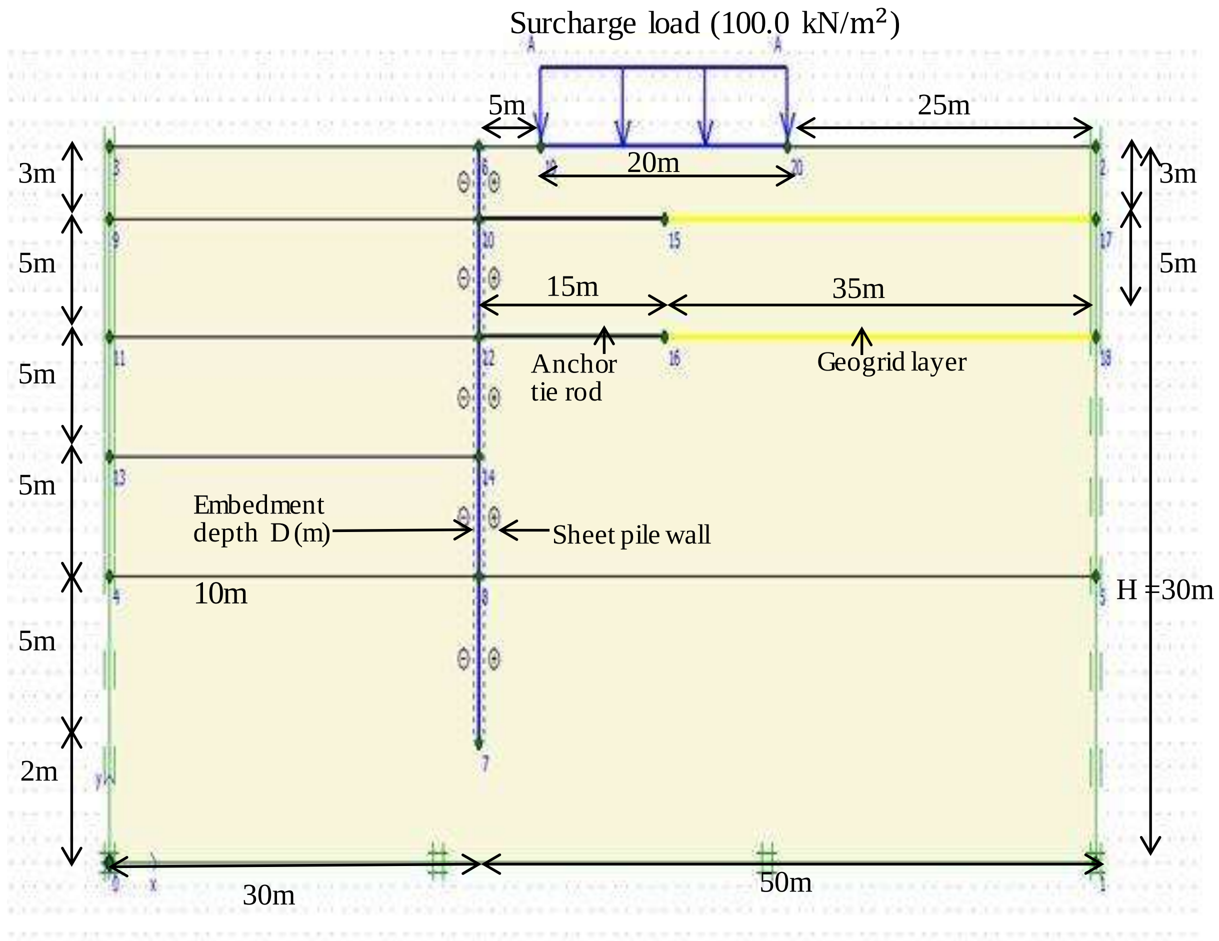


Fig.4.2: Modeling of the anchored sheet pile wall for analysis

4.3. CONVENTIONAL DESIGN METHOD :- FREE EARTH SUPPORT METHOD

The anchored sheet pile is designed according to the limit equilibrium approach. The free earth support method is used for the design of wall. The design method is based on active and passive earth pressures, which are concerned with the failure condition based on the Mohr Coulomb failure criterion. A typical wall section is shown in the above figure. The anchored sheet pile wall design using the free earth support method is summarized below. The wall penetration depth required or the embedment depth is determined by considering the moment equilibrium about the anchor elevation, about upper anchor elevation in this problem.

$$P'_A\, d_A + P_{WA}\, d_{WA} = \frac{P'_P\, d_P}{FS} + P_{WP}\, d_{WP} \qquad \text{……….(1)}$$

P'_A and P'_P are resultant effective active and passive earth forces respectively
P_{WA} and P_{WP} are resultant hydrostatic forces on the active and passive sides of the wall
d_A, d_P , d_{WA} , d_{WP}, d_{WA} are moment arms used in the problem
FS = factor of safety.

Since water level is not taken into consideration, therefore hydrostatic forces cancel each other. Then the above equation (1) can be simplified and rewritten as follows:

$$P'_A d_A = \frac{P'_P\, d_P}{FS} \qquad \text{………..(2)}$$

The penetration depth or the embedment depth is determined from above equation (2) and is calculated as follows :

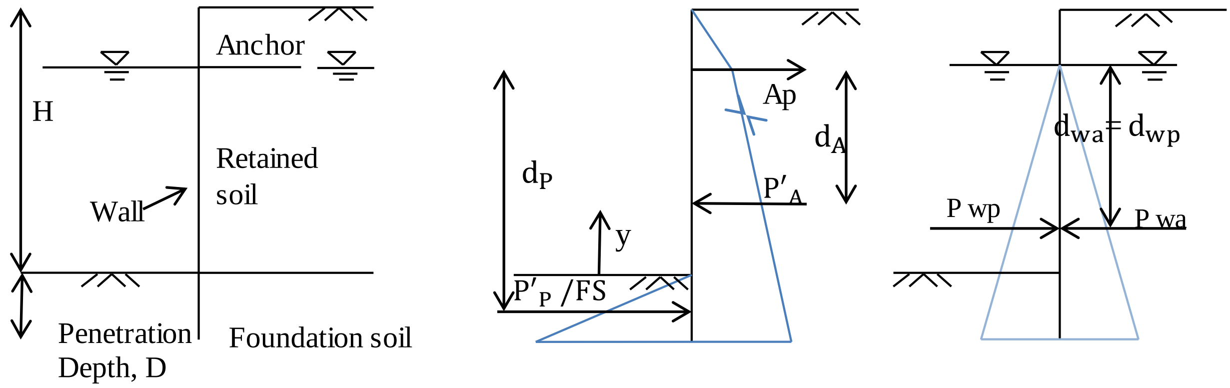
Table 4.1: Penetartion depth

Anchor wall height (m)	Penetration depth (m)
23	10
12	4

Once the penetration depth has been calculated, the anchor forces can be calculated from the horizontal equilibrium and is given as:

$$A_P = P'_A - \frac{P'_P}{FS} \qquad \text{……….(3)}$$

A_P = Anchor forces in tie rod
P'_A and P'_P are resultant effective active and passive earth forces respectively



a) Wall

b) Earth pressures and moment arms

c) water pressures

Fig. 4.3: Anchored sheet pile wall analysis

Based on the active and passive earth pressure distributions and the calculated anchor force, the wall maximum bending moment is determined. The design moment is calculated by applying the moment reduction factor (Rowe 1952) to the calculated maximum bending moment. The sheet pile section is selected based on the design moment and the wall design is completed by selection and design of an anchorage system.

Anchor tie rod :-

The length of anchor tie rod is determined according to the Rankine's active earth pressure failure envelope , the envelope makes an angle of (45 - Φ/2) with the sheet pile wall and the required anchor tie rod length is determined with expression tan (45 - Φ/2) * Sheet pile length.

