JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

GEOTECHNICAL ENGINEERING STREAM

Design, Parametric analysis and Comparison of Geosynthetic Reinforced Retaining Wall with Cantilever Retaining Wall Using Finite Element Method

(Case study of Jimma City)

A Thesis Submitted to Jimma University, School Of Graduate Studies In Partial Fulfillment For Degree On Master of Science In Civil Engineering (Geotechnical Engineering).

By: Adugna Lelisa Kabeta

February, 2021

Jimma, Ethiopia

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Advisor: Anand Hulagabali (PhD)

Co. Advisor: Alemineh Sorsa (PhD Candidate)

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DECLARATION

I, the undersigned, declare that this thesis entitled: **"Design, Parametric analysis and Comparison of Geosynthetic Reinforced Retaining Wall with Cantilever Retaining Wall Using Finite Element Method: Case study of Jimma City"**

is my original work, and has not been presented by any other person for an award of a degree in this or any other university, and all sources of material used for this thesis have to duly acknowledge.

Name of researcher: Adugna Lelisa **Signature**____________ **Date** 17/ 02/ 2021

As Master's research Advisors, I hereby certify that I have read and evaluated this MSc Thesis prepared under my guidance by Adugna Lelisa entitled: **"Design, Parametric analysis and Comparison of Geosynthetic Reinforced Retaining Wall with Cantilever Retaining Wall Using Finite Element Method Case study of Jimma City"**

Main Advisor: Prof. Anand Hulagabali. **Signature**____________ **Date** 16 / 02/ 2021

Co advisor: Mr. Alemineh Sorsa. **Signature**____________ **Date** 17/ 02/ 2021

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I would like to appreciate my lovely family who is always with me, supporting and encouraging deserves respect and thank for their help, without it I could not be fruitful. Last, but not least, the moral support of my relatives, friends, and fellow graduate students and the cooperation of different private and governmental organization is not out of mind.

ABSTRACT

Soil is generally weak in tension and relatively strong in compression and shear. The concept of reinforcing a soil mass by incorporating a material that is strong in tensile resistance is similar to that of reinforced concrete. Through the inter-face friction, the reinforcement restrains lateral deformation of the soil next to the reinforcement and therefore increases the stiffness and strength of the soil mass. Geosynthetics have emerged as exciting engineering materials in reinforcing backfill soil of retaining wall.

Due to this analysis and design of mechanically stabilized earth (MSE) wall is crucial this day. To do so finite element method is used to analyze the MSE wall. This research study is more concerned on determining and comparison of the stability of both MSE wall and cantilever retaining wall. For case study some representative soil samples were collected based on ASTM sampling procedures for the characterization of the soil under the retaining wall and backfill soil. The retaining wall were analyzed with plain strain model and 15-node elements are utilized. A total height Plaxis Version 8.2 is designed for two-dimensional modeling and analysis of physical space. In addition, parametric analysis of MSE wall also done. Global stability, facing panel deformation and tension force in the geogrid is calculated using Finite element method. The vertical deformation of MSE and cantilever retaining (CR) wall is 0.1m and 0.187m respectively. The horizontal deformation MSE wall and CR wall is 0.31m and 0.57 mm respectively. Factor of safety for global stability of MSE wall is 1.673 and cantilever retaining wall is 0.475. This shows by 78% the stability is improved.

MSE wall is stable and suitable than GRS-RW for this site based on global stability and facing panel deformation. And sandy soil backfill material, PET type of geogrid is the safest for MSE wall construction. For very small construction area, and low geotechnical properties of soil site condition using MSE wall than CR wall is appropriate and the best.

Key words: *Retaining wall, Finite Element Analysis, Geosynthetics, Reinforced soil, Stability.*

CONTENTS

LIST OF FIGURE

LIST OF TABLES

ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
CDOT	Colorado Department of Transportation
DACSAR	Deformation Analysis Considering Stress Anisotropy and orientation
ETB	Ethiopian Birr
FHWA	Federal Highway Administration
GRS	Geosynthetic Reinforced Soil
GRS-RW	Geosynthetic Reinforced Soil Retaining Wall
LRFD	Load and Resistance Factor Design
MSE	Mechanically Stabilized Earth
RSS	Reinforced soil slopes
USA FHWA	United State Federal Highway Administration
US	United State
2D	Two Dimensional
CRW	Cantilever Retaining Wall
FEM	Finite Element Method
HDPE	High Density Polyethylene
PET	Polyethylene Terephthalate
PP	Polypropylene

CHAPTER ONE

1. INTRODUCTION

1.1 Background

Soil is generally weak in tension and relatively strong in compression and shear. The concept of reinforcing a soil mass by incorporating a material that is strong in tensile resistance is similar to that of reinforced concrete. The reinforcing mechanisms of reinforced soil and reinforced concrete, however, are somewhat different. In reinforced soil, the bonding between the soil and the reinforcement is derived from soil-geosynthetic interface friction, and in some cases also from adhesion and passive resistance. Through the inter-face friction, the reinforcement restrains lateral deformation of the soil next to the reinforcement and therefore increases the stiffness and strength of the soil mass [10].

The technology of geosynthetic reinforced soil systems has been used extensively in transportation systems to support the self-weight of the backfill soil, roadway structures, and traffic loads. The increasing use and acceptance of soil reinforcement has been triggered by a number of factors, including cost savings, aesthetics, simple and fast construction techniques, good seismic performance, and the ability to tolerate large differential settlement without structural distress[9].

Geosynthetics have emerged as exciting engineering materials in wide array of application – transportation, geotechnical, environmental, hydraulic and private development applications [1].

A geosynthetic is defined as follows: Geosynthetic, n – a planar product manufactured from polymeric material used with soil, rock, earth or other geotechnical engineering related material as an integral part of a human made project, structure or system [1].

Among the different areas of geosynthetic application, geotechnical engineering, especially in retaining wall are mostly used. Geosynthetic products perform five main functions: separation, reinforcement, filtration, drainage, and containment (hydraulic barrier). MSE (i.e., reinforced soil) walls are basically comprised of some type of reinforcing element in soil fill to help resist lateral earth pressures. When compared with conventional retaining wall systems, there are often significant advantages to MSE walls. MSE walls are very cost effective, especially for walls in fill embankment cross sections. Furthermore, these systems are more flexible than conventional earth retaining walls such as reinforced concrete cantilever or gravity walls. Therefore, they are very suitable for sites with poor foundation and for seismically active areas.in recent time, geosynthetic reinforced soil (GRS) structures, including retaining walls, slopes, embankments, roadways, and load bearing foundations, have gained increasing popularity in different countries. A GRS walls have two components: a facing element and a GRS mass. Figure 1.1 shows a schematic diagram of typical GRS wall with modular block facing [3].

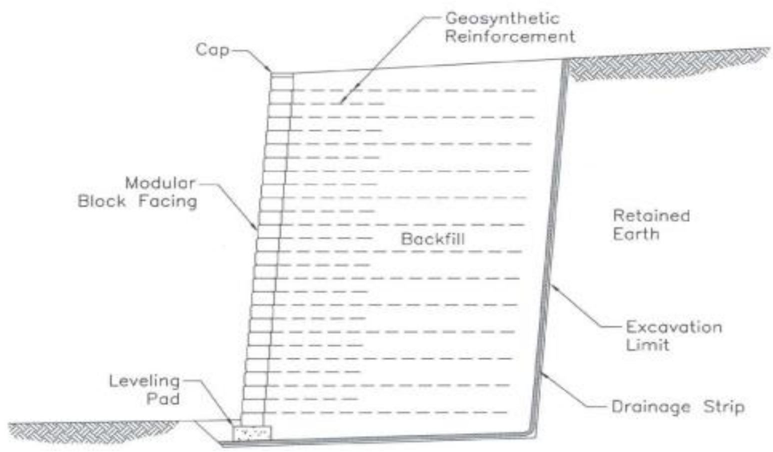


Figure 1-1 Typical cross section of a GRS wall with modular block facing. Adapted from [2].

The GRS wall facing may be of various shapes and sizes. A significant benefit of using geosynthetics is the wide variety of wall facings available, resulting in beautiful aesthetic options.

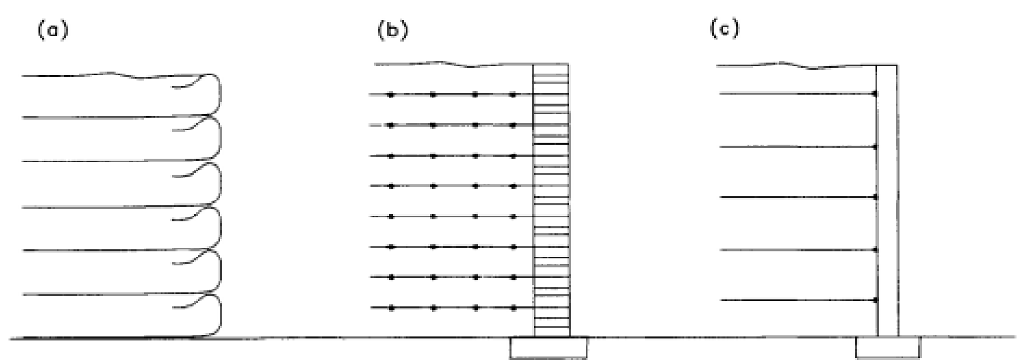


Figure 1-2. Reinforced retaining (MSE) wall systems using geosynthetics: a) with wrap around geosynthetic facing, b) with segmented precast concrete or timber panel, c) with full height (propped) precast panel [3].

1.2 Statement of the Problem

Retaining wall failure is critical issue on the Highway, slope stability and any civil structure which needs horizontal wall supports. One of the reasons causing these failures happened is improper or error in selection of retaining wall type for specific site condition.

In our country it is not common to use software based design of retaining wall rather the design agencies practice the method by referring the hardcopy of design guideline manual and calculation. Therefore, human mistake and error cannot be fully avoided in the design. Which leads to unsafe and uneconomical design of retaining wall.

1.3 Significance of the Study

The construction of MSE wall is cost effective, requires less site preparation and area. In recent years, many MSE wall failure cases have been observed because of insufficient knowledge about wall design and analysis. Since Geosynthetic technology is growing faster than ever. So, it is very important to understand the behavior of MSE wall with respect to various aspects, such as internal and external stability analysis. Regarding to this, this research is carried out to design and analyze GRS-RW, to analyze the behavior of MSE wall for reinforcement lengths and backfill soil properties. Using this technology to retaining wall or any civil structure have a significant advantage. Before, planning this kind of structure, one can do systematic analysis based on the present study.

1.4 Research Question

The basic question to be answered after this study is:

- How to model GRS wall and CRW using Finite Element Method?
- How can a Geosynthetic Reinforced retaining wall be an alternative mechanism for replacing the Cantilever retaining wall?
- How to know the effect of different parameters on stability analysis?

1.5 Objective of the Study

1.5.1 General Objective

The main objective of this study is to design, parametric analysis and Compare of MSE retaining wall and CRW.

1.5.2 Specific Objective

- To model GRS and CRW using Finite Element Model.
- To compare the GRS wall and cantilever retaining wall.
- To know the effect of different parameters on reinforced soil retaining wall stability.

1.6 Scope of the Study

This study determines and compare the stability, horizontal and vertical displacement GRS-RW and cantilever retaining wall. To do this laboratory test is done to determine engineering property of the soil. Both disturbed and undisturbed soil sample is collected. Two test pit from each test pit two sample is taken at 3m and 6m depth from the ground level. The weight of rigid pavement and vehicle is taken as distributed load by applying on the surface of retaining wall vertically downward. The facing structure is facing panel of 20mm thickness and geogrid type of geosynthetic is used as a reinforcement. The analysis of parameters such as type reinforcement (HDPE, PET and PP), type of backfill soil (Gravel, Sand, Silt and Clay), and length of reinforcement (Four, Five, and Six meter) effect on retaining wall is done.

1.7 Organization of the Thesis

This thesis contains five different chapters: **Chapter 1** is an introductory chapter outlining the problem statement and objective of the thesis. **Chapter 2** provides a literature review. Generally review about the mechanically stabilized retaining wall design and analysis. **Chapter 3** Methodology of the thesis. **Chapter 4** Analysis and result discussion. **Chapter 5** Conclusion and recommendation.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Background

Mechanically Stabilized Earth (MSE) walls have continually been a focus of study since their inception into standard engineering practice. The method of constructing an earth retaining structure consisting of soil and minimal reinforcement is both effective and cost efficient. The industry of MSE walls is continually striving to become more effective and cost efficient to remain competitive in the market. This increase comes by gaining a greater understanding of wall performance compared to current standard design practices and by developing new methods of soil reinforcements. This chapter provides the background information on current design practices called the K-Stiffness method and Finite element analysis of MSE wall [33].

2.2 K-Stiffness Design Methodology

2.2.1 General

The K-Stiffness Method was developed by Allen and Bathurst for the Washington Department of Transportation in cooperation with the US Department of Transportation's Federal Highway Administration (Allen & Bathurst, 2003). The purpose of the paper was to provide a detailed study of the performance of MSE walls constructed either of extensible or inextensible reinforcements in controlled laboratory settings or in field applications. The study concluded that the AASHTO design methods used in practice overestimate the behavior actually seen in MSE walls, especially those constructed with extensible materials. The K-Stiffness method was presented in the paper as a possible design alternative that more accurately represents what is observed in MSE walls. This method achieves a more accurate approximation for the tension values seen in the internal design of a geosynthetic reinforced MSE wall and considers variables such as reinforcement type, sizing, spacing, and strength. External and global stability requirements are still required to meet the defined AASHTO requirements (Allen & Bathurst, 2003). The method was developed empirically from the behavior observed in the case studies analyzed in the paper. The K-Stiffness Method for geosynthetic walls will be presented in the following sections [33].

2.2.2 Internal Design

The general governing equation for the K-Stiffness method for internal design of geosynthetic walls is given in Equation 2.1.

$$T_{max}^{i} = S_{v}^{i}\sigma_{h}D_{tmax} \text{---} 2.1$$

where T_{max}^{i} is the maximum load per unit width of wall in a given individual layer of reinforcement [33], This equation accounts for the typical internal design characteristics for a MSE wall such as the height of the wall, surcharge loads, vertical spacing, unit weights, etc., and is similar to the AASHTO specification defined in Equation 2.1 but includes two new factors, D_{tmax} and Φ. These factors modify the loads per unit wall width to more accurately reflect the behavior exhibited. D_{tmax} is a load distribution factor that changes the assumed geometry of the loads in the reinforcements as the depth increases, Φ is the general influence factor and incorporates the global stiffness factor, Φ_g, the local stiffness factor, Φ_{local}, the facing stiffness factor, Φ_{fs}, and the facing batter factor, Φ_{fb} as given in Equation 2.2. Equation 2.2 will be explained in greater detail later in this chapter (Allen & Bathurst, 2003)

$$\Phi = \Phi_g \Phi_{local} \Phi_{fs} \Phi_{fb} \text{---} 2.2$$

σh, given in Equation 2.1, is the average load over the height of the wall per unit width of wall and is calculated using Equation 2.3. Rather than calculating the lateral earth pressure per layer of reinforcement material, it is simply averaged over the height of the wall.

$$\sigma_h = 0.5k\Upsilon(H + S \text{---} 2.3$$

Where σ_h is the equivalent height of the uniform surcharge pressure and is therefore equal to q/y, H is the height of the wall, ϒ is the unit weight of the wall, and K is the lateral earth pressure coefficient. The lateral earth pressure coefficient is calculated using Equation 2.4

$$K = K_O = 1 + sin\varphi_{ps} \text{---} 2.4$$

Where φ_{ps} is the peak plane strain friction angle. It is to be noted that Allen and Bathurst use the lateral earth pressure coefficient, K, taken as the at-rest soil conditions, K_o[33].

2.2.3 Influence Factor ϕ

The influence factor, Φ as previously given in Equation 2.2 incorporates four variables that account for the relative stiffness of the reinforcement. Φ_g is the global stiffness of the reinforcement, Φ_{local} accounts for the local variations of stiffness in the reinforcement, Φ_{fs} is the stiffness of the facing elements, and , Φ_{fb} is the batter of the face of the wall [33].

2.3 Past Experiences in GRS Retaining wall

The first GRS wall was built in Rouen, France, in 1971 [17]. It was an experimental wall constructed by using a non-woven geotextile and a low quality backfill (wet, clayey, and sensitive soil) and the first geotextile wall built in the USA was initiated by the Forest Service in 1974 and was built at the Oregon State University They first conducted small-scale model test [18]. Based on these model tests, geotextile walls were constructed in Siskiyou National Forest in Oregon in 1974 and Olympic National Forest in Shelton, Washington, in 1975 [21]. Later in the mid-1990s, the FHWA worked with CDOT and developed a low-cost generic wall system using lightweight concrete blocks. Rather than securing the blocks to the reinforcement with connections, as in MSE technology, the concrete facing blocks were frictionally connected to the GRS mass. The interface between the blocks and the geosynthetic provided enough friction to resist block movement. This method of connection in combination with closely spaced reinforcement layers created a facing system that adjusts to relieve stress without transferring loads to the facing. The Federal Highway Administration (FHWA) refined the CDOT method to account for vertical load-bearing applications, resulting in the development of GRS retaining wall, followed by GRS-RS.

2.4 Advantage and disadvantage of using MSE wall

Mechanically stabilized earth (MSE) walls use geosynthetics as reinforcements that are embedded in granular backfill. The reinforcement and the soil together form wall or embankment. Compared with conventional (reinforced) concrete walls, the MSE walls have the following advantage and disadvantage [5]:

Advantage

- Increased internal integrity because of the geosynthetics tensile strength and the friction between the soil and the reinforcement.
- Increase shear resistance to resist slope failure.
- Rapid construction.
- Flexible wall system accommodating large differential settlement.
- Suited for seismic regions.

Disadvantages:

- Require large base width
- Not applicable to location requiring future access to underground utilities.
- Susceptible to damages during construction.

MSE walls are constructed in layers. During the installation, the geosynthetics should be orientated such that the direction with higher tensile strength is perpendicular to the wall face to maximize the reinforcement and prevent failure. MSE walls typically have fasciae that cover the wall faces. The fasciae prevent ultraviolet damage to the geosynthetics, provide esthetics, or are used to anchor the reinforcements. The fasciae can be interlocking precast concrete modular blocks or precast concrete panels that are fixed to the finished wall faces. Welded wire panels, gabion baskets, and treated timber facings can also serve as MSE fasciae. Generally, the fasciae are not considered to contribute to the internal or external stability during the design.