Anchor tie rod length = Sheet pile length (m) x tan $(45 - \Phi/2)^{o}$

Table 4.2: Anchor tie rod

S.no	Sheet pile wall height (m)	Active failure envelope	Anchor tie rod required (m)	Anchor tie rod Provided (m)
1	15	15* tan $(45 - 35/2)^{o}$	7.808	15
2	20	20* tan $(45 - 35/2)^{o}$	11.93	15

Specification of material properties: -

Material properties of the granular backfill: -

Table 4.3: Granular backfill

Soil properties	Values	Units
Material Model Material type Soil peak friction angle, Φ Cohesion, c Dilation angle, (degrees), ψ Unit weight, unsaturated Unit weight, saturated Stiffness modulus Poisson's ratio Interface	Mohr coulomb model Undrained 35 -- 0.0 17.00 20.00 $2 * 10^4$ 0.30 Rigid	 (degrees) (kPa) (degrees) (kN/m^3) (kN/m^3) (kPa)
Anchor Prestress force	 200	 (kN/m)

Material properties of the cohesive backfill: -

Table 4.4: Cohesive backfill

Soil properties	Values	Units
Material Model Material type Soil peak friction angle, Φ Cohesion, c Dilation angle, (degrees), ψ Unit weight, unsaturated Unit weight, saturated Stiffness modulus Poisson's ratio Interface	Mohr coulomb model Undrained 24 20 0.0 16 18 $2 * 10^4$ 0.25 Rigid	 (degrees) (kPa) (degrees) (kN/m^3) (kN/m^3) (kPa)
Anchor Prestress force	 200	 (kN/m)

Material properties of the Steel Sheet pile wall (diaphragm plate) : -

Table 4.5: Sheet pile wall

Parameters	Name	Value	Unit

Type of behavior	Material type	Elastic (HYS Steel)	-
Elastic modulus	E	$2* 10^5$	kN/m^2
Normal stiffness	EA	$7.5 *10^6$	kN/m
Flexural rigidity	EI	$1.2 *10^5$	kNm^2/m
Equivalent thickness	D	0.346	m
Weight	W	8.300	kN/m/m
Poisson's ratio	U	0.150	-

Material properties of the Anchor rod : -

Table 4.6: Anchor rod

Parameters	Name	Value	Unit
Type of behavior	Material type	Elastic (HYS Steel)	--
Normal stiffness	EA	$2.0*10^5$	kN
Spacing out of plane	L	2.50	m
Maximum force	F max,comp	$1 * 10^{15}$	kN
	F tmax,tension	$1 * 10^{15}$	kN
Anchor prestress force	F	200	kN/m

Material properties of the Geogrid sheets : -

Table 4.7: Geogrid sheet

Parameters	Name	Value	Unit
Type of behavior	Material type	Elastic	--
Normal stiffness	EA	$1.0*10^5$	kN/m

Interfaces at various sections :-

Sheet pile wall (diaphragm plate) and anchor and geogrid layers are modeled as linear elastic units. Their unit weight, stiffness modulus and Poisson's ratio are taken accordingly. Two different types of interface were utilized: horizontal interfaces between geogrids and backfill soil, and vertical interfaces between sheet pile wall and backfill soil. Sheet pile wall and soil interfaces are illustrated in Figure 4.4.

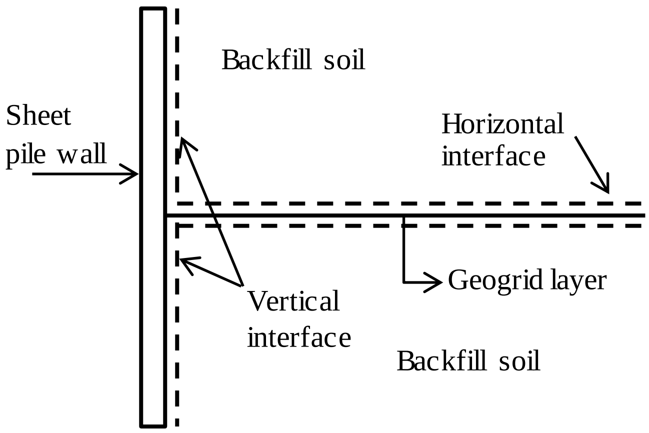


Fig. 4.4: Interfaces at various sections

Geogrid :-

The extruded biaxial polypropylene geogrid reinforcement was modeled using infinite elastic elements. In the above model, the geogrid layers are connected to the backside of the modular blocks or wall with help of anchors.The bond between elastic modular blocks or wall and the elastic anchor element was rigid since slippage is not a concern in the elastic model (no shear strength parameter in elastic material). It was observed that there was no evidence of the geogrid pulling out (or deformation) from the backfill material after the analysis.

Boundary and Toe Conditions :-

A horizontal (basically x-direction) restraint boundary was assigned to the right side and to the left side of the model. The bottom boundary of the model was assumed as fixed in both the x and y directions. In the physical model, a vertical fixity is assumed at the bottom of the model in the numerical analysis. Also, on the left and right side of the model provided a horizontal fixity but not the vertical fixity (y – direction) and enabled the measurement of horizontal and vertical reactions.

Construction Process :-

The construction of the wall was modeled with the 'staged construction' procedure, where soil layers of equal thickness (the same as the height of one layer) were placed sequentially until the final excavation soil height is reached.

CHAPTER 5

ANALYSIS AND DISCUSSION

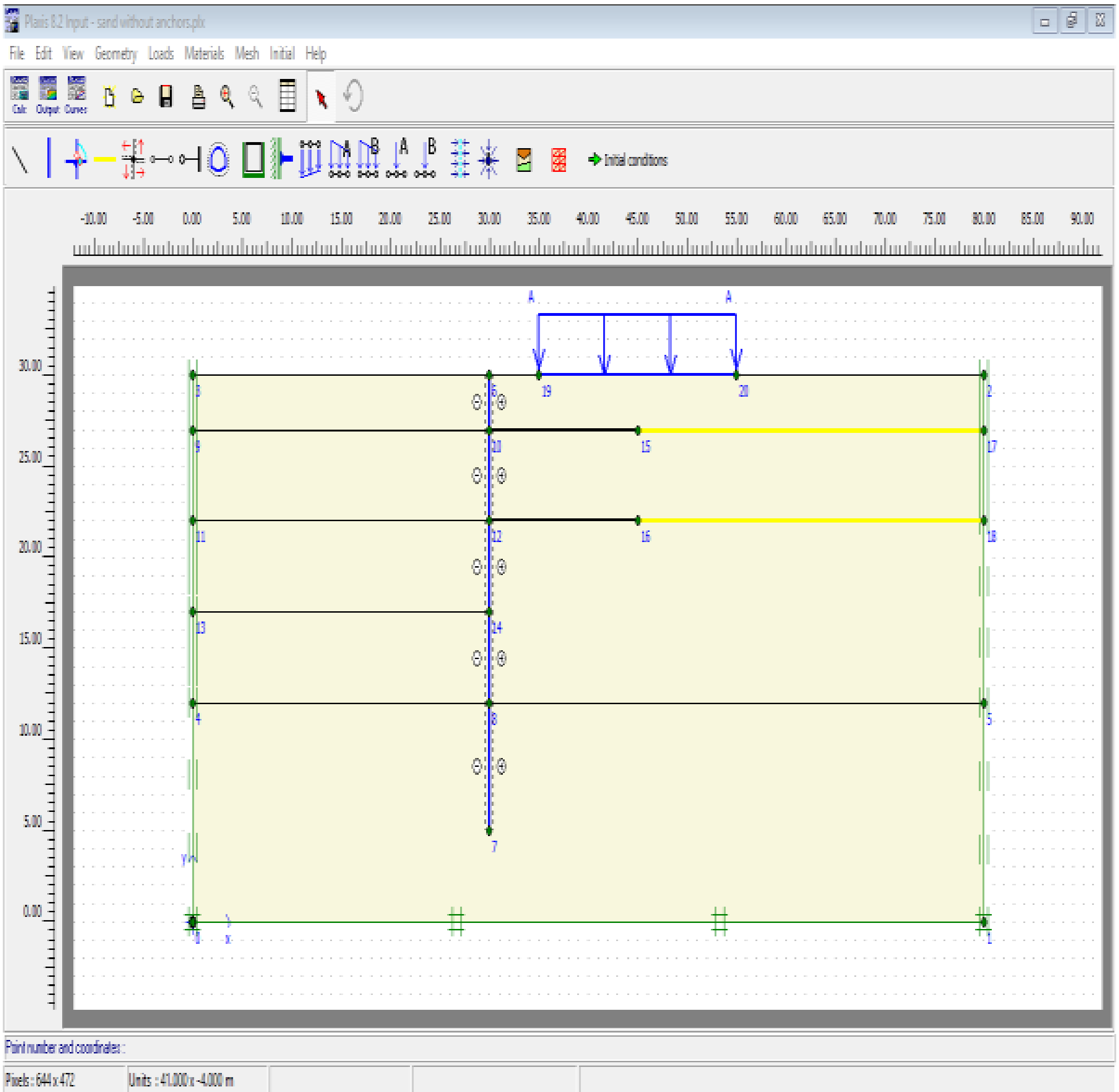


Fig. 5.1: Modeling of the excavation problem

5.1 MODELS GENERATED IN PLAXIS 2D WITH DIFFERENT TYPES OF BACKFILLS.

1. The basic dimension generated in all the sheet pile wall models are 80m x30m which is considered in the soil cluster.
2. The cluster is filled with respective soil models with given properties accordingly and properties of the plate (sheet pile wall), anchor rods and geogrids are also

defined. After that the mesh is generated and initial conditions or initial stresses is filled and the calculation of the respective backfill has been done.

5.2 RESULTS OBTAINED FROM PLAXIS 2D AFTER ANALYSIS OF SHEET PILE WALL MODELS.

5.2.1 Sheet pile wall having clay as backfill without active anchor and geogrid.

5.2.2 Sheet pile wall having clay as backfill with active anchors and geogrids.

5.2.3 Sheet pie wall having sand as backfill without active anchors and geogrids.

5.2.4 Sheet pile wall with sand as backfill with active anchors and geogrid.

5.2.1 Sheet pile wall having clay as backfill without anchors and geogrids.

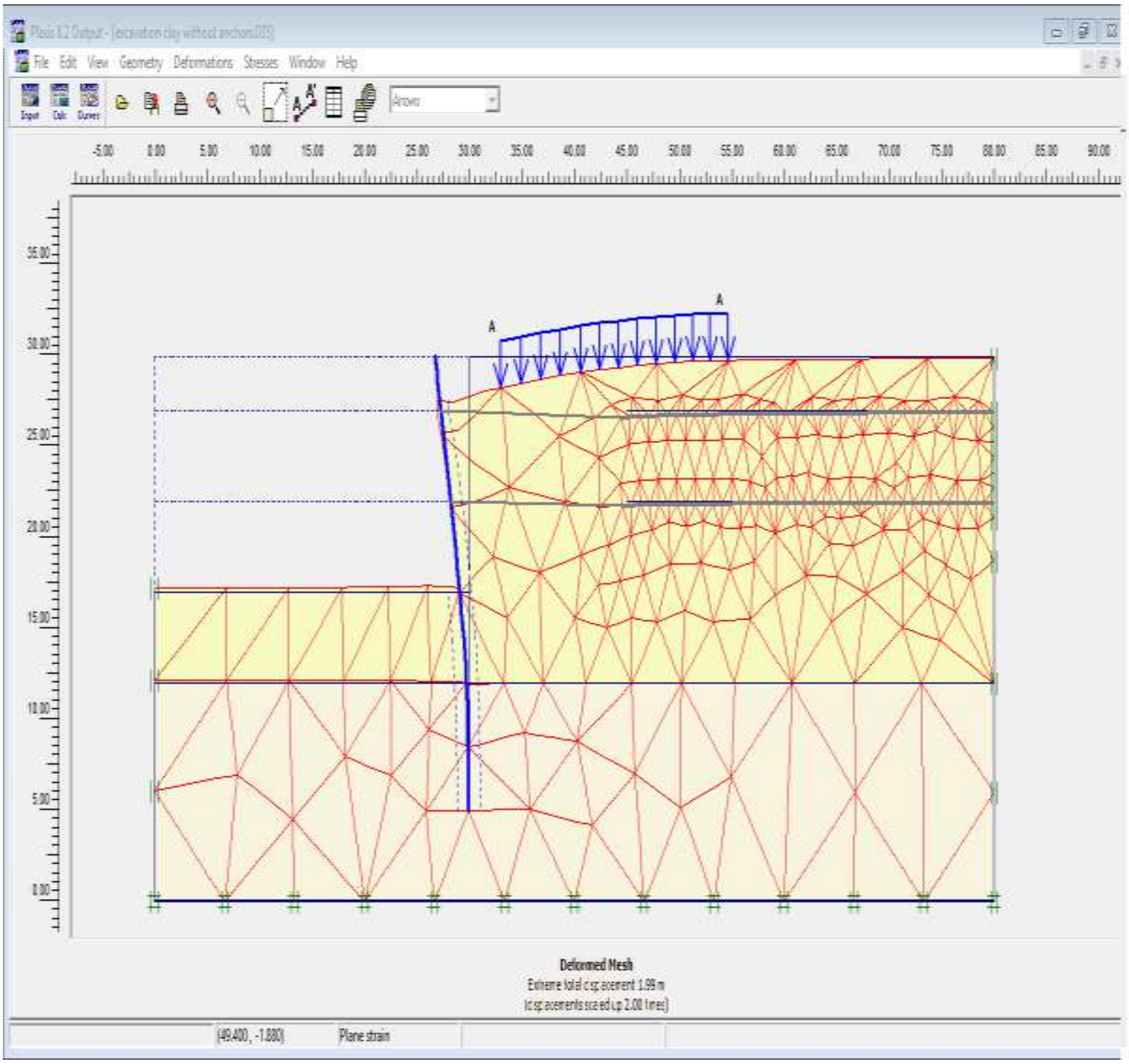


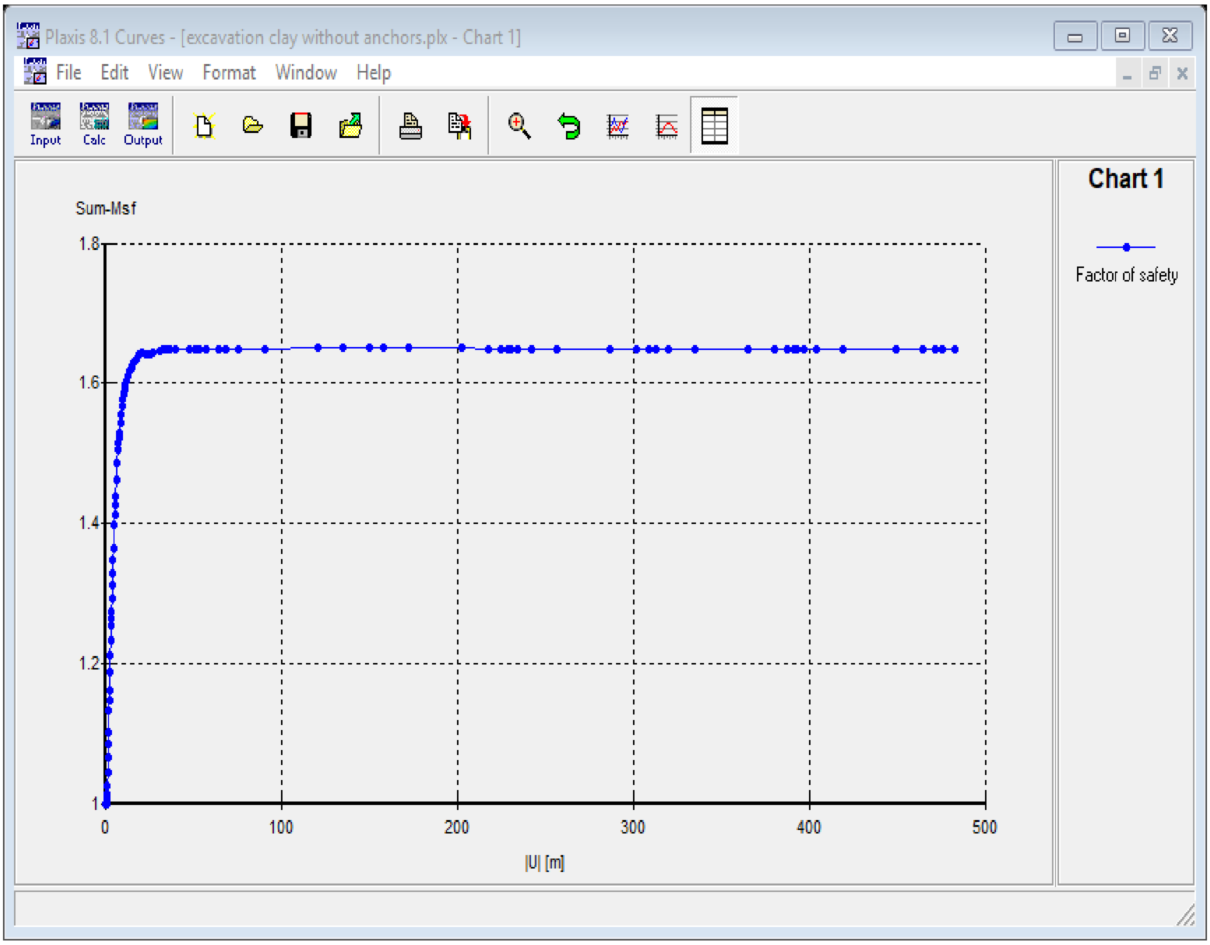
Table 5.1

Points - [excavation clay without anchors.plx - Chart 1]