2.5 Geometric Model

For the purposes of this study, the wall aspect ratio for walls with reinforcement is described as the ratio of the length of the reinforcement (L) to the height of the wall (H). In contrast, the wall aspect ratio for walls without reinforcement is described as the ratio of the width of the wall (W) to the height of the wall (H). Examples of these two conditions are shown in Figures 2.1 and 2.2.

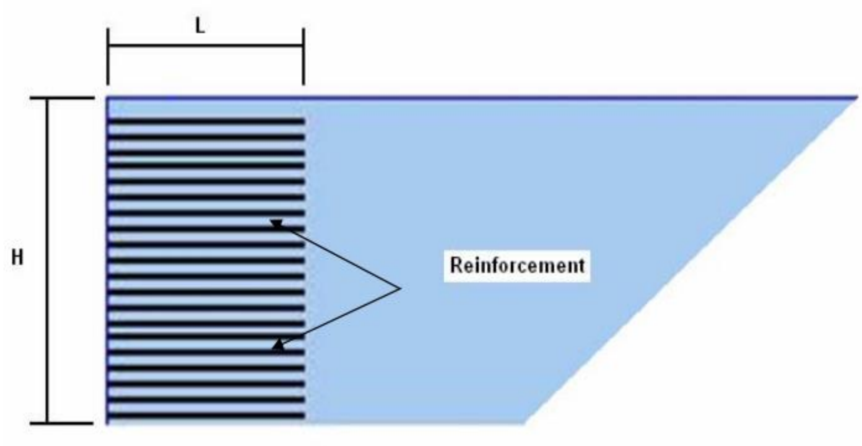


Figure 2-1. Example of wall aspect ratio defined as L/H.

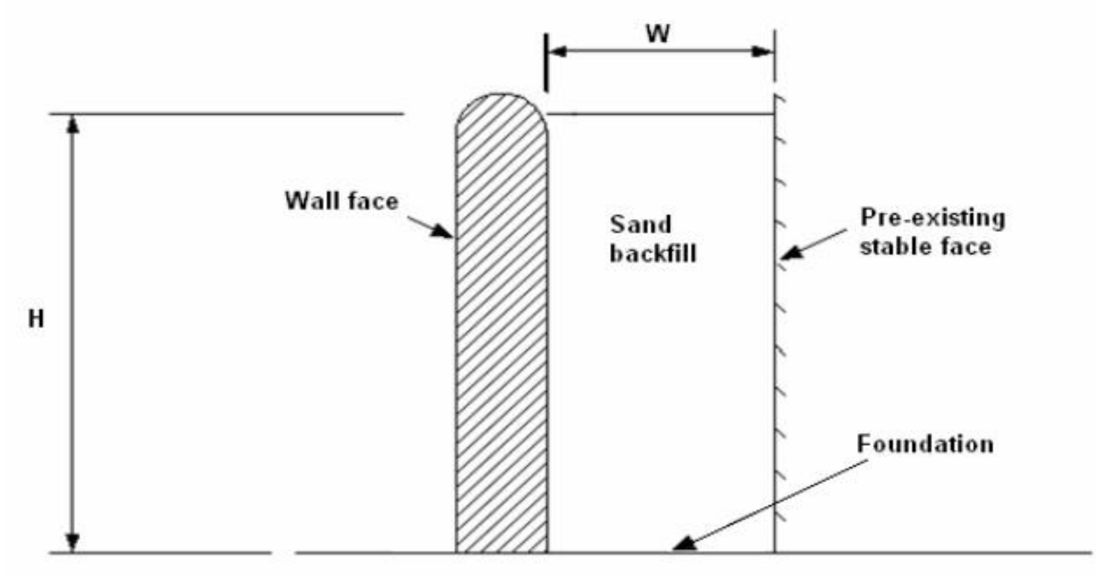


Figure 2-2. Example of wall aspect ratio defined as W/H.

2.6 Material for Construction of Geosynthetics Reinforced Soil Retaining Wall System

The main components of a reinforced earth wall are facing element, reinforcing element and back fill material.

2.6.1 Facing Elements

The function of the facing is to prevent spillage of the fill and provide a suitable architectural treatment to the structure, Vidal (1978) and Jones (1985). Different materials and shapes have been used in facing element such as: semi-elliptical channels made from galvanized steel and hexagonal fiberglass facing elements which are positioned by means of vertical poles[5].

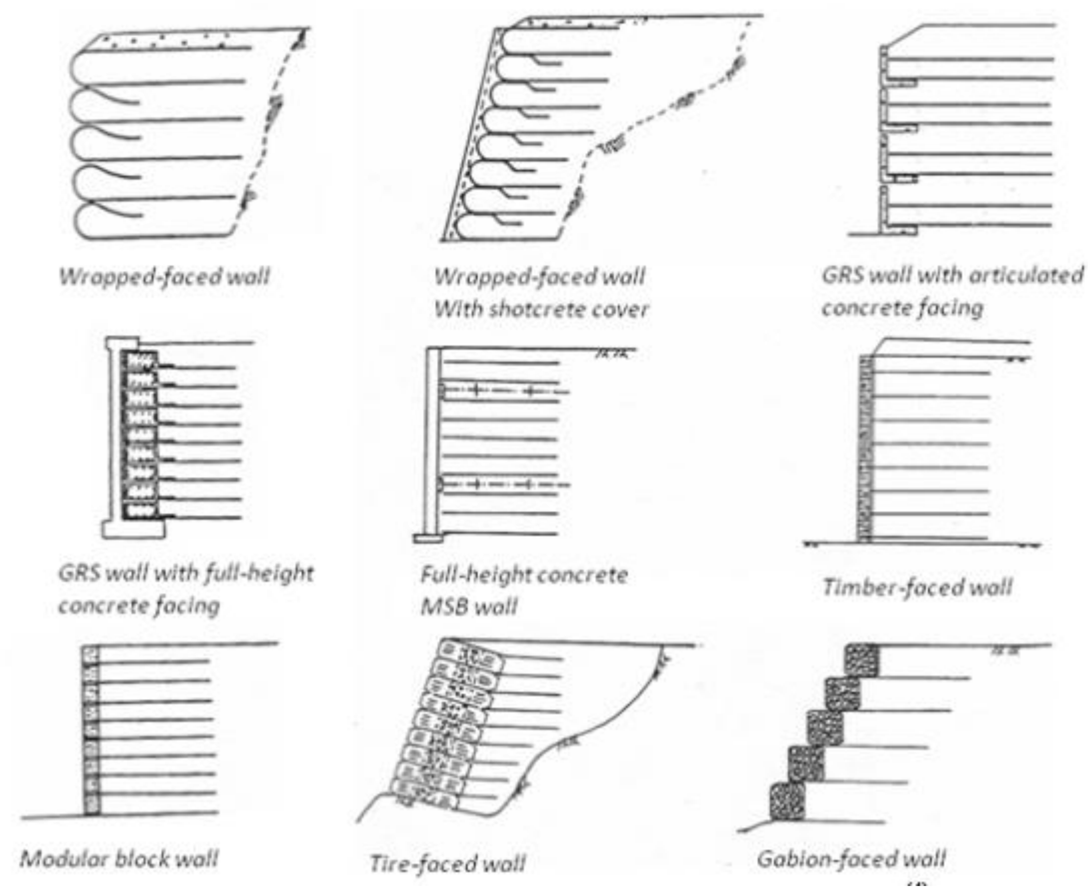


Figure 2-3. GRS wall with different facings. Adapted from [7].

2.6.2 Backfill Material

Backfill selection for GRS-RW is important because it is a major structural component for the retaining wall. Vidal [1] stated that backfill material should be selected which does not contain too much clay and has a sufficient angle of internal friction. According to the Department of Transport in the U.K., Technical memorandum (BE3/78) which was revised in 1987, both frictional and cohesion frictional fill are limited to a maximum particle size of 125mm and frictional fill shall not contain more than 10% passing the 63µm sieve [5]. The selection of appropriate backfill material is critical to the performance of the GRS retaining wall Provide the following general guidelines in selecting the backfill material:

- The material should consist of crushed, hard, durable particles or fragments of stone or gravel that are free from organic matter or deleterious material.
- The material should meet either well-graded (< 12% passing No. 200 sieve) or open-graded aggregate gradations (shown in Figure 2.4) or a blend in between the two.
- The maximum particle size should not exceed 2 in (to avoid damaging geosynthetic layers when compacted).
- The material should have angular particles and have an angle of shearing resistance (or friction angle), $\varphi' \geq 38^o$ (derived from large scale direct shear testing ASTM D3080).
- The material must have: (a) the ability to ensure compaction, (b) the ability to drain water in case of flooding, and (c) good workability (i.e., easier to spread, level, and compact).

2.6.3 Reinforcing Element

The reinforcing elements contribute strength to the backfill. They are usually placed at a regular spacing in horizontal direction. They may have different material such as metal strips with flat or ribbed surface or bars with and anchors or new material which is Geosynthetic material can be used. Geosynthetic material good advantage (corrosion resistant, easily installed, construction time and cost) other reinforcing materials. Geosynthetics have different sub group in it such as: geotextile, geogrid, geonet, geomembrane, geo-composite and etc. Geogrid is used mostly for reinforcement purpose. So that geogrid is used for design and analysis for this research.

The first geogrids appeared on the market in the late 1970s. They were made of HDPE and, after intensive research on product characteristics and design methods. The strength of the geogrid varies between 20 and 250kN/m [10]. Geogrid can be divided in two groups:

1. Stiff geogrids, mostly HDPE with a monolithic mesh structure
2. Flexible geogrids, mostly PET with PVC or acrylic coating with mechanically connected longitudinal and transvers elements

Geosynthetics are primarily used as slope reinforcement for construction of slopes to angle steeper than those constructed with the fill material being used. Geosynthetics used in this manner can provide significant project economy by [3]:

- Creating usable land space at the crest or toe of the reinforced slope;
- Reducing the volume of fill required;
- Allowing the use of less-than-high-quality fill; and
- Eliminating the expense of facing elements required on MSE walls.

Applications which highlight some of these advantages include [3]:

- Construction of new high way embankments;
- Construction of alternatives to retaining walls;
- Widening of existing highway embankments; and
- Repair of failed slopes.

2.7 Soil and Geosynthetic Interaction

Three mechanisms of interaction can be identified in reinforced system:

- Skin friction along the reinforcement
- Soil-soil friction
- Passive thrust on the bearing members of the reinforcement.

Skin friction is the only mechanism with geotextiles and strips. In the case of geogrids, the passive thrust on the bearing members of the grids must also be considered as soil-soil friction, if relative movement occurs in the soil along the grid’s apertures. There are different factors which influence soil-geosynthetic interaction such as: soil particle size, confinement stress, soil density and geosynthetic structure [11].

2.8 Design Consideration of MSE Wall

2.8.1 Stability

At the present time, the common practice used in designing retaining walls with geosynthetic reinforcement is the limit equilibrium analysis. The analysis consists of two major parts:

1) Internal stability: - involves determining tension and pullout resistance in the reinforcing elements length of reinforcement, and the integrity of the facing elements.

- Pullout resistance: $FS \geq 1.5$
- Determine the allowable tensile strength of the reinforcement. The connection between the facing and the reinforcement should be considered, as the connection may limit the design tensile strength.

2) External stability: - involves checking the overall stability of the stabilized mass.

- Check Factor of Safety for global stability

Retaining wall may fail in any of the following, Sliding, Overturning, Bearing capacity shown in figure 2-4.

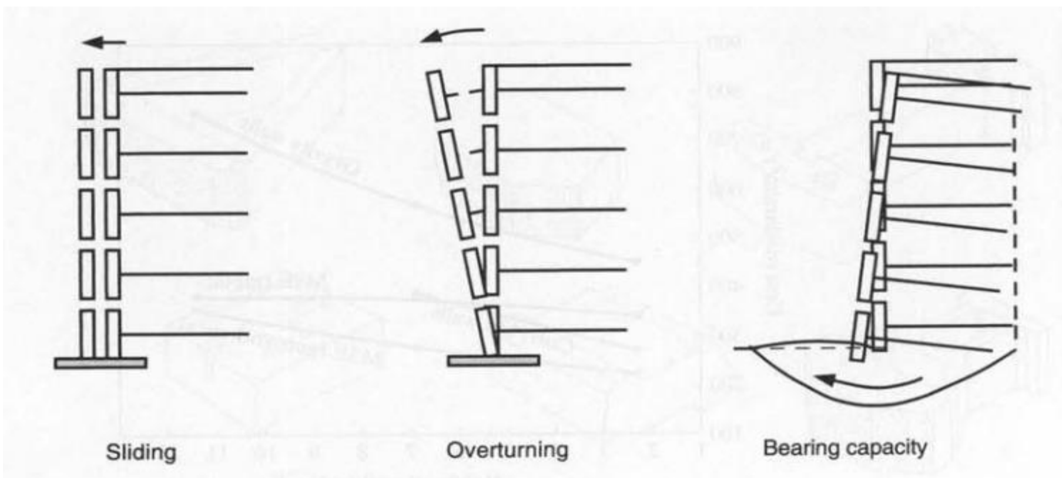


Figure 2-4. Checks for stability against Sliding, Overturning, and Bearing capacity failure will be described below [1].

Check for Sliding

$$FS_{Sliding} = \frac{\Sigma F_R}{\Sigma F_d} \qquad 2.5$$

Where

ΣF_R = Sum of the horizontal resisting forces

ΣF_d = Sum of the horizontal driving forces

Check for Overturning

$$FS_{Overturning} = \frac{\Sigma M_R}{\Sigma M_O} \quad 2.6$$

ΣM_R = Sum of moment of force tending to overturn

ΣM_O = Sum of moment of force tending to resist overturning

Check for bearing capacity

2.8.2 Lateral Earth Pressure

The lateral earth pressure behind the retaining wall must be determined. The lateral earth pressure can be calculated according to classical soil mechanics for active earth pressure. The active earth pressure coefficient (Ka) is calculated according to

$$Ka = \frac{1-sin\emptyset}{1+sin\emptyset} = tan^2(45 - \frac{\emptyset}{2}) \ldots\ldots\ldots 2.7$$

Where ϕ is the friction angle of retained soil. The lateral stress distribution due to the weight of the MSE wall (σ) is found using Rankine's active stress condition

$$\sigma_{h,w} = \gamma_T z K_{ar} \ldots\ldots\ldots 2.8$$

Where $\gamma_r$is the unit weight of the reinforced fill, Z is the depth from the top of the wall, and K_{ar} is the coefficient of active earth pressure [7].

2.8.3 Tie force

The tie force per unit length of the wall, T, developed at any depth Z can be calculated as [11]:

T= active earth pressure at depth z x S_v = $\sigma' S_v$

2.9 Finite Element Studies on Geosynthetic Reinforced Retaining Wall

The finite element method has been used to analyze different types of geotechnical structures, such as earth dams, embankments, shallow and deep foundations, slopes, and retaining walls. The application of the finite element method to reinforced soil structures is relatively recent. Reinforced soil is a complex system that involves interaction between different structural components and soil. Finite element analyses of reinforced soil structures can be conducted using computer programs that simulate soil- structure interaction, i.e. programs should that have the relevant soil and structural elements and material models. The program should be able to simulate the construction sequences, such as backfilling and the installation of reinforced layers and wall facings.

2.9.1 Minimum reinforcement length

FHWA and AASHTO require minimum length of 0.7H or 8 ft in the public transportation sectors. The NCMA design manual (NCMA 2002) specifies a minimum length of 0.6H, which has been widely used in the private sector. Nowadays, the 0.7H or 8 ft criterion has been used worldwide based on investigation of simple wall geometries and external stability analyses [32].

2.9.2 Parametric analysis of mechanical stabilized earth retaining wall

Behavior of reinforced retaining wall depends upon the type of back fill soil, foundation soil and reinforcements used in the system. In the present study, reinforced wall had been analyzed using finite element numerical tool PLAXIS 2D. Different types of reinforcements such as, HDPE Geogrid, PET Geogrid and Ribbed steel strip were used for wall. Also, backfill and foundation soil was varied with different types such as, sand, gravel, silt, clay. Walls deformations, ground settlement behind the wall and facing panel deformations were observed for different types of reinforcements, backfill and foundation soil. Ground settlements are found to be lesser for steel reinforcements behind the wall along the horizontal profile. HDPE and steel reinforcements are found to be more reliable, because deformations and settlements found to be less compared with PET Geogrid. Gravel found to exert lesser wall deformation because of its good drainage property. Even the settlements behind the wall were found to be lesser for gravel material. Hence it is adopted as good backfill and foundation material. Also, effect of surcharge loads on behavior of MSE wall was studied. It was observed that, for smaller magnitude surcharge loads, deformations observed were less [20].

CHAPTER THREE

3. RESEARCH METHODOLOGY

3.1 Introduction

In order to reduce high construction cost and time of a new retaining wall a suitable alternative was sought. Based on published literature and other accessible source, current design methods and construction practices; design example is performed in accordance to Geosynthetic Design and Construction Guideline [16]; following this Finite element computer software is used to model numerical model and analyzation.

3.2 Study area

The study area is in Ethiopia, Jimma university main campus. Jimma is the largest city in southwestern Ethiopia. Located in the Jimma zone of the Oromia region, this city has a latitude and longitude of 7°40'N 36°50'E and altitude of 1763m. In jimma, the climate is warm and temperate. Jimma is a city with a significant rainfall. Even in the driest month there is a lot of rain. The average temperature in jimma is 18.9 °C. In a year, the average rainfall is 1624 mm.