Curve: Factor of safety

Point	Step	|U| [m]	Sum-Msf
131	128	397.08	1.64
132	129	404.55	1.64
133	130	419.48	1.64
134	131	449.35	1.64
135	132	464.29	1.64
136	133	471.75	1.64
137	134	475.49	1.64
138	135	482.95	1.64

OK Print... Copy



Graph 5.1: FOS vs total displacement

The results obtained from the analysis are:

1. Total displacements = 1.99 m.
2. The factor of safety of the model is 1.64 [Table 6.1A].
3. Model is safe.

5.2.2 Sheet pile wall having clay as backfill with anchor and geogrid: -

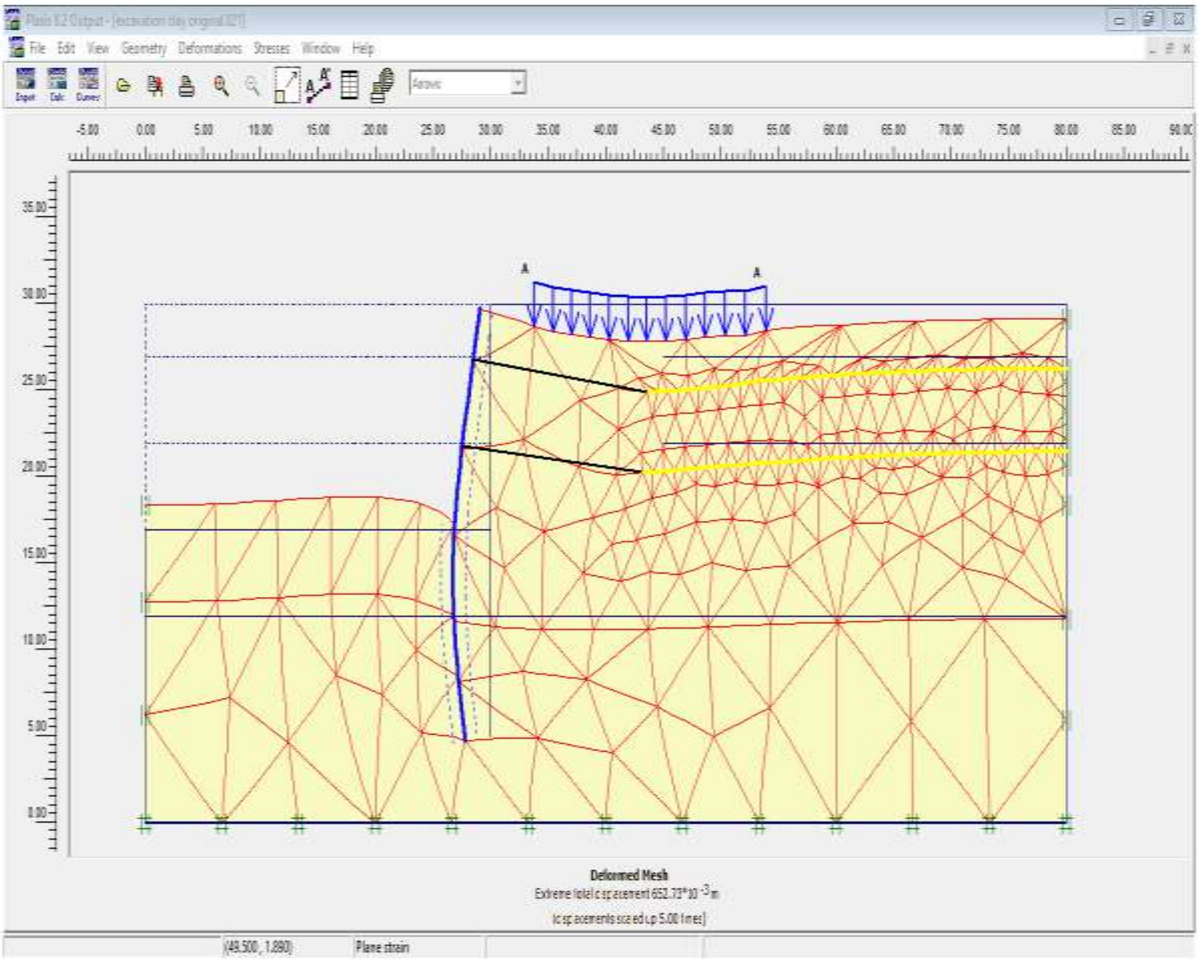


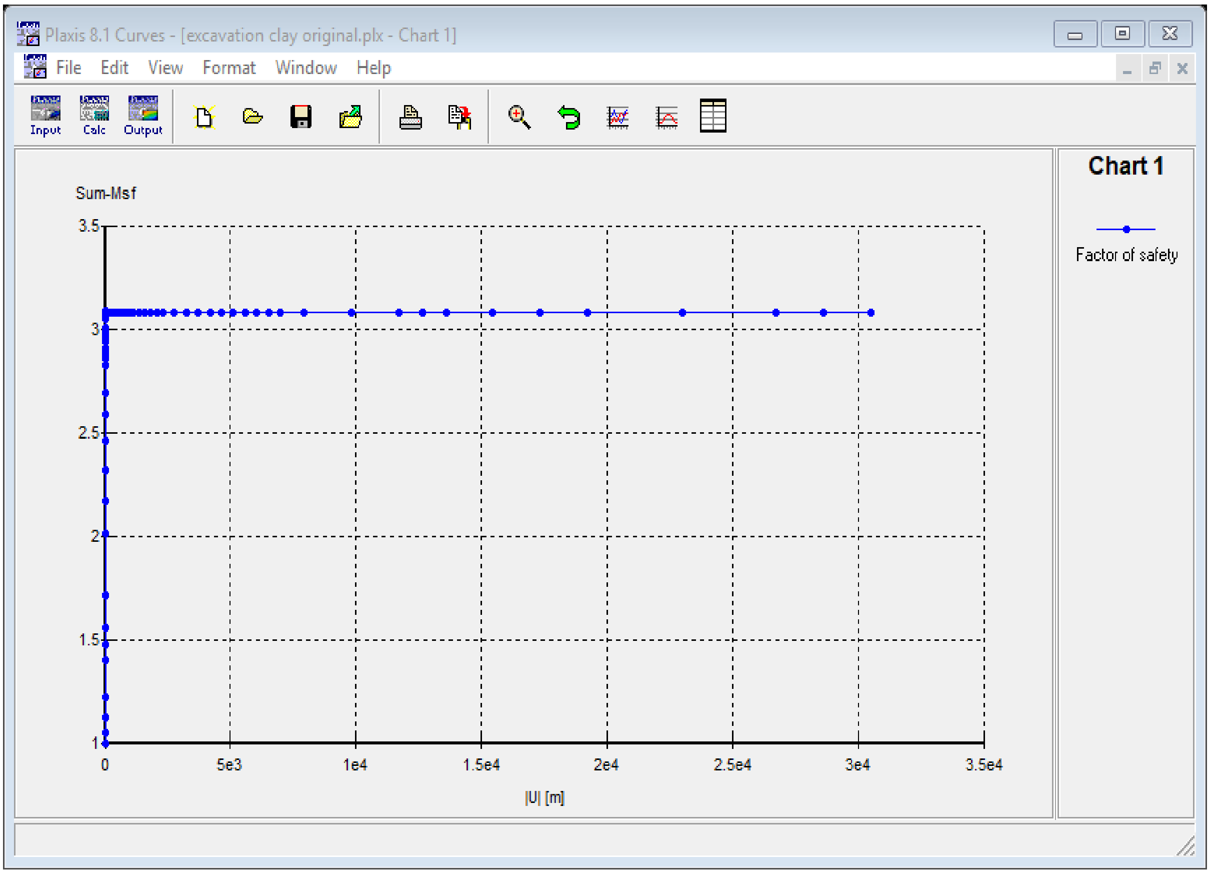
Table 5.2

Points - [excavation clay original.plx - Chart 1]

Curve: Factor of safety

Point	Step	|U| [m]	Sum-Msf
119	114	1.356e4	3.07
120	115	1.544e4	3.07
121	116	1.732e4	3.0
122	117	1.919e4	3.0
123	118	2.295e4	3.08
124	119	2.67e4	3.08
125	120	2.858e4	3.08
126	121	3.046e4	3.08

OK Print... Copy

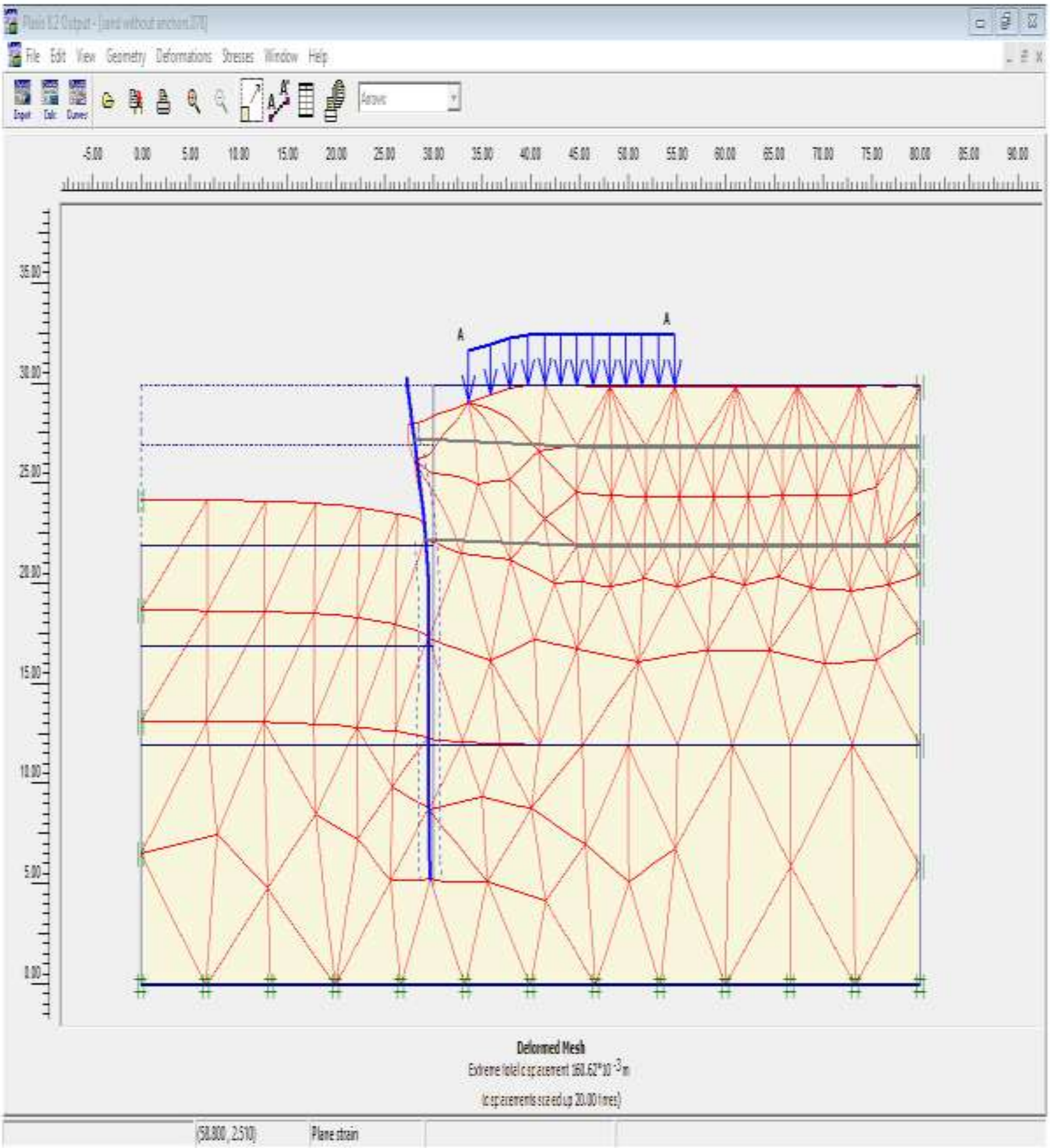


Graph 5.2: FOS vs total displacement

The results obtained from the analysis are:

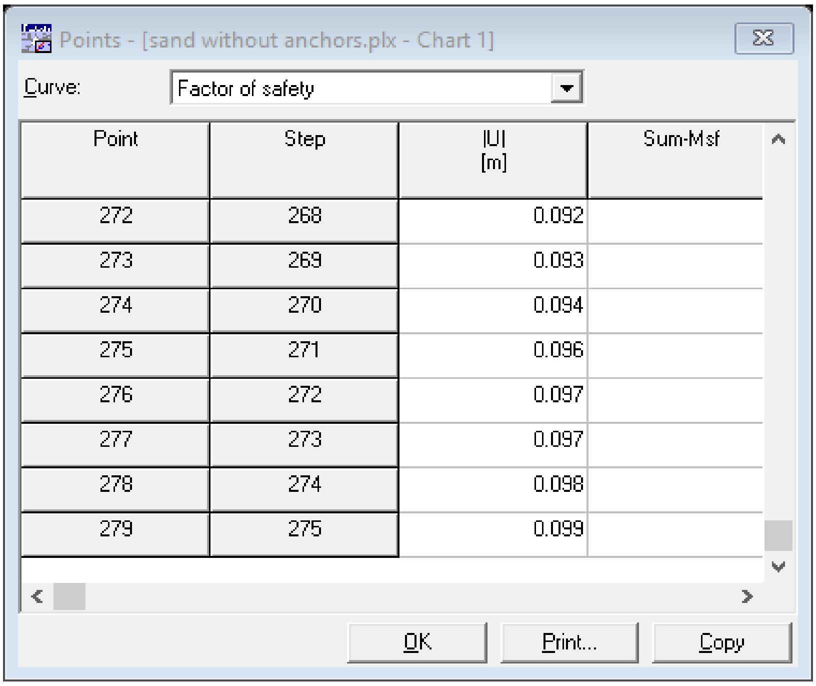
1. Total displacements $= 652.73*10^{-3}$ m.
2. The factor of safety of the model is 3.08 [Table 6.2].
3. The model is safe.

5.2.3 Sheet pile wall having sand as backfill without anchors and geogrids: -



In case of retaining wall with sand as backfill without active anchors and geogrids, the respective model fail in the stability criterion. The model is stable enough in first stage excavation but on doing 2nd stage of the excavation, the model fails and following results come “Prescribed ultimate stage not reached, the model did not sustain.”