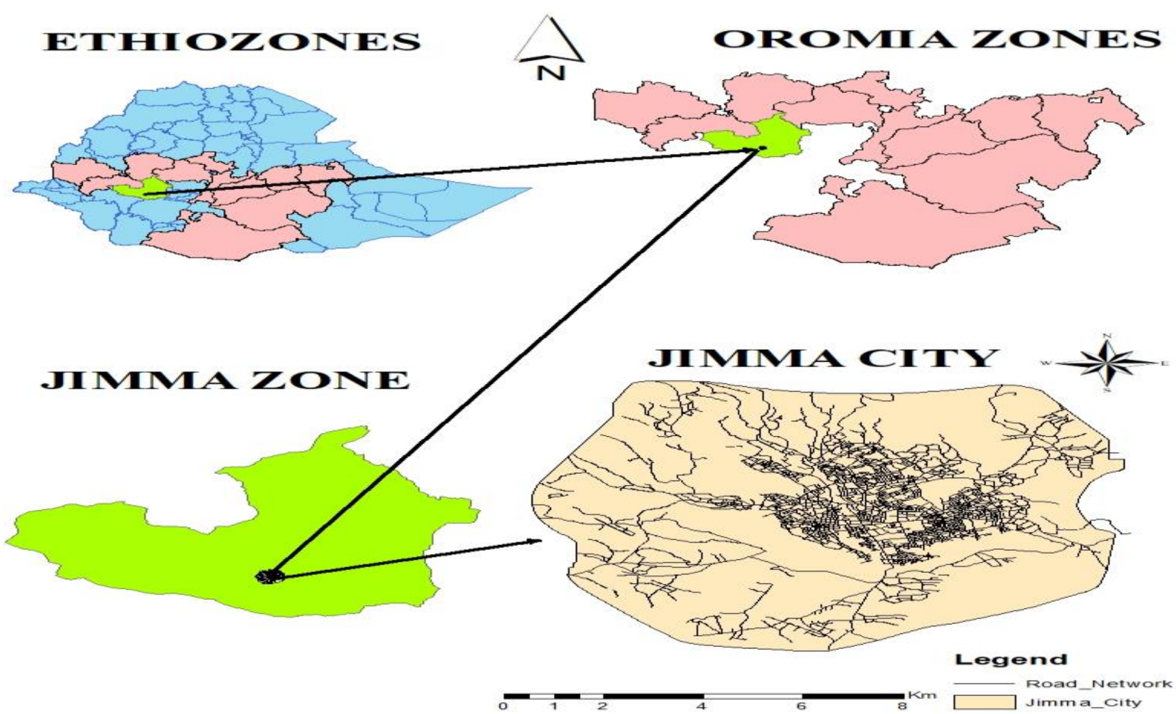


Figure 3-1 Study area

Figure 3-2 Case study site photo

Figure 3-3 Case study area highway alignment

3.3 Study design

This research study concerned mainly on to know the significance and advantage using geosynthetics in retaining structure, analyze and compare MSE retaining wall with CRW and the sensitivity of retaining wall to parametric changes (length of geogrid, soil type and type of geogrid) using numerical model by using Finite Element method (FEM) to determine stability of retaining wall.

3.4 Sample size and sampling procedures

For case study some representative soil samples were collected based on ASTM sampling procedures for the characterization of the soil under the retaining wall and backfill soil and cantilever retaining wall structure dimension is adopted from the contractor which is awarded for the construction of the project.

3.5 Study variable

The study variables considered in this thesis are both independent and dependent variables.

Independent variables

The independent variables which are to be considered for the design and analysis of Retaining wall in this study are listed below.

Angle of internal friction of the soil, **ϕ**

Cohesion of the soil, **c**

Unit weight of the soil**, γ**

Dimension (height and width) of retaining wall

Strength and type of geogrid

Dependent variables

Design and analysis of GRS retaining wall stability.

3.6 Data collection process

Laboratory tests

The soil samples were collected from site using ASTM and AASHTO sample collection procedures. The soil samples were taken at depth of 3m and 6m below ground surface.

Table 3-1 Laboratory testing procedures

Laboratory tests	Standard used
1. UCS (Unconfined Compressive Test)	ASTM, D2166
2. Moisture content	ASTM, D3122
3. Specific gravity	ASTM, D2854
4. Grain size analysis	ASTM, D422
5. Atterberg limit	ASTM, D4318
6. Permeability	ASTM, D5084

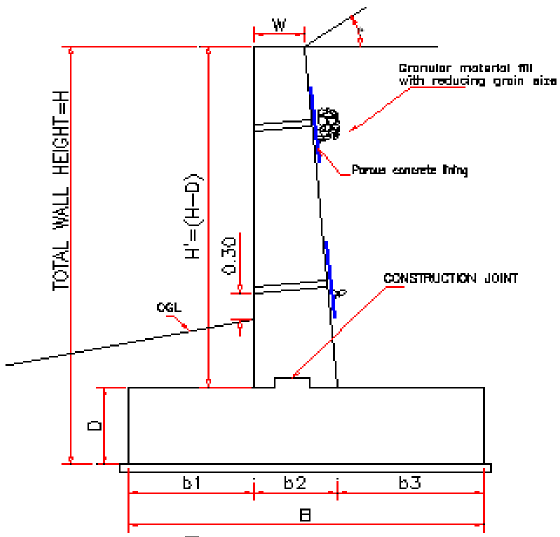
Geogrids

Geogrids are matrix like materials with large open spaces called apertures, which are typically 10 to 100mm between ribs that are called longitudinal and transverse, respectively. A geosynthetic material used as reinforcement in this study is biaxial geogrids is used. The property of geogrid is as shown below on Table 3-2 [33].

Table 3-2 Property of geosynthetic used (Geogrid).

Property	Unit	Quantity
Aperture dimensions	Mm	46
Minimum Rib thickness	Mm	1
Ultimate tensile strength	kN/m	21.9
Tensile modulus	kN/m	321
Length of reinforcement (m)	M	5
EA	(kN/m)	653
EI of the wall	(kNm^2/m)	$1.2 * 10^5$

Cantilever Retaining wall Property



Retaining wall height = 9m	
T	0.55m
H	6m
b1	1.5m
b2	1m
b3	1.5m
D	1m
B	4m

Figure 3-3 Geometry and Dimension of retaining wall.

3.7 Modeling

The Retaining wall were analyzed with plain strain model and 15-node elements are utilized. A unit for Length, Force and Time are used (m, kN and day). A total height Plaxis Version 8.2 is designed for two-dimensional modeling and analyses of physical space. A graphical interface allows the user to draw a cross-section of the physical space. In the study of non-deformable walls, the physical space has five main components: the backfill, the backfill-wall face and backfill-stable face interface, the wall face, the existing stable face, and the foundation. An example cross-section of the region modeled with Plaxis is shown in Figure 3.4.

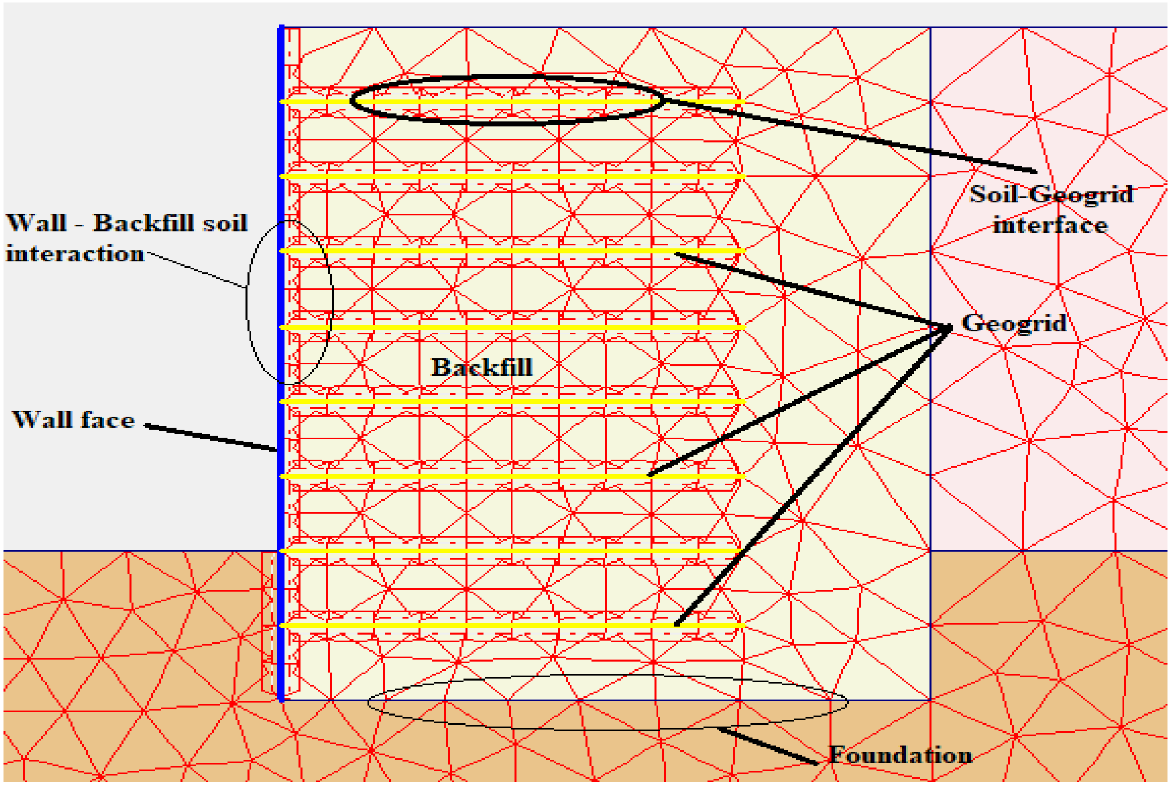


Figure 3-4 Geometry showing finite element model of the physical space retaining wall.

3.7.1 Backfill

The backfill was modeled using a finite element mesh created by Plaxis. The mesh consisted of 15-node triangular elements. The backfill is divided into several horizontal layers, as shown in Figure 3-5, so that elements were confined into discrete horizontal layers that were later used to simulate "stages" of construction in the analyses with Plaxis. The locations of nodes and stress points in a 15-node triangular element are shown in Figure 3-5. The size of the elements in the mesh may be selected prior to generating the mesh.

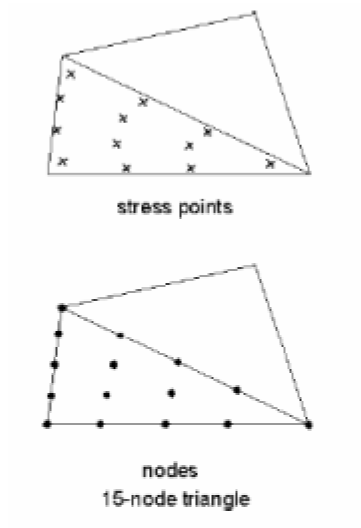


Figure 3-5 Example of nodes and stress points for 15 node tri-angular elements (Plaxis 2005)

3.7.2 Soil-wall interaction

The soil-wall interaction was modeled using thin rectangular elements called interface elements. The locations of nodes and stress points in a 5-node interface element are shown in Figure 3-6. The interface element shown in Figure 3-6, is given a small, finite thickness in Plaxis, but in reality the interface has zero thickness. In Plaxis, interface elements are assigned an imaginary virtual thickness, which is a dimension used to define the material properties of the interface in Plaxis. The virtual thickness is the product of a virtual thickness factor and the size of triangular elements. By default, Plaxis uses a virtual thickness factor equal to 0.10. The default value of the virtual thickness factor was used in all simulations.

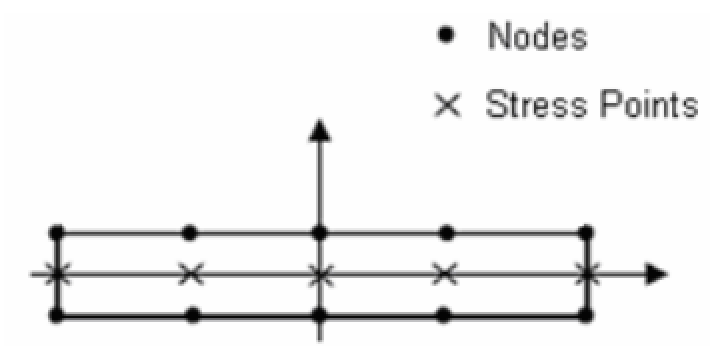


Figure 3-6 Location of nodes and stress points in a 5 node interface element (2005)

Each element is connected to other elements or to a boundary. Triangular elements will share the nodes along each side of the triangle. When a triangle is connected to an interface element, they also share nodes, as shown in Figure 3-7.

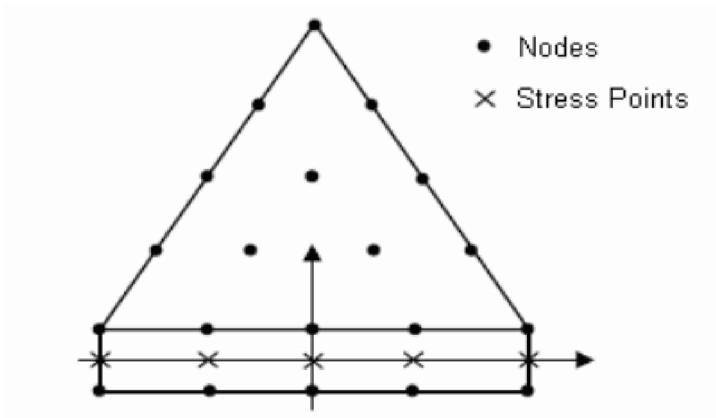


Figure 3-7 Location of nodes and stress points when a 15-node triangular element is connected to a 5-node interface element (Plaxis 2005)

3.7.3 Boundary Condition

A total fixity boundary condition was imposed at the foundation for all simulations. The nodes along a boundary having a total fixity boundary condition were fixed against horizontal and vertical movement. Both the horizontal fixity with the freedom to move vertically and the total fixity condition were imposed at the wall face and existing stable face to study the effects of the boundary conditions on displacements. The total fixity condition was applied to simulate a rough wall, i.e., a wall with a surface that produces friction between the soil and wall. The nodes along a boundary having a horizontal fixity boundary condition with the freedom to move vertically were fixed against horizontal movement and free to move in the vertical direction. The horizontal fixity condition was applied to simulate a smooth wall, i.e., a wall with a surface that has no interaction with the soil.

3.7.4 Soil Constitutive Models

A Mohr-Coulomb constitutive models were investigated to model the soil in Plaxis. The models are described below.

Mohr-Coulomb model

The Mohr-Coulomb model is an elastic-plastic model (Figure 3.8). In this model a yield surface is defined such that when the soil reaches or surpasses a predefined stress state, deformation is no longer completely recoverable. Five soil constitutive parameters are required for the Mohr-Coulomb model: Young's Modulus (E), Poisson's ratio (ν), angle of internal friction (φ'), cohesion (c'), and dilatancy angle (ψ). In all simulations, the goal was to model the backfill as a cohesion less material. Because the Mohr-Coulomb model is simple and requires relatively few parameters, it was used to simulate laboratory tests.

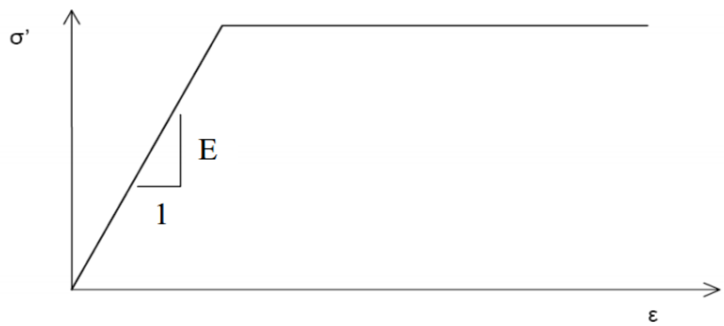


Figure 3-8 Stress-strain relationship for Mohr-coulomb model (Plaxis 2005)

Angle of Internal Friction (φ') the values selected for the angles of internal friction (φ') varied depending on what was being studied. Cohesion (c') in all the simulations performed for this study, the soil was modeled as cohesion less soil. However, in Plaxis, when the value of the cohesion is equal to zero, a warning message cautions, "Use small cohesion to improve calculation performance". The Plaxis documentation suggested using a value equal to 0.20 kPa (4 psf) (Plaxis, 2005). This value of cohesion was used in all simulations.

Dilatancy (ψ).The dilatancy angle (ψ) describes the behavior of soil during expansion and will depend on the angle of internal friction. The Plaxis documentation recommends that the dilatancy angle be chosen such that it is 30 degrees less than the angle of internal friction (φ') (Plaxis, 2005). Thus,

$$\psi = \varphi - 30 \quad \text{.......................... Eq. 3.1}$$

Equation 3-5 was used to determine the value of the dilatancy angle for all simulations in the study. In Mohr Coulomb model the boundary condition at the panel face is fixed horizontal movement and free vertical movement.

3.7.5 Loading model

Since at the top of the retaining wall, rigid pavement road is constructed, so the dead weight of the rigid pavement plus vehicular load is used at the top of retaining wall as uniformly distributed load. The worst case of traffic load at that section is medium truck which is water tanker vehicle used to transport water. The vehicular load is taken from EBCS manual for Medium truck load 500kPa and dead weight of rigid pavement is 48.90kPa. The total distributed load of 550kPa is used for the analysis.

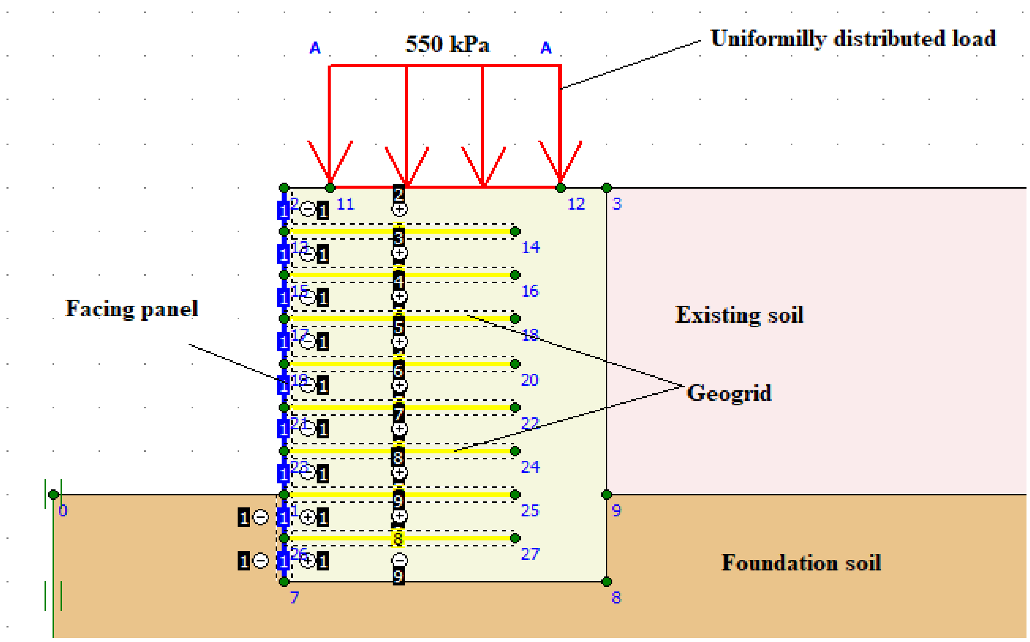


Figure 3-9 uniformly distributed Loading model

3.8 Analysis by Plaxis 2D

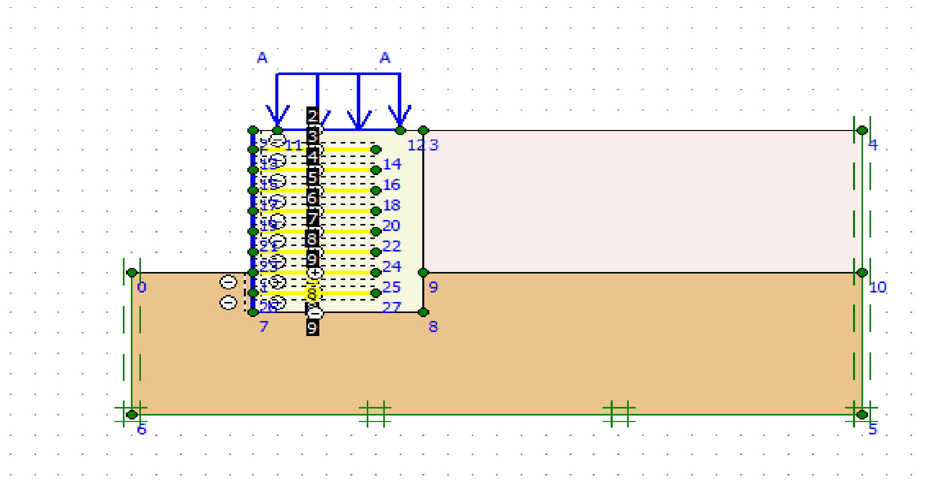


Figure 3-10 Geometric model of MSE wall

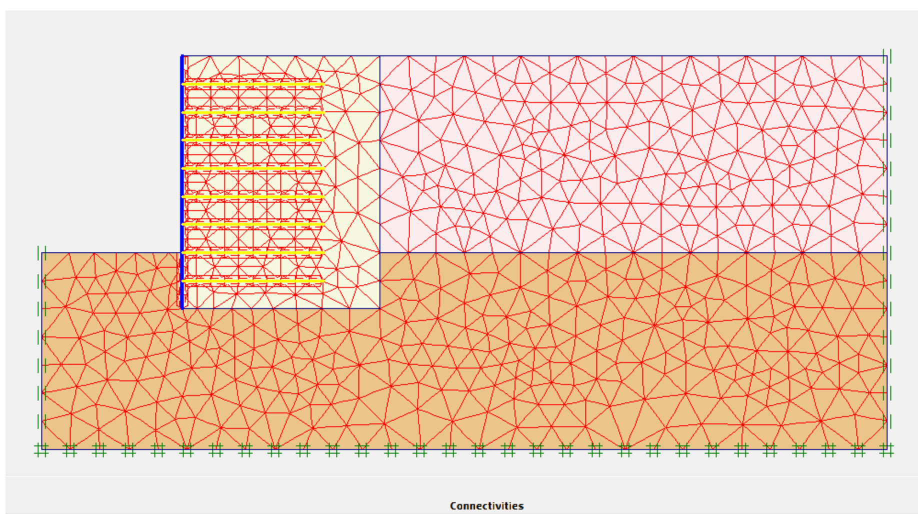


Figure 3-11 Mesh of model

Parametric Analysis of MSE wall modelling

Behavior of reinforced retaining wall depends upon the type of back fill soil, type and length of reinforcement used in the system. So that in this section, the behavior of geosynthetic reinforced soil walls is studied by the numerical method (FEM) with PLAXIS 2-D software. The effect of factors such as: Type of soil (backfill soil and sand gravel silt, and clay), reinforcement type (HDPE, PET, and PP) and reinforcement length (Four meter, five meter and six meter). Then, displacement of MSE wall, facing panel deformation and tension of reinforcement is investigated and analyzed using the software.

A. Effect of different Backfill soil on MSE wall

In this section, the MSE wall displacement (horizontal and vertical displacement), facing panel deformation, and tension in reinforcement of MSE wall is investigated for different type of soil (Sand, Gravel, Silt, and clay) of the backfill soil. The property of soil, reinforcement and the geometry of facing panel used in the analysis is as shown below in the Table 3.3.

Table 3-3 Different soil and their property used as backfill, Adapted from [33]

Property of a soil	Sand	Gravel	Silt	Clay
Soil condition	Drained	Drained	Drained	Drained or Undrained
Material Models	MC	MC	MC	MC or Modified MC
Soil Class	GC (Clayey gravels)	SC (Clayey Sands)	MH (Inorganic Silt)	CH (Inorganic Clay)
Unit weight kN/m^3	17	18	19	15
Angle of internal friction	33	35	18	22
Modulus of elasticity (MPa)	$3 * 10^4$	$1.2 * 10^5$	$1.5 * 10^3$	1000
Cohesion (kPa)	5	5	56	10
Poisson's ratio	0.3	0.25	0.3	0.33

B. The effect of reinforcement length on MSE wall

Analysis is carried out for different length of reinforcement of geogrid with the same property. For this analysis 4m, 5m, and 6m length of geogrid reinforcement is used and analyzed for the total, horizontal, and vertical deformation of MSE wall, displacement of facing panel and axial force in the geogrid. The property of soil (reinforced, backfill, and foundation soil) and reinforcing geogrid is used from laboratory test.

Table 3-4 Property of geogrid. Adopted from [5]

Property	Geogrid
Length of reinforcement (m)	4,5,6m
EA (kN/m)	653

C. Effect of reinforcement type on MSE wall

Using different geogrid type as a reinforcement can affect directly to the value of deformation of MSE wall and facing panel, and tension force of geogrid. The property of the reinforcements are shown below in the Table 3.5.

Table 3-5 Type and property of geogrid reinforcements

Geogrid Property	PP (Polypropylene)Geogrid	PET (Polyethylene Terephthalate)Geogrid	HDPE (High density Polyethylene)Geogrid
Structure	Punched sheet and drawn	Knitted	Punched sheet and drawn
Thickness	0.002	0.002	0.002
Modulus of elasticity(kPa)	213	534	950
Area (t*unit length)(m^2)	0.002	0.002	0.002

3.9 Data processing and analysis

The use Geosynthetic reinforced soil retaining wall system was evaluated with a parametric analytical study and stability analysis using finite element computer software's. Linear-elastic finite element models of the proposed system with varying design parameters (e.g., Geogrid length, geogrid type, different backfill soil property) was subjected to design loads, and critical response characteristics were monitored (e.g., stiffness, max element/weld stresses and ranges). The maximum stresses and ranges were used to assess the fatigue response of the connections. Finally, among the different parameter used to know the stability or safeness of the MSE wall the global stability of the wall, horizontal and vertical deformation of the facing panel and tension force in the geogrid are used in the analysis. The loading is uniformly distributed loading system is used because the highway is rigid pavement.

3.10 Ethical consideration

In this research the ethical considerations will not be that much of a problem because, searching alternatives of construction system can speedup infrastructure development of the country. The permission of Jimma University and concerned local administrative and Ethiopian roads authority is acquired in order to conduct this research study.

CHAPTER FOUR

4. RESULTS AND DISCUSSIONS

4.1 Laboratory Soil Property

Table 4-1 Natural soil geotechnical property.

	Natural Foundation soil	Natural Retained soil
Unit weight	18.24	18.41
Moisture	39.80	41.31
Dry unit weight	13.05	13.03
Unconfined compressive strength	103	124
Cohesion	51	62

Specific Gravity

The specific gravity, G_s of the soil at $20^{\circ c}$ is 2.72.

Grainsize analysis

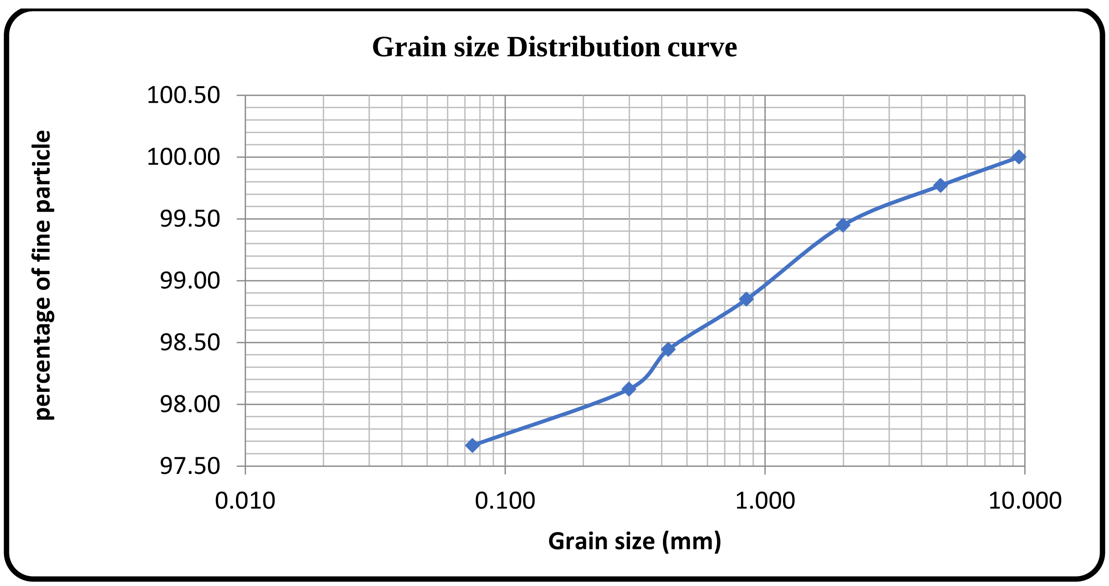


Figure 4-1 Grain size distribution curve of sample soil

Atterberg Limit

Liquid limit is 72%

Plastic limit is 58%

Plastic Index is 14%

Based on this test result and unified soil classification system the soil is fine grained soil, and using the plasticity chart the soil class is MH or OH.

4.2 Result for MSE wall with geogrid of Existing natural soil as a Backfill

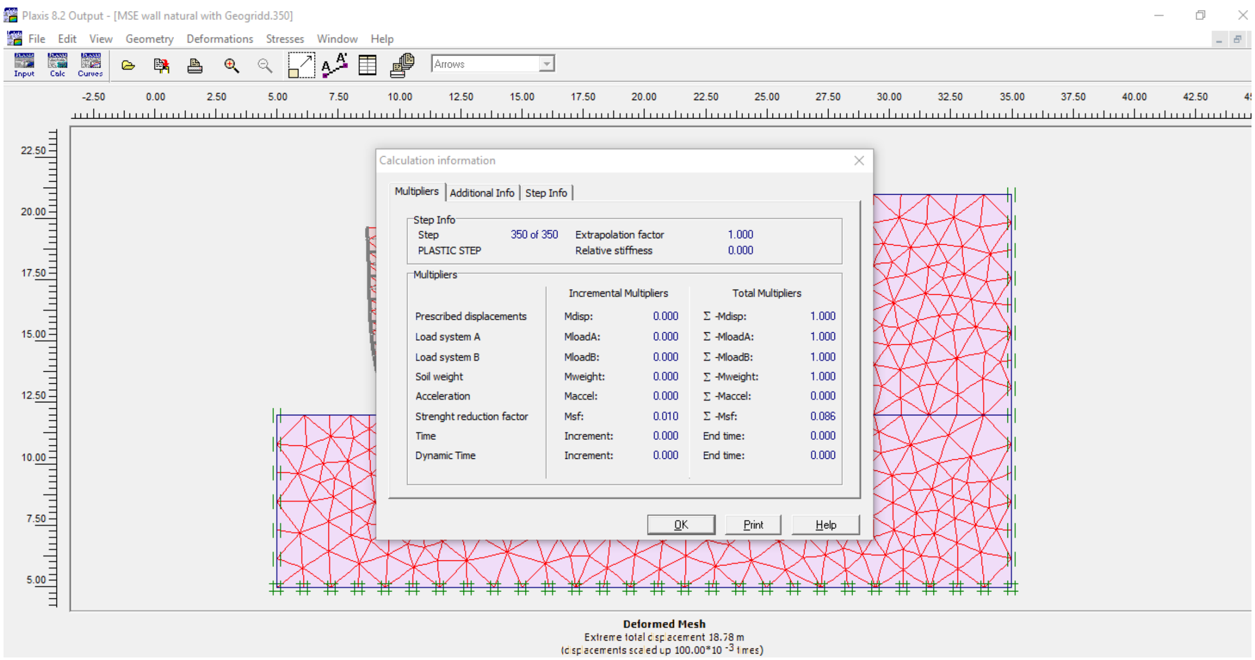


Figure 4-2 Calculation information

Table 4-2 Result of MSE wall with geogrid reinforcement

Height of wall = 7m	Result	Remark
Total displacement (m)	0.246	Soil body collapses
Vertical displacement (m)	0.211	Soil body collapses
Horizontal displacement (m)	0.166	Soil body collapses
Factor of safety	0.086	Soil body collapses

4.3 Result of MSE wall with Geogrid

The result for MSE wall vertical and horizontal deformation, global stability and other is shown in Table 4.2 below.

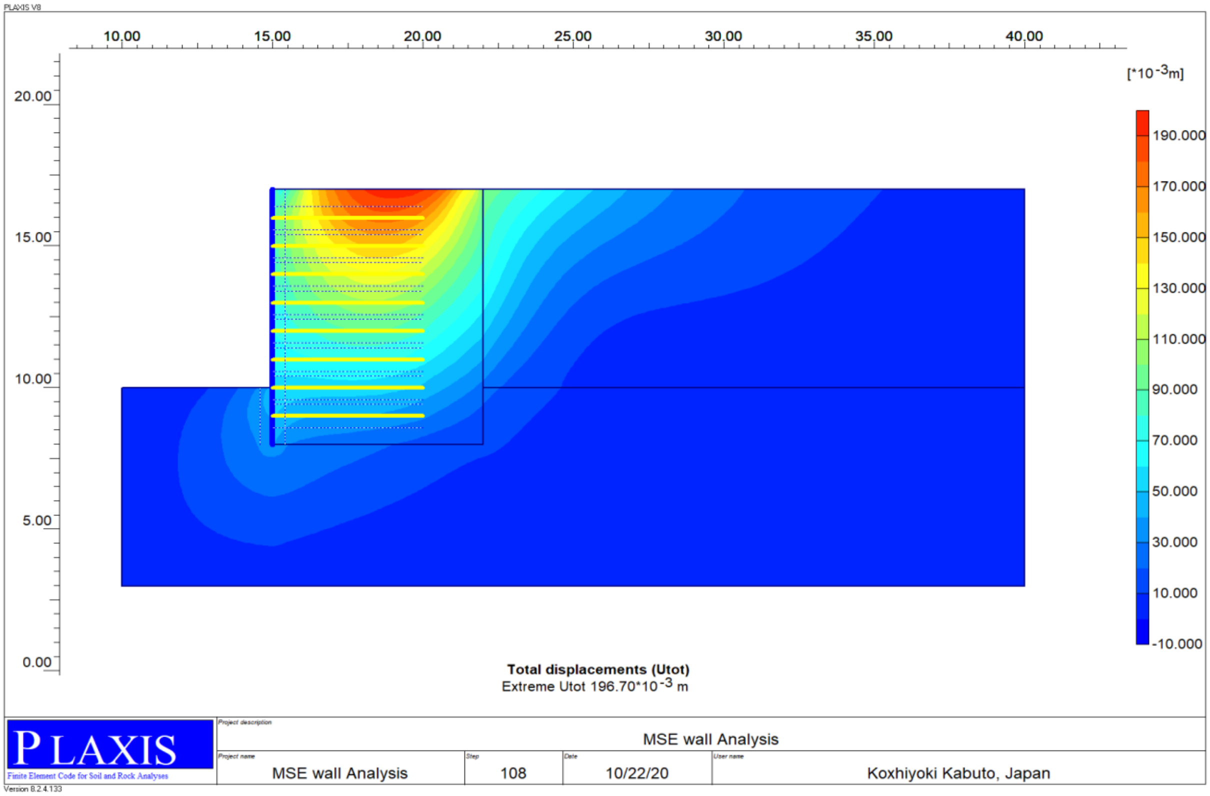


Figure 4-3 Deformation mesh of overall system

Table 4-3 Result of MSE wall with geogrid reinforcement

Height of wall = 7m	**Result**
Total displacement (m)	0.115
Vertical displacement (m)	0.100
Horizontal displacement (m)	0.052
Factor of safety	1.637