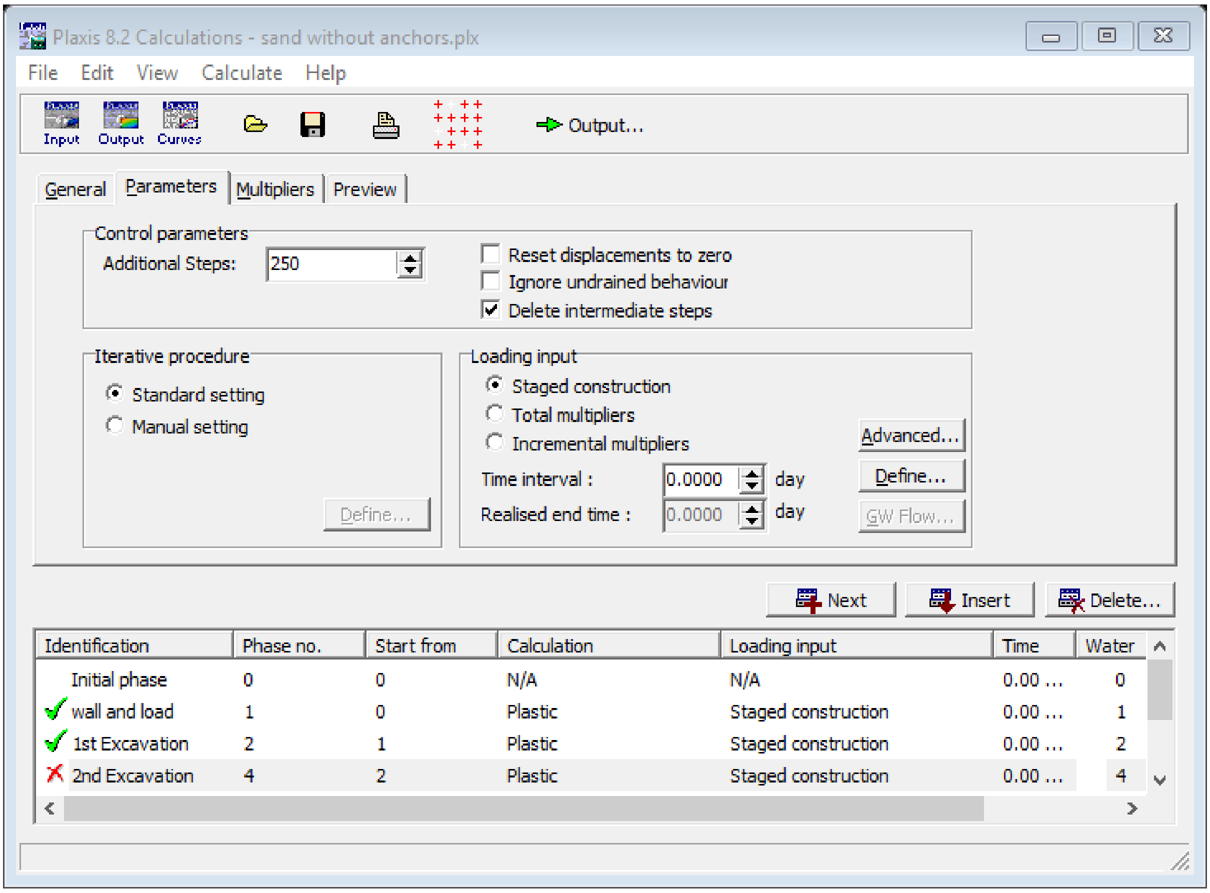
Table 5.3


Points - [sand without anchors.plx - Chart 1]

Curve: Factor of safety

Point	Step	|U| [m]	Sum-Msf
272	268	0.092	
273	269	0.093	
274	270	0.094	
275	271	0.096	
276	272	0.097	
277	273	0.097	
278	274	0.098	
279	275	0.099	

OK Print... Copy



Graph 5.3: FOS vs total displacement

The results obtained from the analysis are:

1. Total displacements $= 160.62 \ast 10^{-3}$ m.
2. Model is <u>not</u> safe.

5.2.4 Sheet pile wall with sand as backfill with anchors and geogrids: -

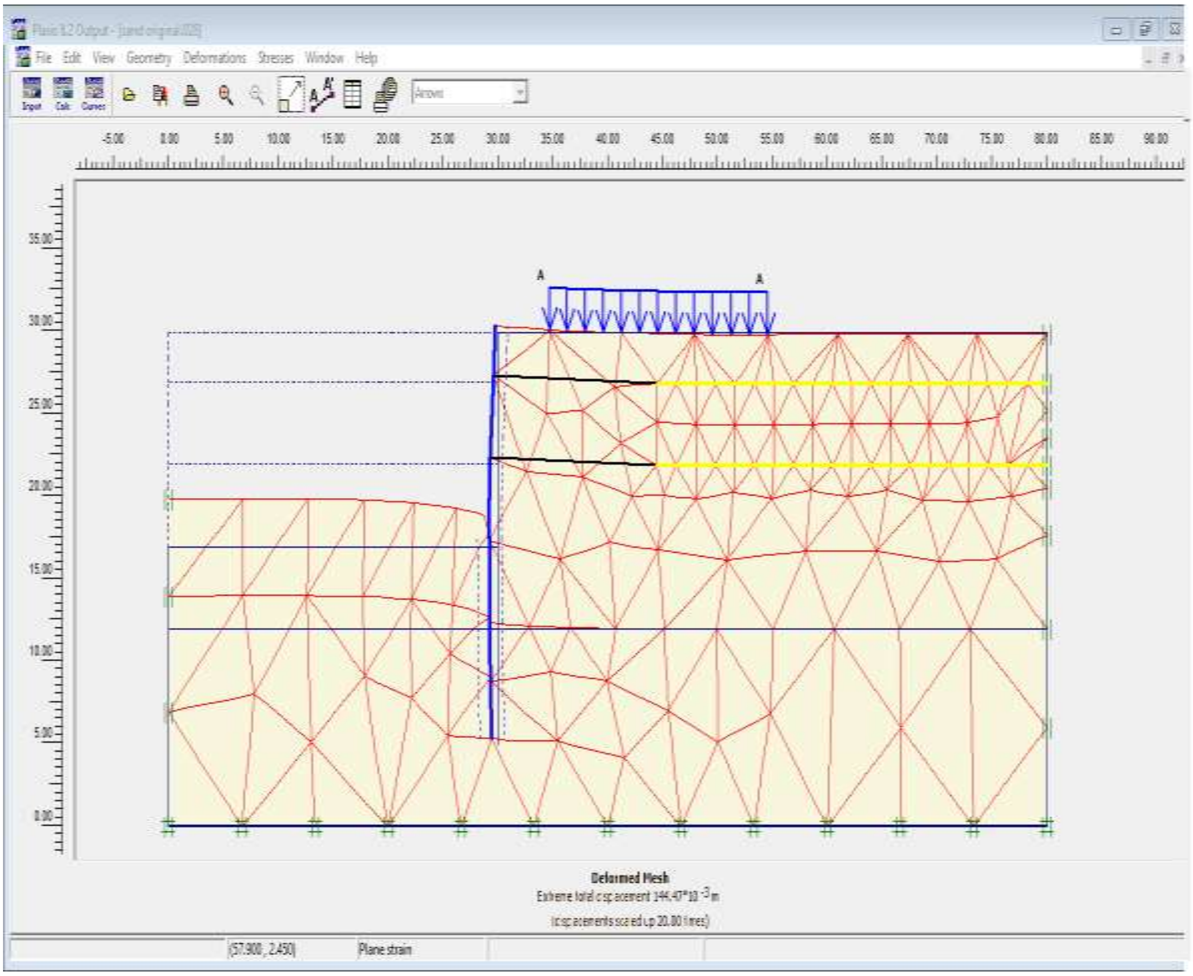


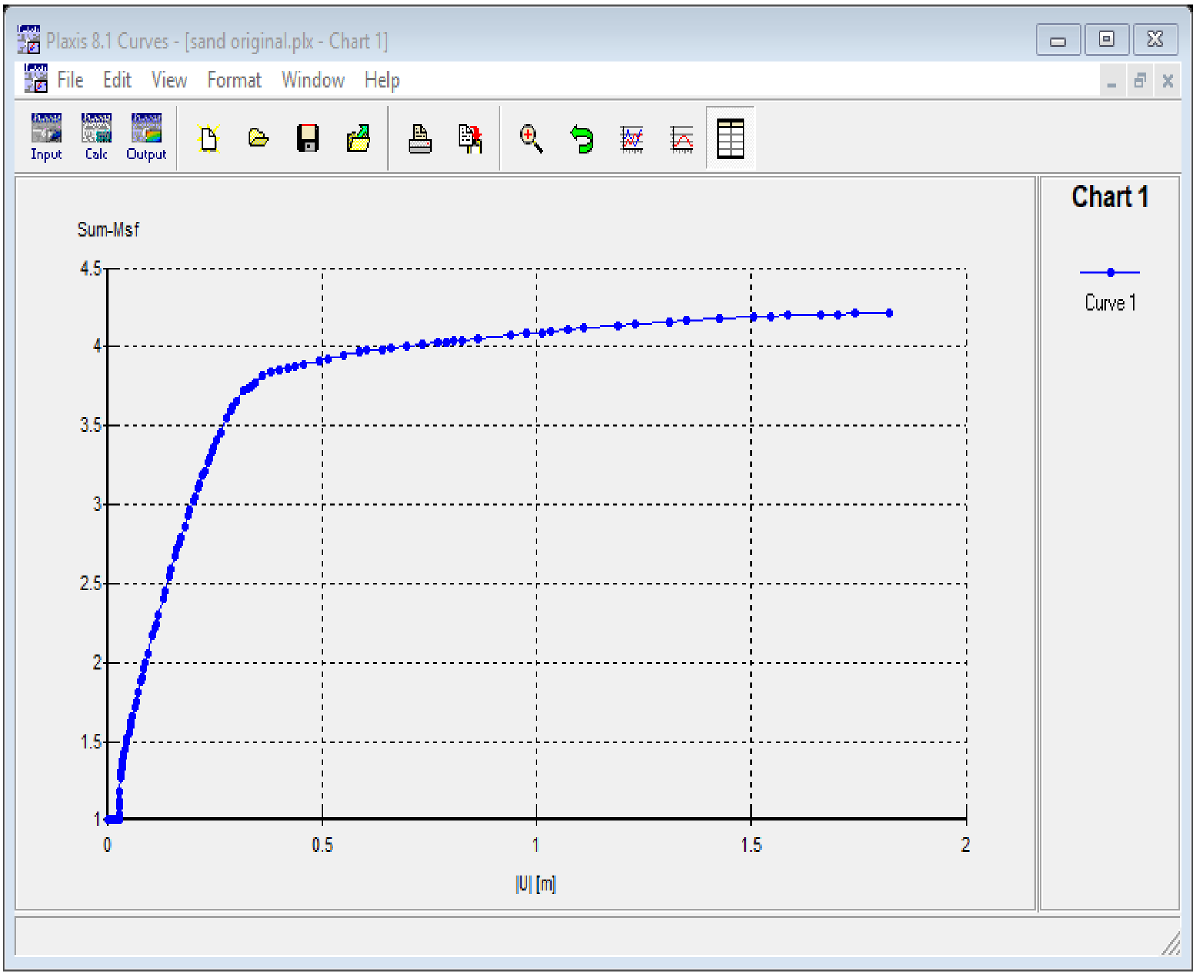
Table 5.4

Points - [sand original.plx - Chart 1]

Curve: Curve 1

Point	Step	|U| [m]	Sum-Msf
126	121	1.427	4.18
127	122	1.506	4.19
128	123	1.545	4.19
129	124	1.585	4.19
130	125	1.663	4.20
131	126	1.702	4.20
132	127	1.742	4.20
133	128	1.82	4.21

OK Print... Copy



Graph 5.4: FOS vs total displacement

The results obtained from the analysis are: -

1. Total displacements $= 144.47 * 10^{-3}$ m.
2. The factor of safety of the model is 4.21 [Table 6.4].
3. The model is safe.

Respective values of displacements and FOS of clays backfill with surface load of 100 kN/m^2 with and without reinforcement

Table 5.5. Cohesive backfill

Anchors and geogrids	Mesh generated	Displacements (mm)	FOS
Not present	Medium	$1.99 * 10^3$	1.64

Present	Medium	652.73	3.08

Respective values of displacements and FOS of granular (sand) backfill with surface load of 100 kN/m^2 with and without reinforcement.

Table 5.6. Granular backfill

Anchors and geogrids	Mesh generated	Displacements (mm)	FOS
Not present	Medium	160.62	Not safe
Present	Medium	144.47	4.21

CHAPTER 6

CONCLUSION

6.1 CONCLUSIONS: -

On the basis of present study and analysis the following conclusions are drawn: -

6.1.1 Clay backfill :-

1. Sheet pile wall constructed with clay backfill without geogrid reinforcement has larger displacement equal to 1.99 m and factor of safety equal to 1.64 but it is stable in failure criterion. So it considered as safe model.
2. Sheet pile wall constructed with clay backfill with geogrid reinforcement has medium displacement equal to 652.73mm and factor of safety equal to 3.08 which is safe . So it is considered as safe model.

6.1.2 Granular backfill :-

1. Sheet pile wall constructed with sand backfill without geogrid reinforcement has displacements equal to 160.62 mm but the structure is not stable and safe. So it is a failure case.
2. Sheet pile wall constructed with sand backfill has smaller displacements equal to 144.47mm and factor of safety equal to 4.21 which is safe. So it is considered as safe model.

6.1.3 Geogrid unreinforced sheet pile wall: -

1 Sheet pile wall constructed with clay backfill is safe in the stability criterion and factor of stability of 1.64.

2 Sheet pile wall constructed with sand backfill is not safe in the stability criterion.

3 From the above comparison, it is found that sand has smaller displacement values but It fails in the stability criterion stability whereas clay model has a factor of safety equal to1.64. So clay is considered as more suitable earth retaining material in case of unreinforced earth sheet pile wall.

6.1.4 Geogrid reinforced sheet pile wall: -

1. Sheet pile wall constructed with clay backfill has factor of safety of 3.08.
2. Sheet pile wall constructed with sand backfill has factor of safety of 4.21.

3. From the above comparison, it is found that sand displacement values and more factor of safety as compared to clay. So sand is considered as more suitable earth retaining material in case of reinforced earth retaining wall.

CHAPTER 7
RESULTS

- Granular backfill

I. Effect of reinforcement vertical spacing

From the analysis this fact also concluded that, as the reinforcements vertical spacing increases, the overall factor of safety value decreases significantly.

II. Effects of reinforcement length

From the analysis this fact also concluded that, as the reinforcement length increases, the overall factor of safety value increases significantly.

III. Failure planes after Ø–c reduction

The incremental shear strain at the end of Ø–c reduction indicates that the failure mechanism is direct sliding.

IV. Tensile loads in reinforcement

The above model analysis shows that, breakage of reinforcement is not expected, because tensile loads can be safely carried by most reinforcement geosynthetics.

- Cohesive Backfill

I. Effect of reinforcement vertical spacing

From the literature analysis this fact can be concluded that, as the reinforcements vertical spacing increases, the overall factor of safety value decreases significantly.

II. Effects of reinforcement length

From the analysis this fact can be concluded that, as the reinforcement length increases, the overall factor of safety value increases significantly.

III. Failure planes after Ø–c reduction

The incremental shear strain at the end of Ø–c reduction indicates that the failure mechanism is direct sliding.

IV. Tensile loads in reinforcement

The above model analysis shows that, breakage of reinforcement is not expected, because tensile loads can be safely carried by most reinforcement geosynthetics.