4.4 Result of MSE wall without Geogrid

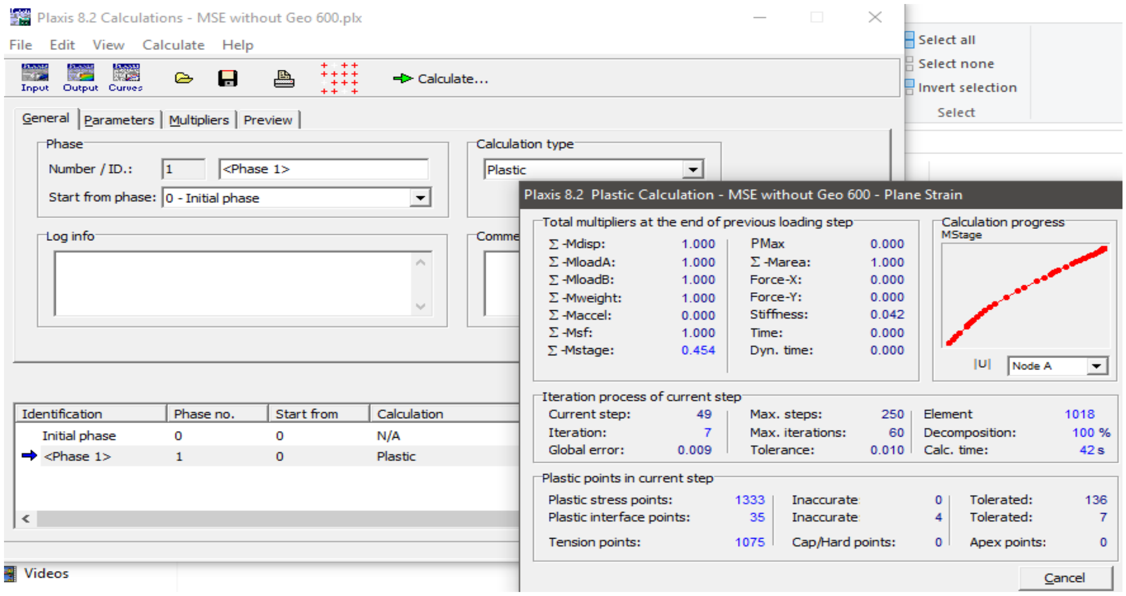


Figure 4-4 Window showing during calculation

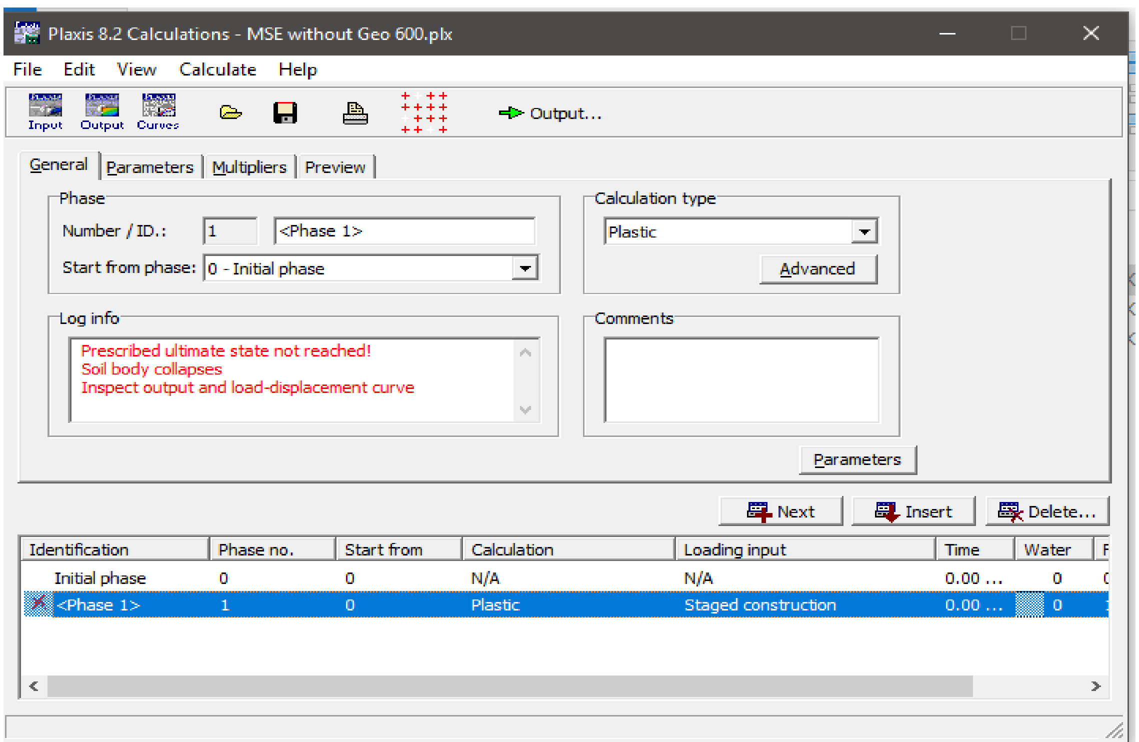


Figure 4-5 Deformed mesh without geogrid reinforcement

Table 4-4 Result of MSE wall without geogrid reinforcement

Height of the 7m	Values	Remark
Total displacement (m)	0.205	Soil body collapses
Horizontal displacement (m)	0.143	Soil body collapses
Vertical displacement (m)	0.187	Soil body collapses
Factor of Safety	0.151	Soil body collapses

4.5 Result of CR wall

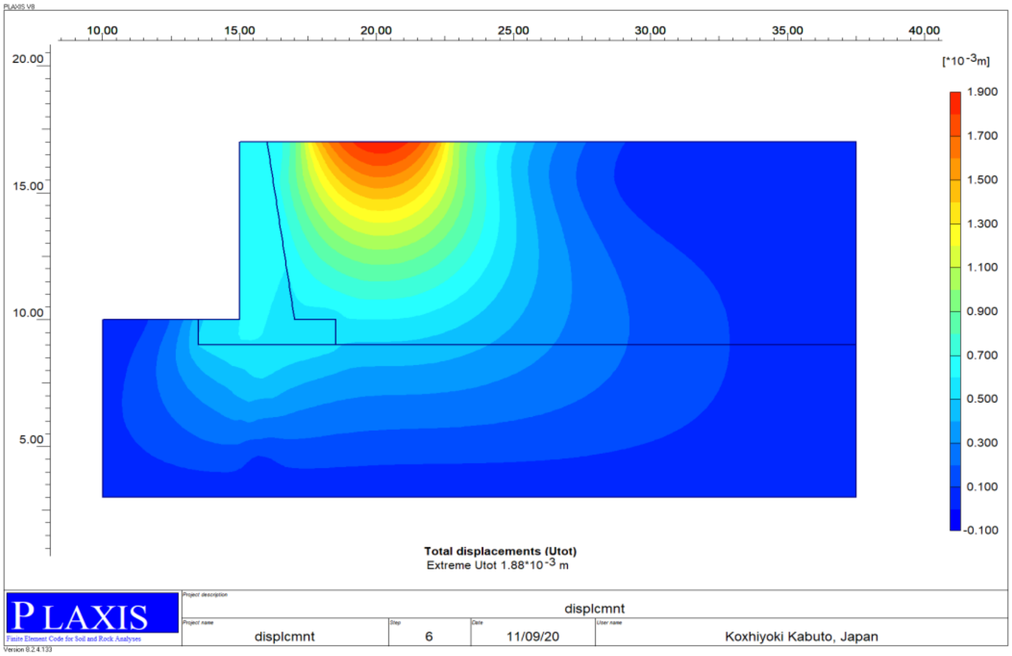


Figure 4-6 Shadings of total displacement of cantilever retaining wall

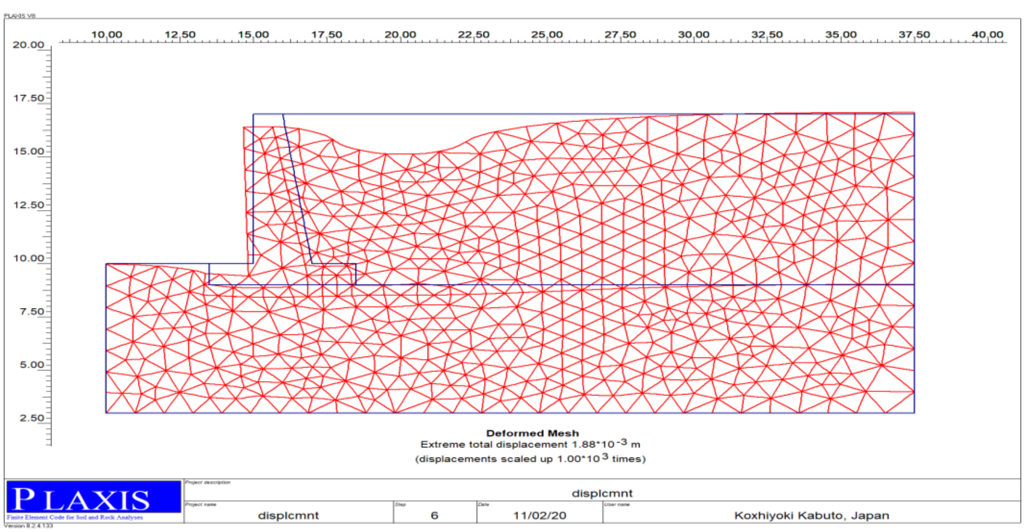


Figure 4-7 Deformed mesh of cantilever retaining wall

Table 4-5 Result for CR wall

Height of the 7m	New
Total displacement (m)	0.328
Horizontal displacement (m)	0.310
Vertical displacement (m)	0.187
Factor of safety	0.475

The analysis show that MSE wall is more stable than Cantilever retaining wall. As it is shown above the global stability of MSE wall higher than CRW and the Total, horizontal and vertical deformation of the MSE wall is less than CRW. As a result the stress developed at the back of MSE wall is less than CRW, those the surcharge and backfill soil weight load is supported mostly by geogrid reinforcement and facing panel. But in MSE wall without geogrid reinforcement the system collapses before reaching the prescribed ultimate state.

4.6 Parametric Analysis of MSE Wall

4.6.1 Effect of Different Backfill Soil on facing panel of MSE Wall

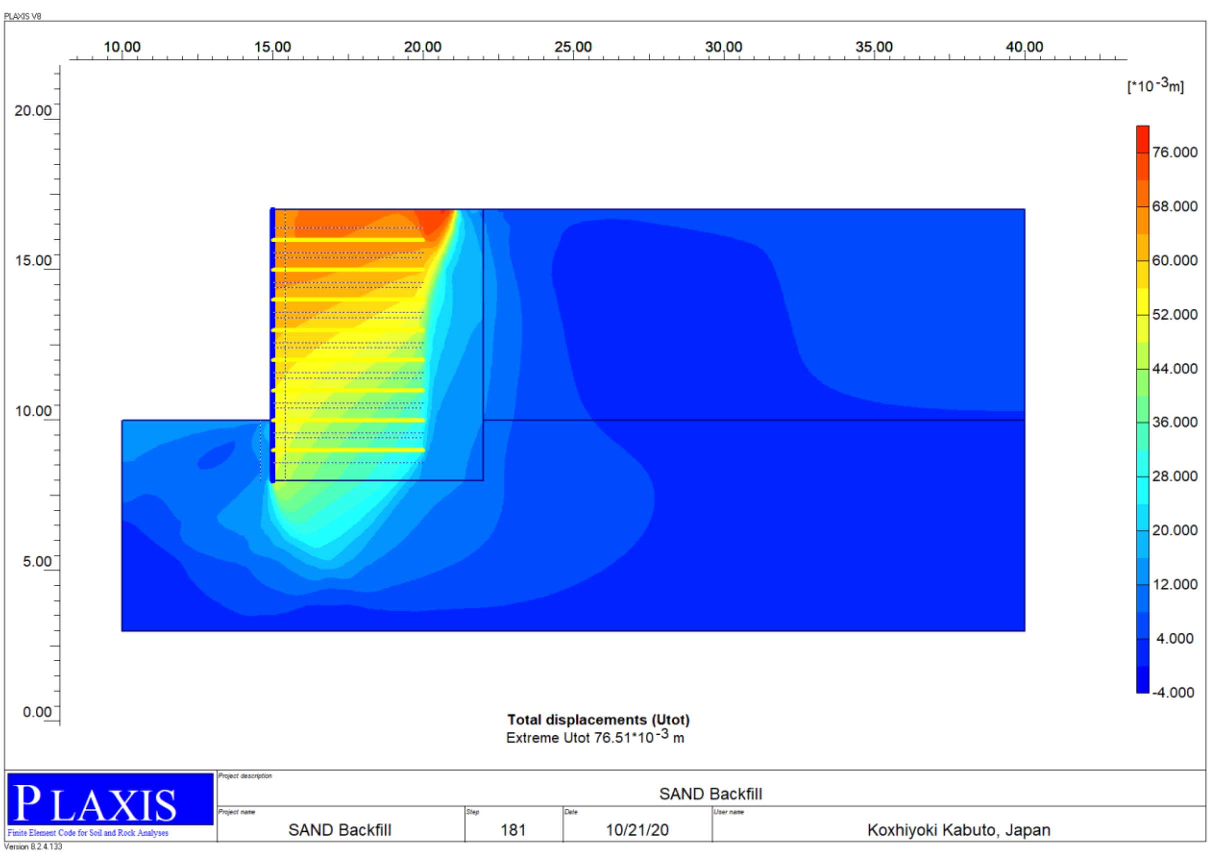


Figure 4-8 Total displacement distribution

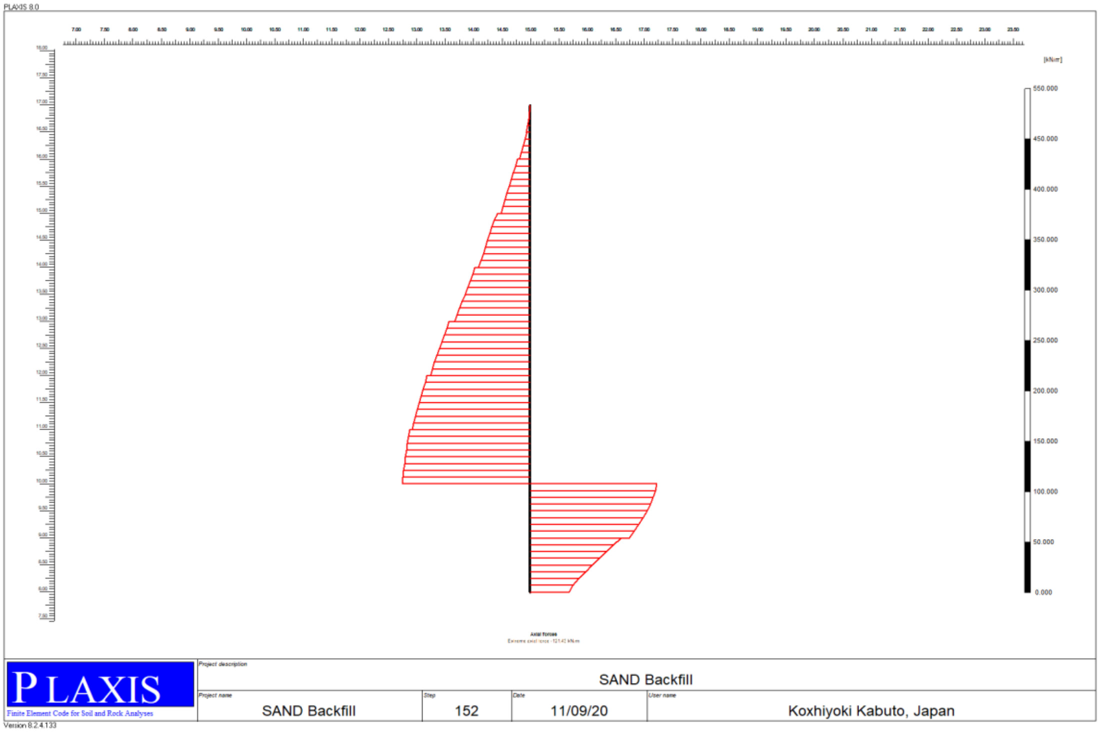


Figure 4-9 Axial force diagram on facing panel

Table 4-6 Result for different backfill soil

Height of the 7m	Gravel	Sand	Silt	Clay
Horizontal displacement (m)	0.012	0.078	0.318	0.844
Vertical displacement (m)	0.010	0.033	0.122	0.208
Axial force (kN/m)	58.68	121.43	164.61	159.30
Shear force (kN/m)	12.96	31.71	53.30	75.96
Bending moment (kNm/m)	11.01	48.66	98.92	173.46

The facing panel, forces and bending moment on the facing panel affected by using different type backfill soil. Based on the analysis using coarser soil as a backfill is the safest than finest soil type. In addition as shown on the table 4-5 the value is increasing as the soil size decreasing. So using coarser soil as backfill material is highly recommended for MSE wall.

4.6.2 Effect of Reinforcement Length on facing panel of MSE Wall

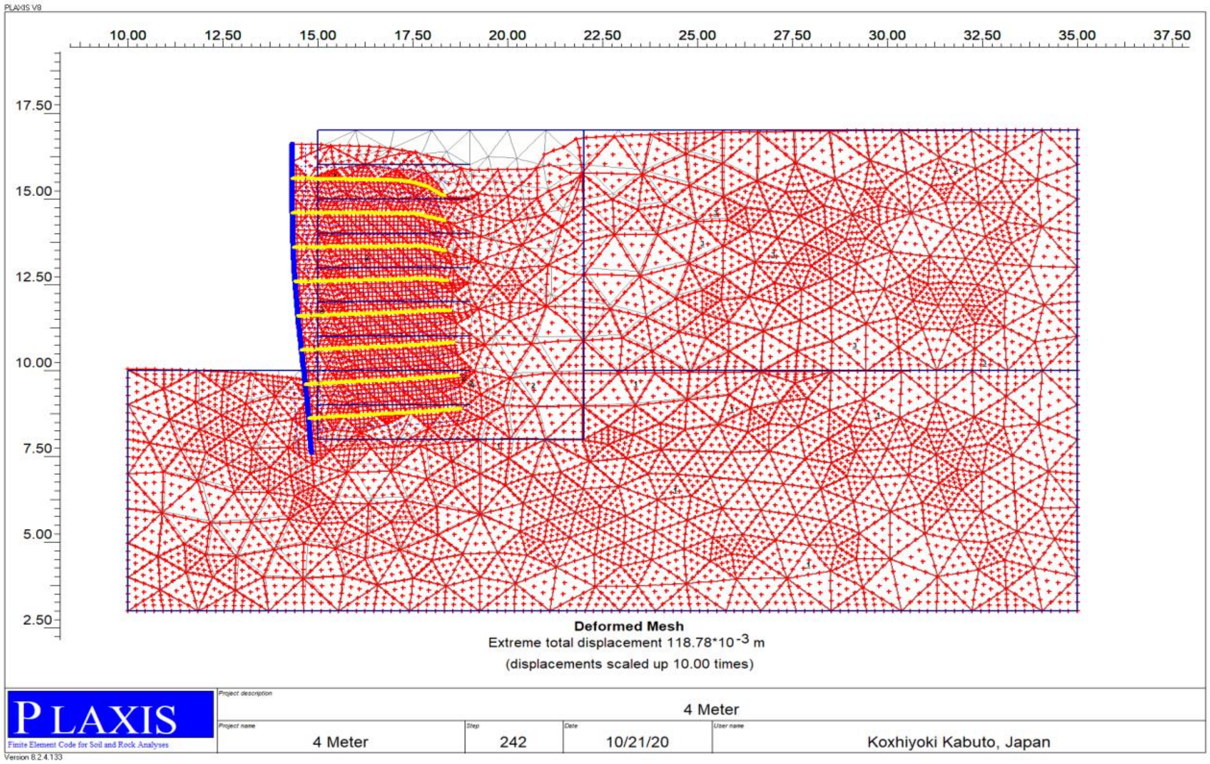


Figure 4-10 Deformed mesh

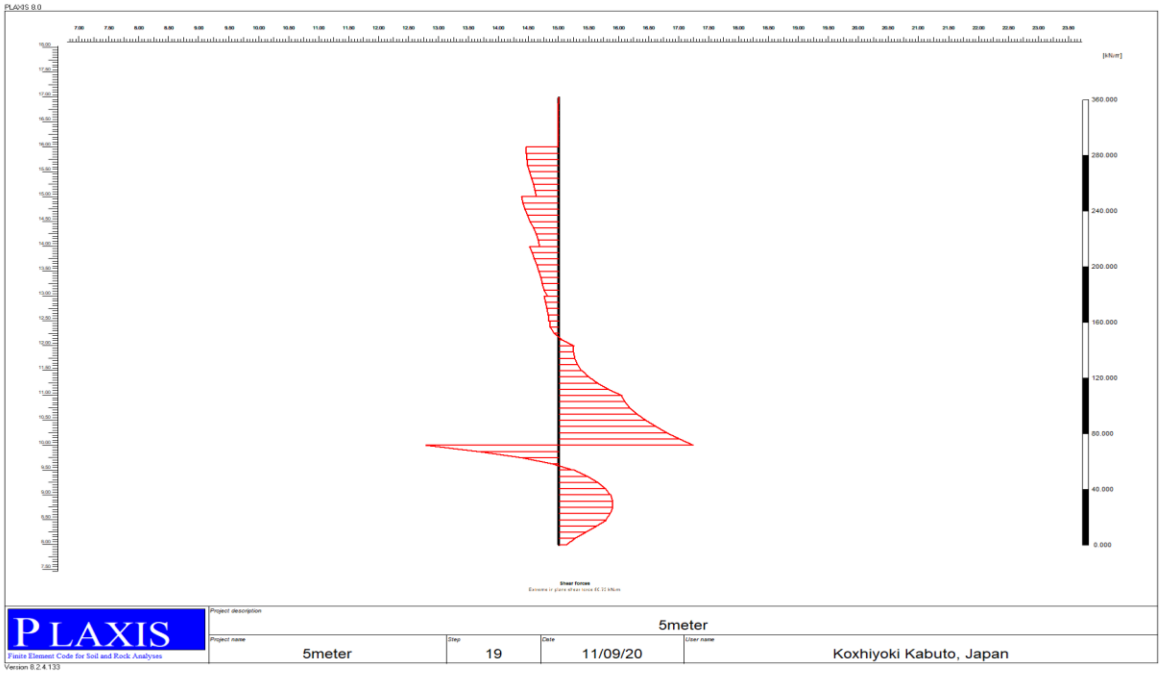


Figure 4-11 Shear force diagram of facing panel

Table 4-7 Result for different reinforcement length

Height of the 7m	Four meter	Five meter	Six meter
Horizontal displacement (m)	0.01517	0.09246	0.35071
Vertical displacement (m)	0.01022	0.03932	0.04185
Axial force (kN/m)	63.45	210.27	214.30
Shear force (kN/m)	13.71	80.73	139.92
Bending moment (kNm/m)	7.39	50.47	118.19

As it is shown above in the figure as the length of reinforcement increases the stability of the wall also increases. The facing panel deformation, forces and bending moment on the facing panel decreases as the length of the geogrid increases. But if the length increases beyond five meter the stability remains unchanged.

4.4.3 Effect of Type of Reinforcement on facing panel of MSE Wall

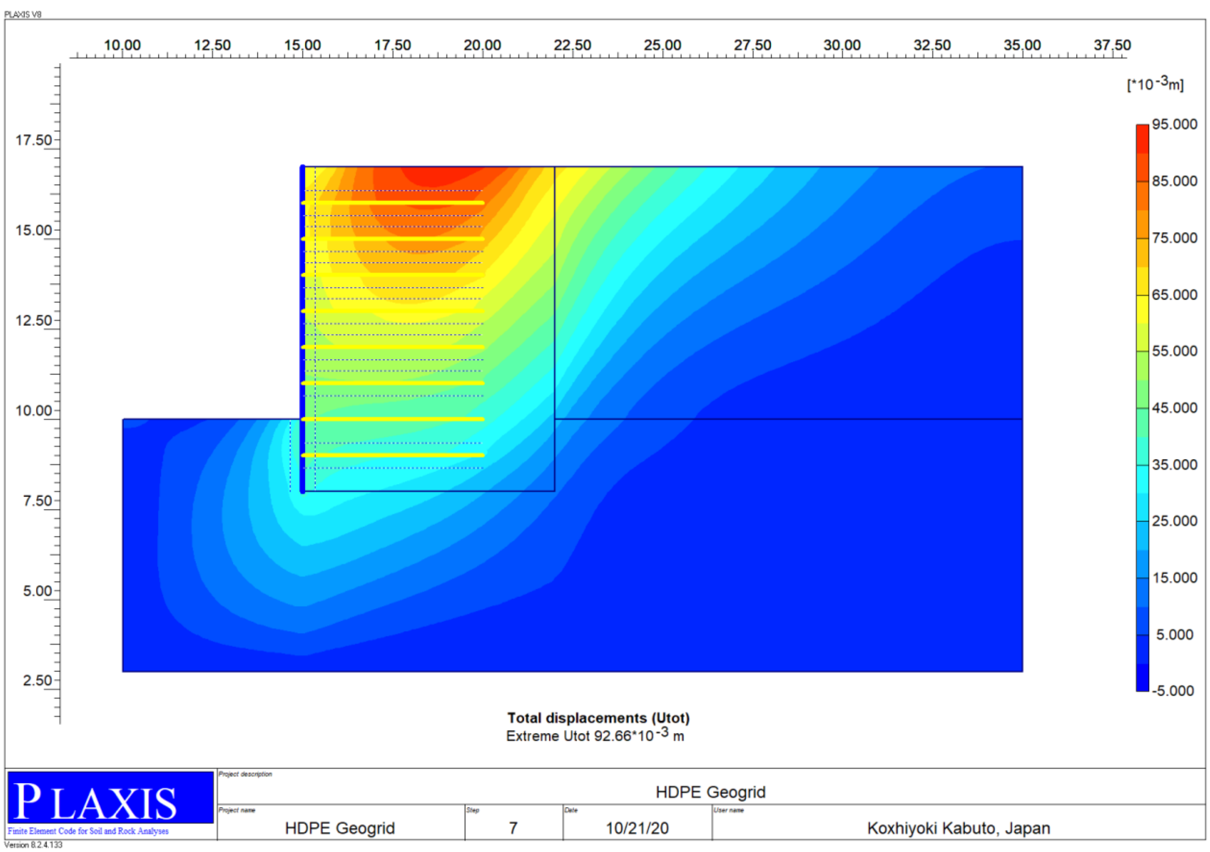


Figure 4-12 Facing panel deformation

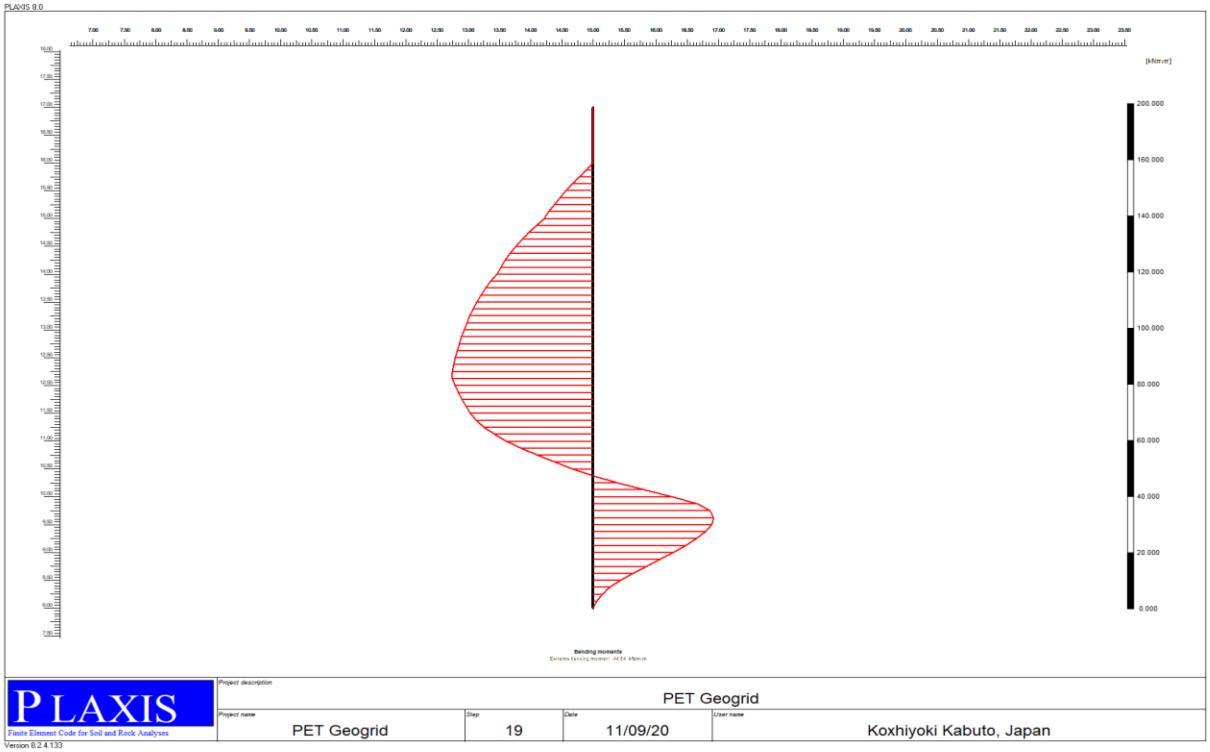


Figure 4-13 Bending moment diagram on the facing panel

Table 4-8 Result for different reinforcement type

Height of the 7m	HDPE	PET	PP
Horizontal displacement (m)	0.086	0.077	0.094
Vertical displacement (m)	0.039	0.039	0.038
Axial force (kN/m)	209.58	209.48	222.61
Shear force (kN/m)	75.85	79.48	102.97
Bending moment (kNm/m)	56.75	44.84	143.75

Using different geogrid type as a reinforcement it directly affects the stability of MSE wall. As the analysis shows the value of horizontal and vertical deformation, and bending moment of facing panel decreases when the reinforcement is PET and also axial and shear force developed on the facing panel is lower for PET geogrid.

4.5 Result discussion

Based on this study the front face wall deflection response is derived for MSE wall with and without geogrid and CR wall of height 7m and road width 7.5m considering self-weight of wall. Similar response is obtained for other parametric combinations by varying the properties of backfill material (sand, gravel, silt, clay), type (PP, HDPE, PET) and length (4m, 5m, 6m) of reinforcement (Table 3-3, Table 3-4 and Table 3-5). The result is obtained using surcharge load acting on both retaining system is uniform distributed and constant that is 550 kPa.

The behavior of MSE wall when the natural soil is used as a backfill material global stability is 0.086 and the total deformation, horizontal and vertical deformation is 0.246m, 0.211m and 0.166m respectively.

The vertical deformation of MSE with geogrid and CR wall is 0.1m and 0.328m respectively. The horizontal deformation MSE wall with geogrid and CR wall is 0.052m and 0.187 mm respectively. Factor of safety for global stability of both walls are 1.637 and 0.475 by keeping the other parameter constant (Figure 4.2, 4.3 and 4.4). The deformation of CR wall is higher than MSE wall for the same loading condition and MSE wall with geogrid is stable than CR wall as the analysis indicates. However, MSE wall without geogrid reinforcement the soil body collapses before reaching prescribed ultimate state (Table 4-2, Table 4-3, and Table 4-4).

In current investigation variety of backfill soils sand, gravel, silt and clay and the wall is resting on assumed hard strata foundation. In case of Gravel backfill soil horizontal and vertical deformation, axial and shear force and bending moment on the retaining wall are 0.012m, 0.010, 58.68kN/m, 12.96kN/m and 11.01kNm/m respectively. And for Sand backfill soil horizontal and vertical deformation, axial and shear force and bending moment on the retaining wall are 0.078m, 0.033m, 121.43kN/m, 31.71kN/m and 48.66kNm/m respectively. When the backfill soil is silty type of soil the horizontal, vertical deformation, axial force, shear force and bending moment of the retaining wall are 0.318m, 0.122m, 164.61kN/m, 53.30kN/m and 98.92kNm/m respectively. The last backfill soil used in this study is clay type of soil. Horizontal, vertical deformation, axial force, shear force and bending moment on the retaining wall are 0.844m, 0.208m, 159.30kN/m, 75.96kN/m and 173.46kNm/m respectively (Table 4-5).

In other parametric combination facing panel response against horizontal deflection, vertical deflection, axial force, shear force and bending moment developed in the retaining wall face as the reinforcement length varies (four, five and six meter). The horizontal deflection, vertical deflection, axial force, shear force and bending moment on the retaining wall result when reinforcement length is four meter are 0.015m, 0.01m, 63.45kN/m, 13.71kN/m and 7.39kNm/m. For five meter length of reinforcement the horizontal deflection, vertical deflection, axial force, shear force and bending moment on the retaining wall are 0.092m, 0.039m, 210.27kN/m, 80.73kN/m and 50.47kNm/m. When the reinforcement length is six meter the horizontal deflection, vertical deflection, axial force, shear force and bending moment on the retaining wall value are 0.35m, 0.041, 214.30kN/m, 139.92kN/m and 118.19kNm/m (Table 4-6)

The other parameter that affects the MSE wall considered in this study is type of reinforcement used. The result is for the horizontal deflection, vertical deflection, and axial force, shear force and bending moment developed on the retaining wall when HDPE reinforcement used are 0.086m, 0.039m, 209.58kN/m, 75.85kN/m, 56.75kNm/m respectively. And for PET reinforcement type the value horizontal deflection, vertical deflection, axial force, shear force and bending moment developed on the retaining wall are 0.077m, 0.039m, 209.48kN/m, 79.48kN/m and 44.84kNm/m respectively. At last the PP geogrid reinforcement are used to reinforce backfilled soil of the MSE wall so the analysis result for horizontal deflection, vertical deflection, axial force, shear force and bending moment developed on the retaining wall are 0.094m, 0.038m, 222.61kN/m, 102.97kN/m and 143.75kNm/m respectively (Table 4-7).

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Soil investigation of study area indicate soil is fine grained and classified under MH or OH groups. The Analysis result is,

- Using geogrid as reinforcement in MSE wall improves the overall stability of the wall system by 100% than using MSE wall without geogrid reinforcement.
- Using the MSE wall than CRW improves the global stability by 78%. In addition the horizontal and vertical deflection of the MSE wall less than CR wall. The maximum wall deflection point is at 0.65 times height of wall from bottom ($0.65*7 \approx 4.55$m) which should be taken into account while construction of such wall. This show that MSE wall is more stable than CRW.
- It is clear shown in the analysis, as granular soil used as backfill material the deformation of facing panel decrease and the stability of the system will increases. This is because of free drainage and higher frictional resistance at the interface of soil and reinforcement, there is no slippage of reinforcement. Since permeability is more for gravel and sand, drainage will be good. There will not be excess pore water pressure developed behind the wall.
- Wall deformation ware more for fine soil as a backfill because, there will be excess pore water pressure develops, which leads to more deformation. Outward bulging is major problem encountered in reinforced earth wall, this numerical analysis shows the same.
- In addition varying reinforcement length, i.e. reinforcement extended to the zero force line, does not provide any significant improvement in force distribution above five meter that is when the ratio of reinforcement length to the height of facing panel is 0.7, that is in this study case beyond 5m length of reinforcement.
- In other case PET geogrid reinforcement found to be reliable and the deformation of front face of retaining wall is lesser than HDPE and PP reinforcement of MSE wall. This is because of the higher axial stiffness.

5.2 Recommendation

In this research an attempt was made to check and compare the stability and facing wall deformation of MSE and CRW which is found jimma university compound Cantilever retaining wall. In addition to this the effect of different backfill soil, length and type of reinforcing geogrid checked separately for MSE wall. Depending on this investigation the following recommendation is made:-

- In this study the parameter used for comparison of MSE and CR wall are horizontal and vertical deformation and global stability. But for a better result it is good to consider additional parameter such as stress and strain developed in the retaining wall.
- In parametric analysis the parameter used are type of backfill soil, Length and type of Geogrid only. So if other parameters such as foundation soil type, length and type of facing panel should be considered in order to get a better analysis MSE retaining wall project.

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APPENDIX

APPENDIX - A

Test result of index property of soils for case study

1. **UCS (Unconfined Compressive Test) ASTM, D2166**

The representative soil sample taken from the case study site of five different samples are taken tested as shown below.




Table A- 1 Unconfined compressive test result

Trial	Max. Stress (Kpa) or Unconfined compressive strength (qu) (KN/m^2)	Unit weight (KN/m^3)	Moisture (%)	Dry Unit weight (KN/m^3	Cohesion (c) (KN/m^2)
BS-T-01	98.10179219	18.304776	40.53976	13.02462	49.0508961
BS-T-02	91.78944718	18.102011	39.48216	12.97801	45.8947236
BS-T-03	117.7648965	18.304776	39.36758	13.13417	58.8824483
TS-T-01	113.8145376	18.422875	41.49489	13.02017	56.9072688
TS-T-02	134.7865527	18.391496	41.13066	13.03154	67.3932763
	111.2514452	18.305187			55.6257226

2. Grain size analysis of case study area


Table A- 2 Grain size analysis of case study area

Sieve size (mm)	Mass of Retain on Each Sieve (g)	Percentage of Retained Soil	Percentage of cumulative Retained Soil	Percentage of Passing Soil Particle
9.500	0	0.00	0.00	100.00
4.750	2.3	0.23	0.23	99.77
2.000	3.2	0.32	0.55	99.45
0.850	6	0.60	1.15	98.85
0.425	4.06	0.41	1.56	98.44
0.300	3.21	0.32	1.88	98.12
0.075	4.56	0.46	2.33	97.67
pan	976.670	97.67	100.00	0.00
sum	1000.000			

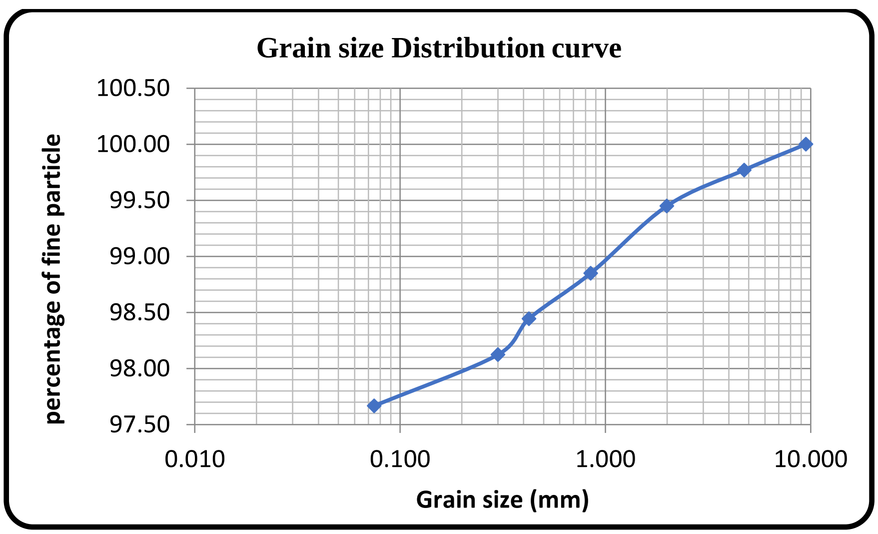

Figure A- 1 Grain size distribution curve of the study area

3. Permeability of case study area

Falling method permeability test

Cross-sectional area of stand pipe, a = 2.093cm2

Length of soil specimen in permeameter, L = 11.65cm

Cross-sectional area of soil specimen, A =81.03cm2

Table A- 3 Permeability calculation result of case study

Trial	1	2	3
Head, h_o(cm)	101	100	88.4
Head,h_1 (cm)	79.5	83.2	64.5
Time, t (s)	10:54:23	24:15:39	39:41:17
Temperature, T (^oc)	21	21	21
Permeability at T^oc, K_T	0.003662015	0.0071576	0.00576499
Permeability at 20^oC, K_{20}	0.003574564	0.0137743	0.01710158
Average K_{20} (cm/s)	0.011483478		