NOTATIONS

Basic SI units are given in parenthesis:

c	cohesion (Pa)
c_i	interface cohesion (pa)
c_{input}	initial cohesion of the soil
$c_{reduced}$	cohesion of the soil after reduction (pa)
E	elastic modulus (pa)
EA	elastic axial stiffness (N/m)
H	wall height
k_a	horizontal active earth pressure coefficient (dimensionless)
k_o	horizontal at rest earth pressure coefficient (dimensionless)
L	reinforcement length (m)
m	stress dependence exponent (dimensionless)
S_v	reinforcement vertical spacing (m)
γ	Unit weight of soil (kN/m^3)
μ	coefficient of friction (dimensionless)
ν	poison's ratio (dimensionless)
ξ	axial strain (dimensionless)
Ø	interface friction angle (degrees)
$Ø_{input}$	initial friction of the soil (degrees)
$Ø_{reduced}$	reduced friction of the soil (degrees)
$Ø_{soil}$	internal friction angle (degrees)
Ψ	dilation angle of soil (degrees)
$\sum_{Msf}$	a reduction element used in finite element Ø–c reduction analysis (dimensionless)

REFERENCES

1. Andresen, L. (2006). “Parametric FE study of loads and displacements of braced excavation in soft clay.” Proc., 6th European Conf. on Numerical Methods in Geotechnical Engineering, Taylor & Francis, London, pp. 399–403..
2. Bilgin, Ö. (2010). “Numerical studies of anchored sheet pile wall behavior constructed in cut and fill conditions.” J Comput. Geotech., 37(3), pp. 399–407.
3. Bathurst, R. J., Walters, D., Vlachopoulos, N., Burgess, P. & Allen, T. M. (2000). “Full scale testing of geosynthetic reinforced walls”: Invited Keynote Paper. ASCE Special Publication No. 103, Advances in Transportation and Geoenvironmental Systems using Geosynthetics, Proceedings of Geo-Denver 2000, August 2000, Denver, CO, USA, pp. 201–217.
4. Bilgin, Ö., and Erten, M. B. (2009). “Analysis of anchored sheet pile wall deformations.” Proc., Int. Foundation Congress and Equipment Expo, ASCE, Orlando, FL, pp. 137–144
5. Brinkgreve, R. B. J., Broere, W., and Waterman, D. (2006). “PLAXIS manual 2D—Version 8,” Balkema, Rotterdam, Netherlands.
6. Benjamin, C. V. S., Bueno, B. S. and Zornberg, J. G. (2007). “Field monitoring evaluation of geotextile-reinforced soil-retaining walls”. Geosynthetics International, 14, No. 2, pp. 100–118.
7. Billiard, J. W. and Wu, J. T. H. (1991). “Load test of a large-scale geotextile-reinforced retaining wall”. Proceedings of Geosynthetic 91 Conference, New Orleans, USA, Vol. 2, pp. 537–548.
8. Brinkgreve, R. B. J., Broere, W., and Waterman, D. (2006). “PLAXIS manual 2D—Version 8,” Balkema, Rotterdam, Netherlands.
9. Brinkgreve, R. B. J. and Vermeer, P. A. (1998). “Finite Element Code for Soil and Rock Analyses”, Version 7.2, Balkema, Rotterdam.
10. Clough, G. W., and Duncan, J. M. (1991). “Earth pressures.” Foundation engineering handbook. H.-Y. Fang, V. N. Reinhold, eds. Van Nostrand Reinhold, New York, pp. 223–235
11. Duncan, J. M. & Chang, C.-Y. (1970). “Nonlinear analysis of stress and strain in soil. Journal of the Soil Mechanics and Foundations” Division, ASCE, 96, No. 5, pp. 1629–1653.
12. Elias, V. and Christopher, B. R. (1997). “Mechanically stabilized earth walls and reinforced soil slopes: Design and construction guidelines”. Federal Highway Administration Demonstration Project 82 Reinforced Soil Structures, National Technical Information Service, Springfield.
13. FHWA (1997). “Mechanically Stabilized Earth Walls and Reinforced Slopes: Design and Construction Guidelines”, Report Number FHWA-SA-96-071. Federal Highway Administration, Washington, DC.
14. Hatami, K. & Bathurst, R. J. (2005). “Development and verification of a numerical model for the analysis of geosynthetic-reinforced soil segmental walls under working stress conditions.” Canadian Geotechnical Journal, 42, No. 4, pp. 1066–1085.

15. Hatami, K. and Bathurst, R. J. (2005). “Development and verification of a numerical model for the analysis of geosynthetic-reinforced soil segmental walls under working stress conditions”. Canadian Geotechnical Journal, 42, No. 4, pp. 1066–1085.
16. Hatami, K. and Bathurst, R. J. (2006). “A numerical model for reinforced soil segmental walls under surcharge loading”. ASCE Journal of Geotechnical and Geoenvironmental Engineering, 132, No. 6, pp. 673–684.
17. Janbu, J. (1963). “Soil compressibility as determined by odometer and triaxial tests.” Proceedings of the European Conference on Soil Mechanics and Foundation Engineering, Wiesbaden, Vol. 1, pp. 19–25
18. Jewell, R. A. (1985). “Limit equilibrium analysis of reinforced soil walls.” Proceedings of the 11th International Conference on Soil Mechanics and Foundation Engineering. Balkema, Rotterdam, The Netherlands, pp. 1705–1708.
19. Karpurapu, R., and Bathurst, R. J. (1995). “Behaviour of geosynthetic reinforced soil retaining walls using the finite element method.” Comput. Geotech., 17(3),pp. 279–299.
20. Leshchinsky, D. & Vulova, C. (2001). “Numerical investigation of the effects of geosynthetic spacing on failure mechanisms in mechanically stabilized earth block walls.” Geosynthetics International, 8, No. 4, pp. 343–365.
21. Leshchinsky, D. & Vulova, C. (2001). “Numerical investigation of the effects of geosynthetic spacing on failure mechanisms in mechanically stabilized earth block walls”. Geosynthetics International,8, No. 4, pp. 343–365.
22. Matsui, T. & San, K. C. (1988). “Finite element stability analysis method for reinforced slope cutting.” International Geotechnical Symposium on Theory and Practice of Earth Reinforcement, Fukuoka, Japan, pp. 317–322.
23. NCMA (1997). “Design Manual for Segmental Retaining Walls”, 2nd edn, Collin, J. G. (Editor). National Concrete Masonry Association, Herndon, VA, USA.
24. Nataraj, M. S., and Hoadley, P. G. (1984). “Design of anchored bulkheads in sands.” J. Geotech. Eng., 110(4), pp. 505–515
25. Ochiai, H., Hayashi, S. & Otani, J. (1993). “Earth reinforcement practice.” Proceedings of the International Symposium on Earth Reinforcement Practice, Fukuoka, Kyushu, Japan, 11–13 November 1992, Vol. 2, pp. 801–828.
26. Potts, D. M., and Fourie, A. B. (1985). “The effect of wall stiffness on the behavior of a propped retaining wall.” Geotechnique, 35(3), pp. 347–352.
27. Rimoldi, P. (1988). “A review of field measurements of the behaviour of geogrid reinforced slopes and walls.” Proceedings of the International Geotechnical Symposium on Theory and Practice of Earth Reinforcement, Fukuoka, Japan, 5–7 October, pp. 571–578.
28. Rimoldi, P. (1988). “A review of field measurements of the behavior of geogrid reinforced slopes and walls.” Proceedings of the International Geotechnical Symposium on Theory and Practice of Earth Reinforcement, Fukuoka, Japan, 5–7 October, pp. 571–578.
29. San, K., Leshchinsky, D. & Matsui, T. (1994). “Geosynthetic reinforced slopes: limit equilibrium and finite element analyses.” Soils and Foundations, 34, No. 2, pp. 79–85.

30. Tefera, T. H., Nordal, S., and Sandven, R. (2006). "Large scale excavation model test on single strutted sheet pile wall and back calculation of soil parameters." Proc., 6th European Conf. on Numerical Methods in Geotechnical Engineering, Taylor & Francis, London, pp. 391–397.
31. Tan, Y., and Paikowsky, S. G. (2008). "Performance of sheet pile wall in peat." J. Geotech. Geoenviron. Eng., 134(4), pp. 445–458.
32. Tefera, T. H., Nordal, S., and Sandven, R. (2006). "Large scale excavation model test on single strutted sheet pile wall and back calculation of soil parameters." Proc., 6th European Conf. on Numerical Methods in Geotechnical Engineering, Taylor & Francis, London, pp. 391–397.
33. U.S. Army Corps of Engineers (USACE). (1994). "Design of sheet pile walls." Engineer manual EM 1110-2-2504, USACE, Washington, DC.
34. U.S. Army Corps of Engineers (USACE). (1996). "Design of sheet pile walls", ASCE, New York.
35. Yoo, S. & Song, A. R. (2006). "Effect of foundation yielding on performance of two-tier geosynthetic-reinforced segmental retaining walls: a numerical investigation." Geosynthetics International, 13, No. 5, pp. 181–194.
36. Zornberg, J. G. & Mitchell, J. K. (1994). "Reinforced soil structures with poorly draining backfills. Part I: Reinforcement interactions and functions." Geosynthetics International, 1, No. 2, pp. 103–147.