4. **Specific Gravity test of case study area**

Table A- 4 Specific gravity of the study area

Trial code	1	2	3
Mass of dry, clean Calibrated pycnometer, M_p	30.71	30.48	30.62
Mass of specimen + pycnometer, $M_{ps,}$ in g	40.82	41.32	41.15
Mass of pycnometer + soil + water, M_{psw}, in g	87.77	87.95	89.36
Temperature of contents of pycnometer when M_{psw} was taken, Ti, in ^oc	23	22.5	23
Density of water @ Ti in g/cm3	0.99757	0.99845	0.99757
Mass of pycnometer + water at temperature Ti,g	81.34	81.19	82.72
Tx in $^o{}_c$	24	24	24
Density of water @ Tx in g/cm3	0.9972	0.9972	0.9972
K @ Tx	0.9991	0.9991	0.9991
Mass of pycnometer + water at temperature Tx,g	81.32	81.13	82.70
Specific gravity @ 20^oc	2.76	2.70	2.72
Average Specific gravity at 20^oc, G_s	**2.72**		

5. Atterberg test

Table A- 5 Determination of atterberg limit case study

Determination		***Liquid Limit (ASTM)***			***Plastic Limit (AASHTO T 090-96)***	
Number of blows		28	23	18		
Test No		01	02	03	01	02
Wt. of Container, (g)		17.75	20.80	6.50	19.67	6.44
Wt. of container + wet soil, (g)		38.77	40.62	25.91	27.10	14.01
Wt. of container + dry soil, (g)		30.84	32.41	17.08	24.40	11.21
Wt. of water, (g)		7.93	8.21	8.83	2.70	2.80
Wt. of dry soil, (g)		13.09	11.61	10.58	4.73	4.77
Moisture container, (%)		60.60	70.70	83.52	57.11	58.70
Average		71.61			57.90	
Determination of (PI) (LL - PL)	***LL (%)***	***72***	**Sieve No. (mm)**			**Soil Classification AASHTO M-145**
	PL (%)	**58**	**2.00**	**0.425**	**0.075**	**A-7-5**
	PI (%)	**14**	**99.5**	**98.4**	**97.7**	**Clayey soils**

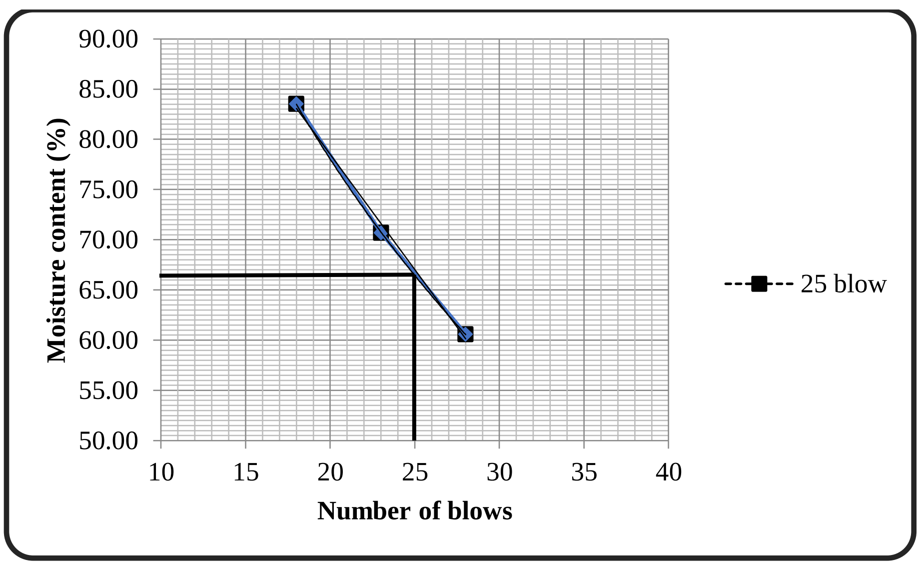

Figure A- 2 Liquid limit test result

APPENDIX – B

MSE wall with geogrid reinforcement result

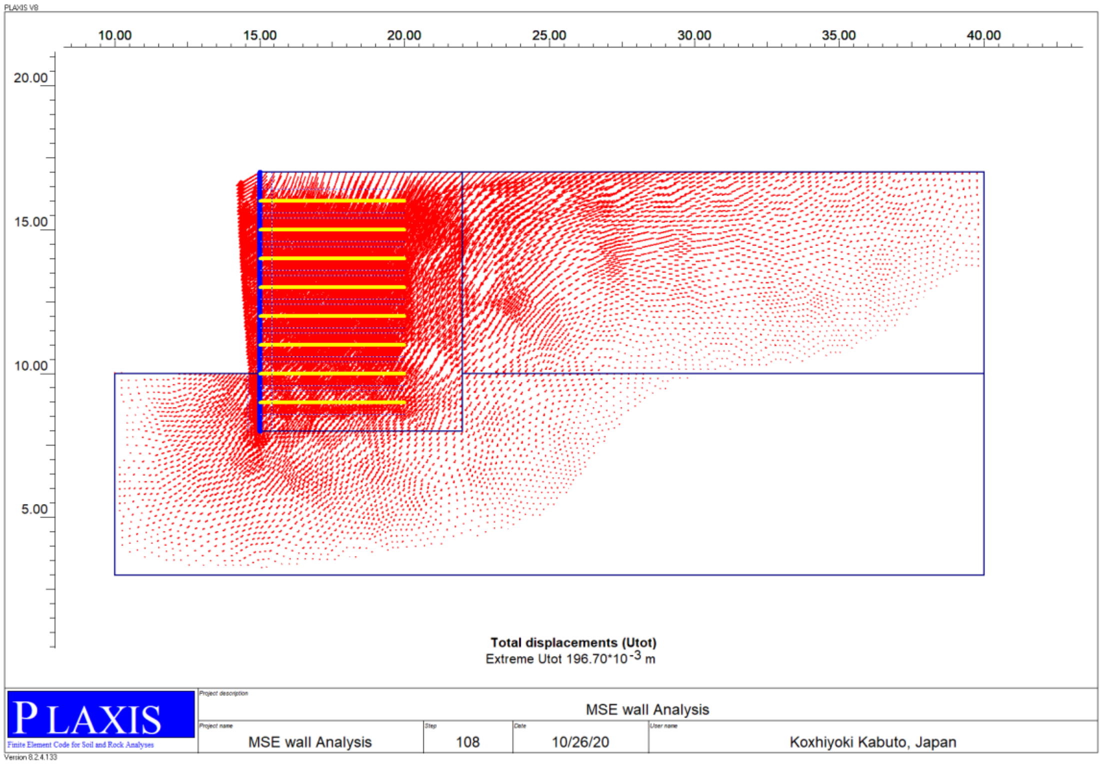

Figure B- 1 Showing total displacement of facing panel

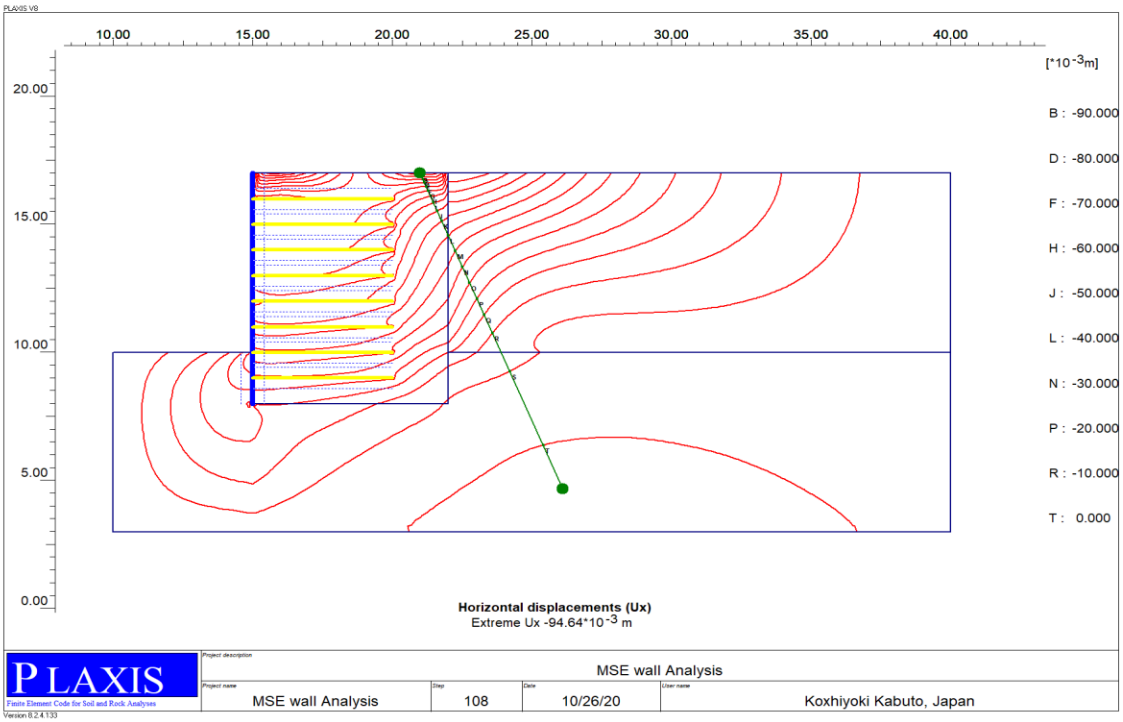

Figure B- 2 Showing horizontal displacement of facing panel

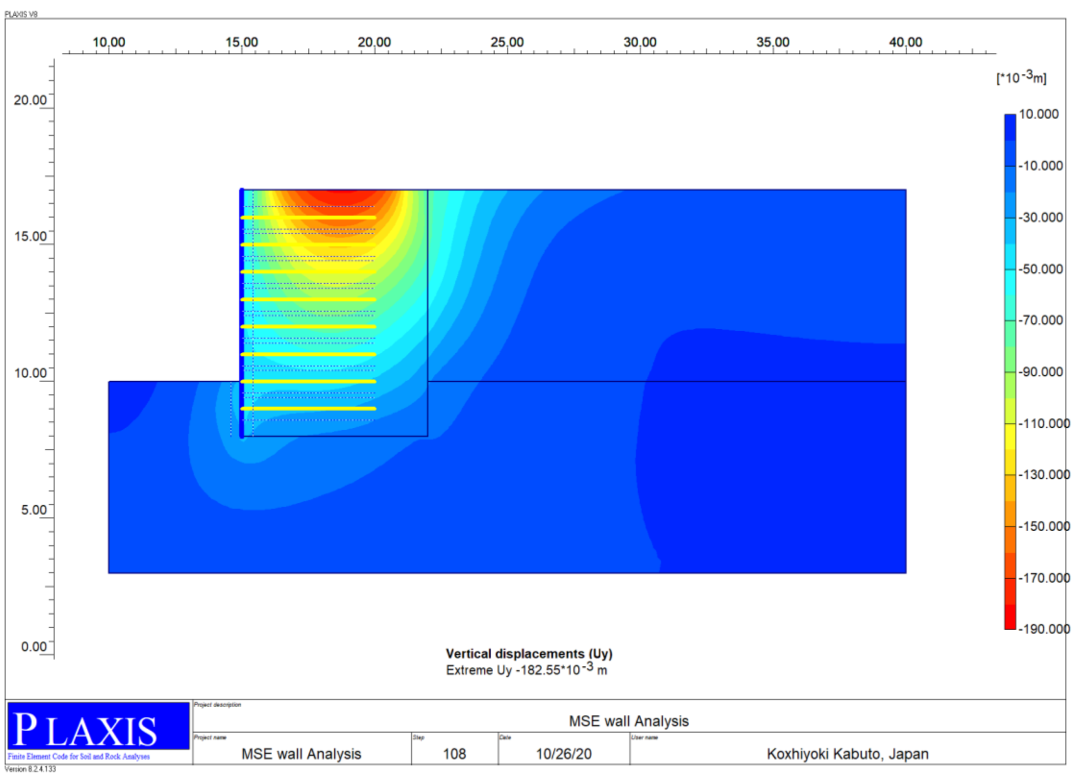

Figure B- 3 Showing vertical displacement of facing panel

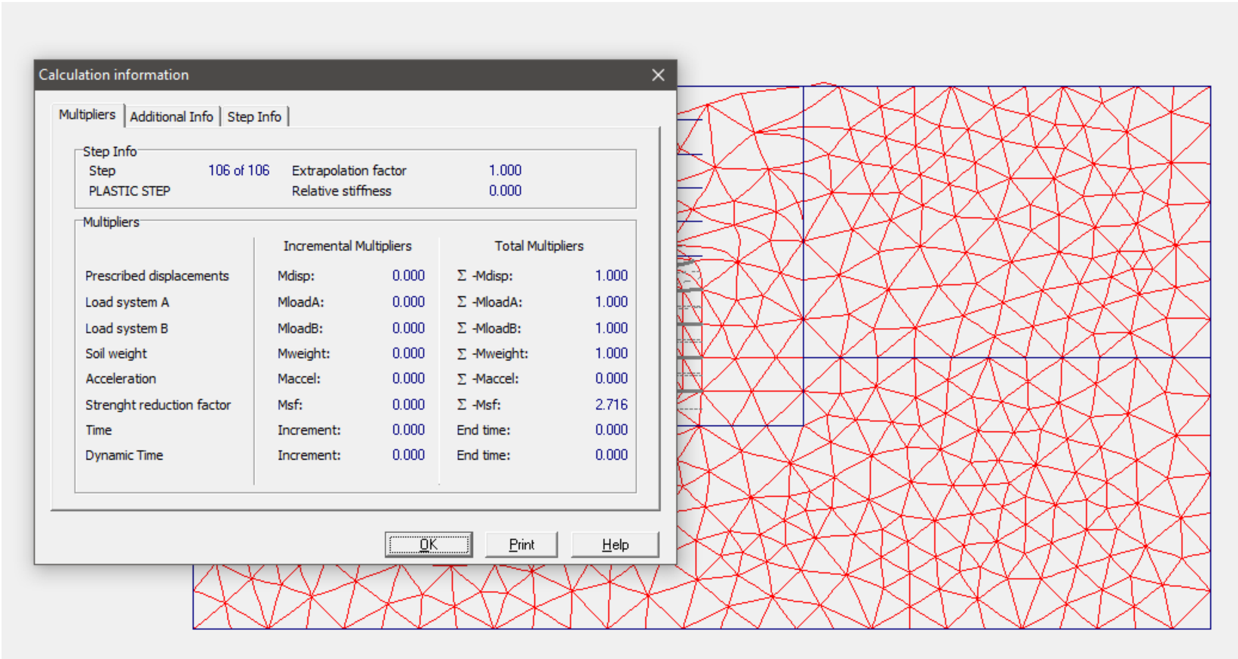

Figure B- 4 Showing calculation information (factor of safety)

Cantilever retaining wall result

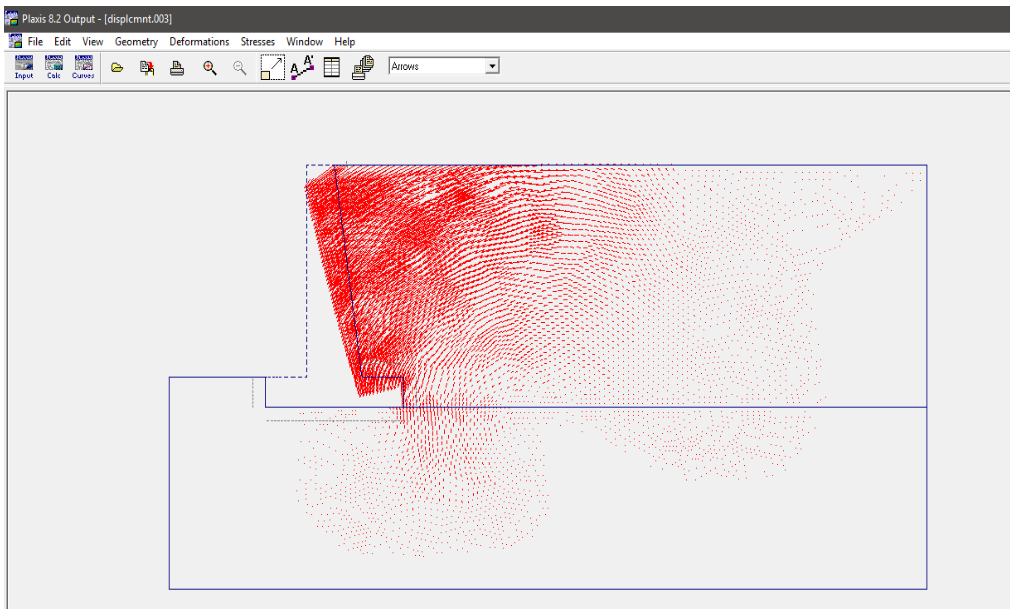

Figure B- 5 Total displacement of Cantilever retaining wall

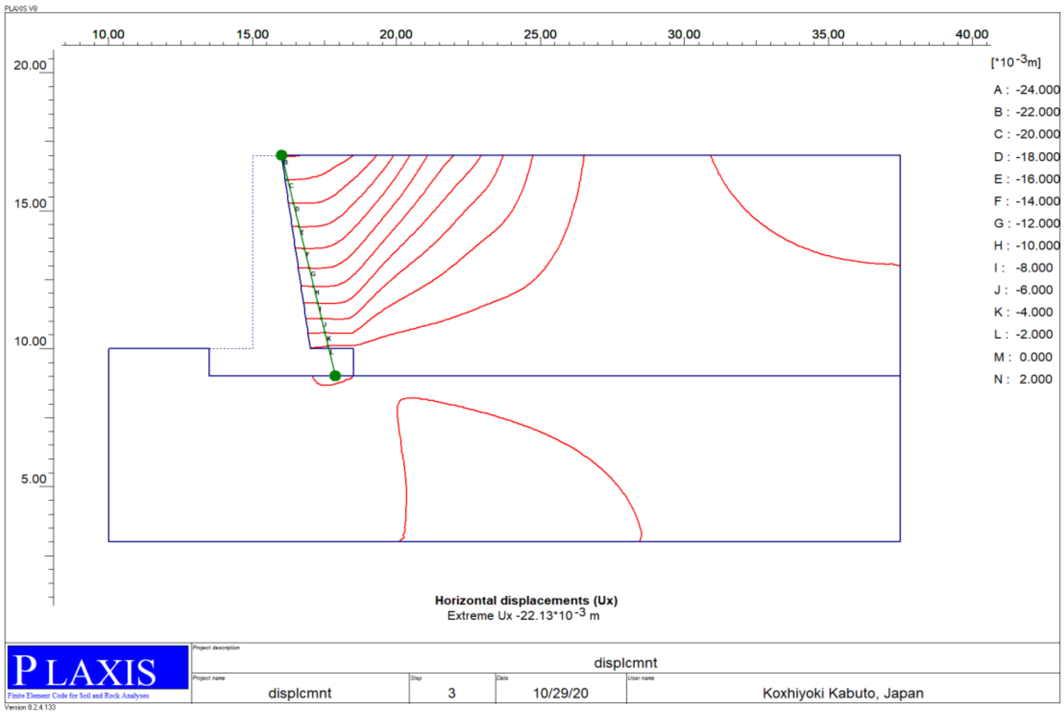

Figure B- 6 Horizontal displacement of Cantilever retaining wall

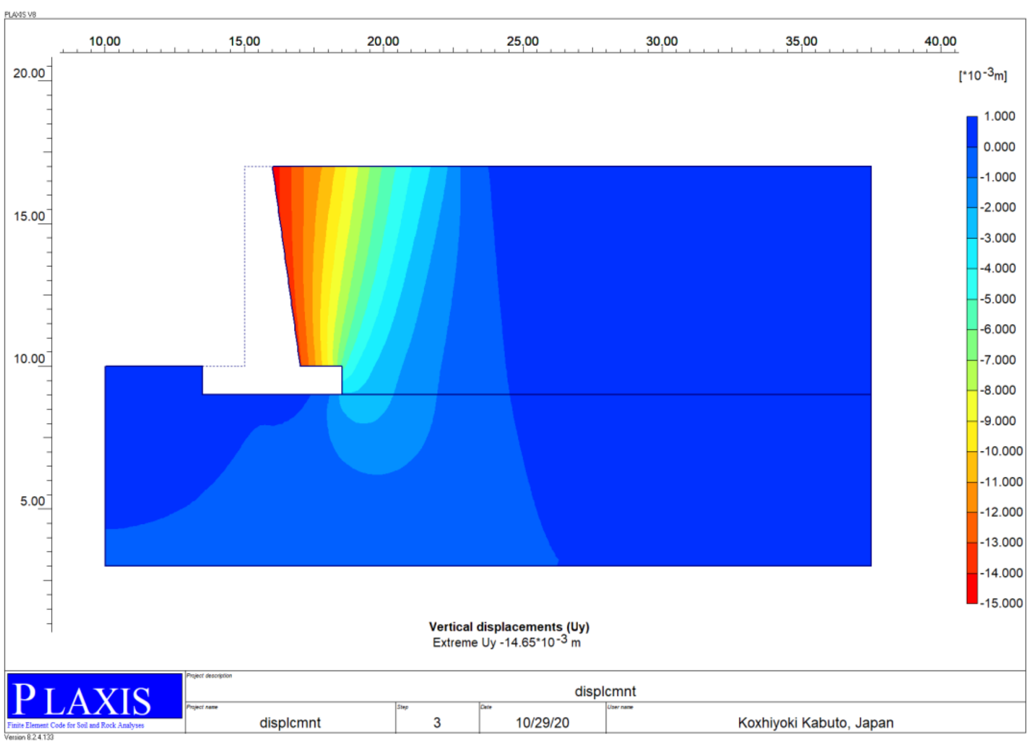

Figure B- 7 Vertical displacement of Cantilever retaining wall

Parametric analysis result

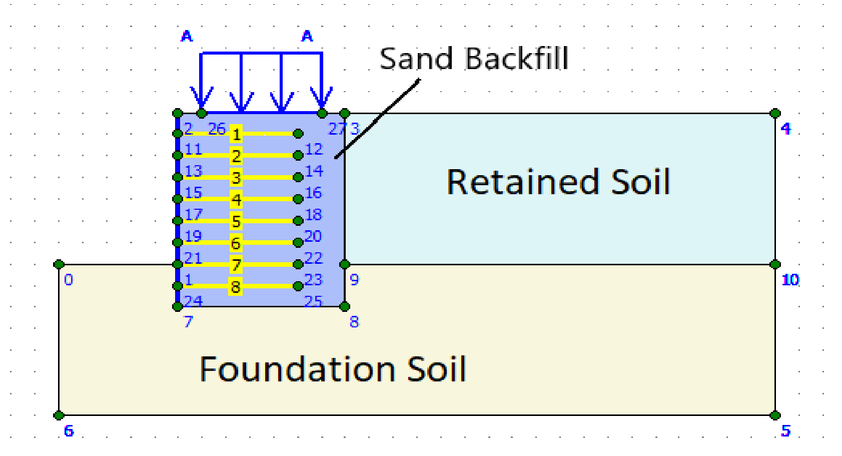

Figure B- 8 Model of sandy soil for analysis of displacement of MSE wall

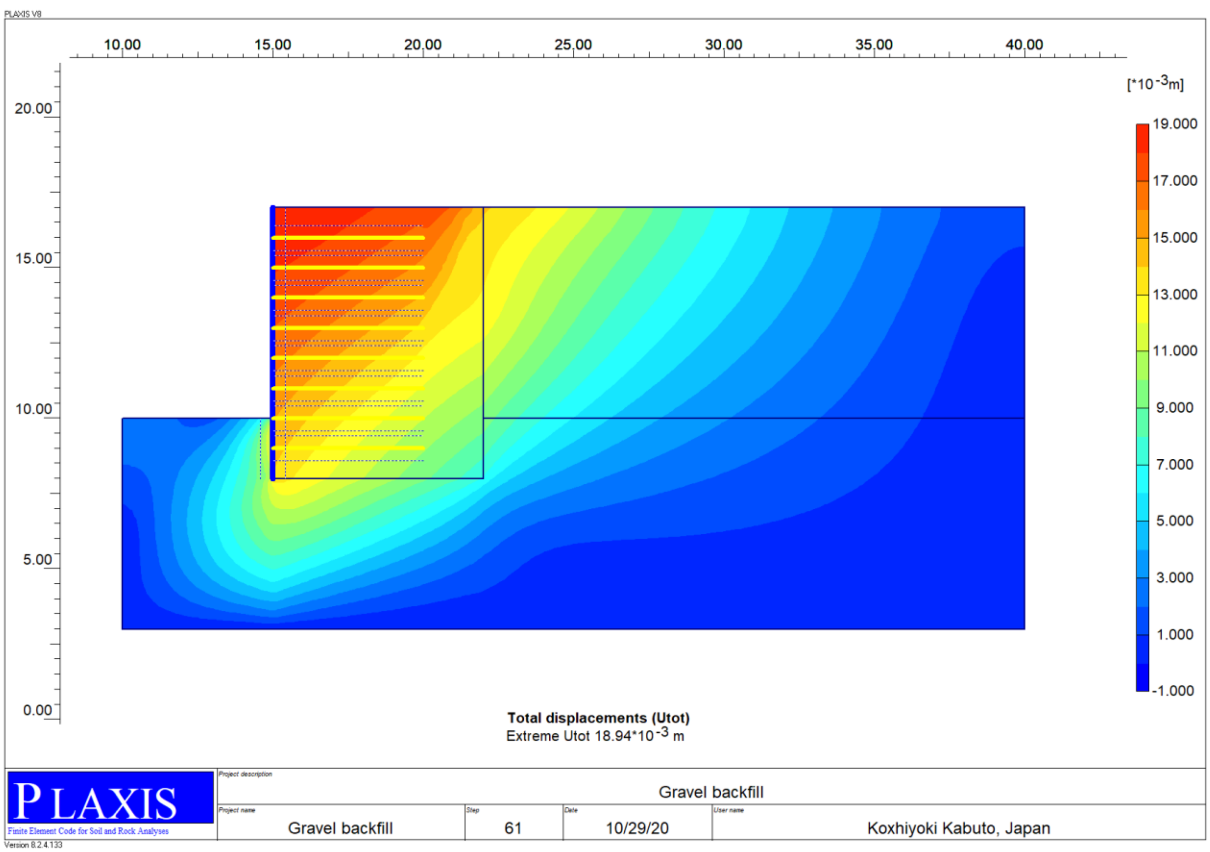

Figure B- 9 Total displacement of all MSE wall system

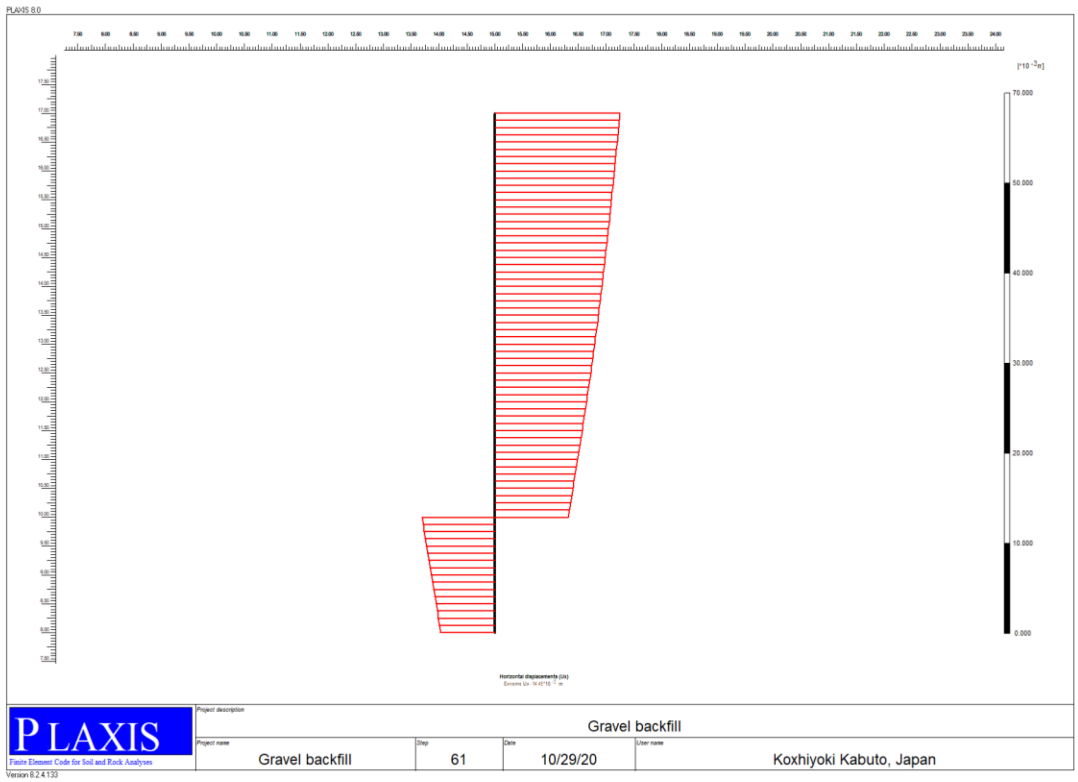

Figure B- 10 Horizontal deformation of facing panel for sand backfills MSE wall

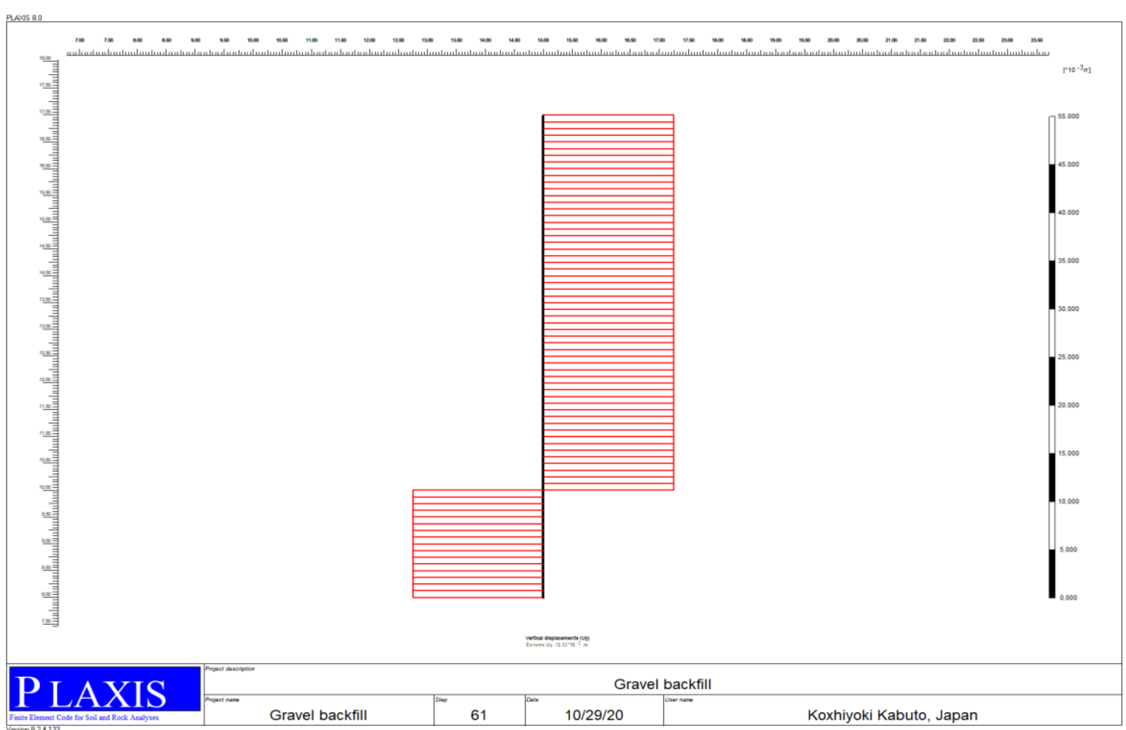

Figure B- 11 Vertical deformation of facing panel for sand backfills MSE wall

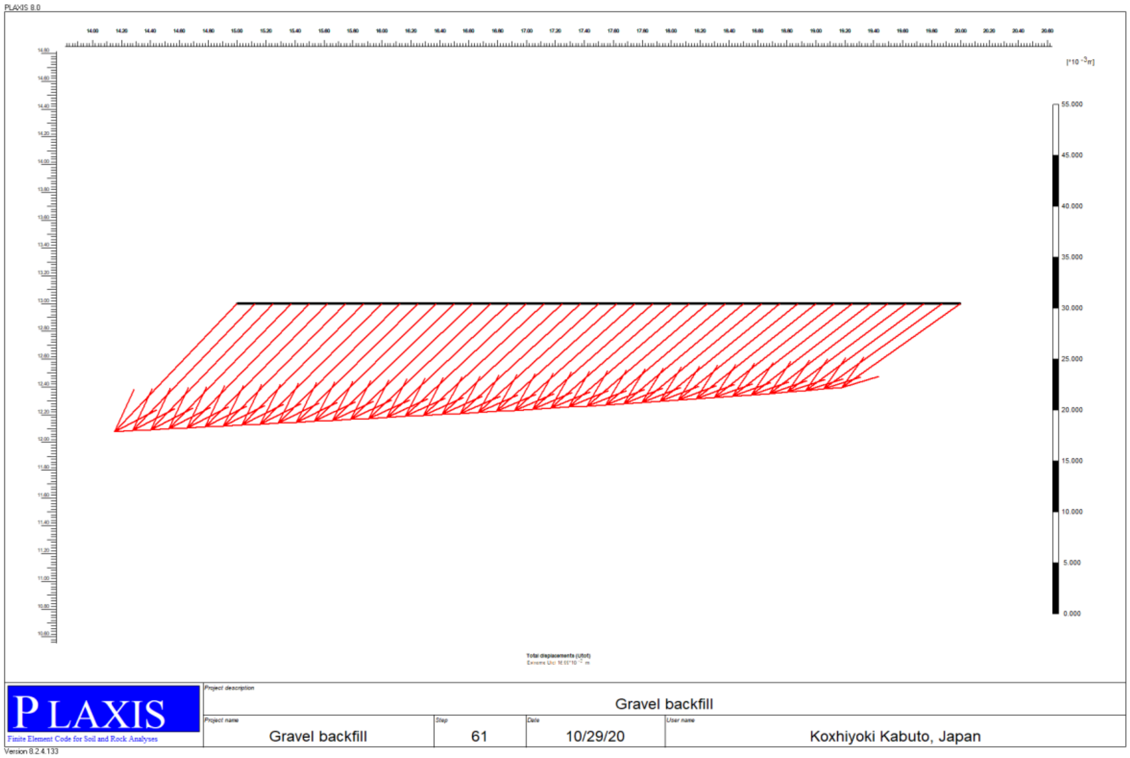

Figure B- 12 Tension force of geogrid reinforced for sand backfill MSE wall

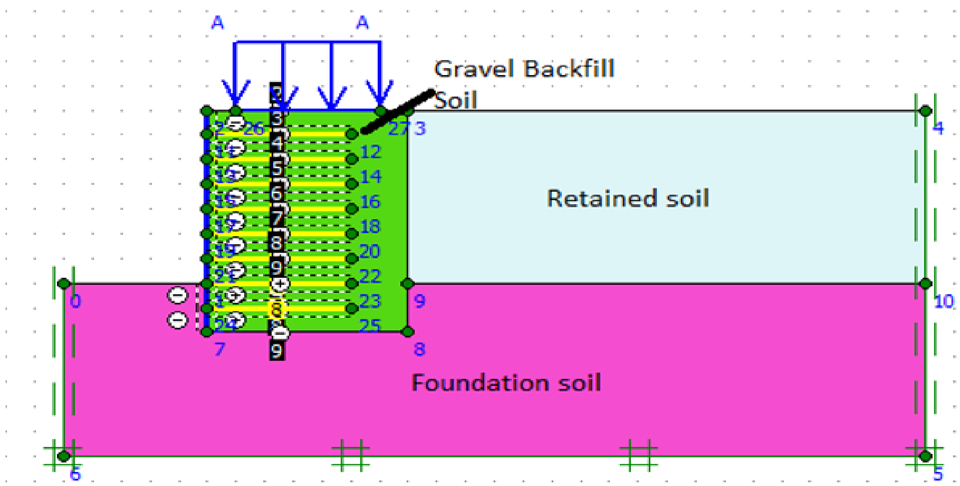

Figure B- 13 Gravel backfill soil MSE wall model

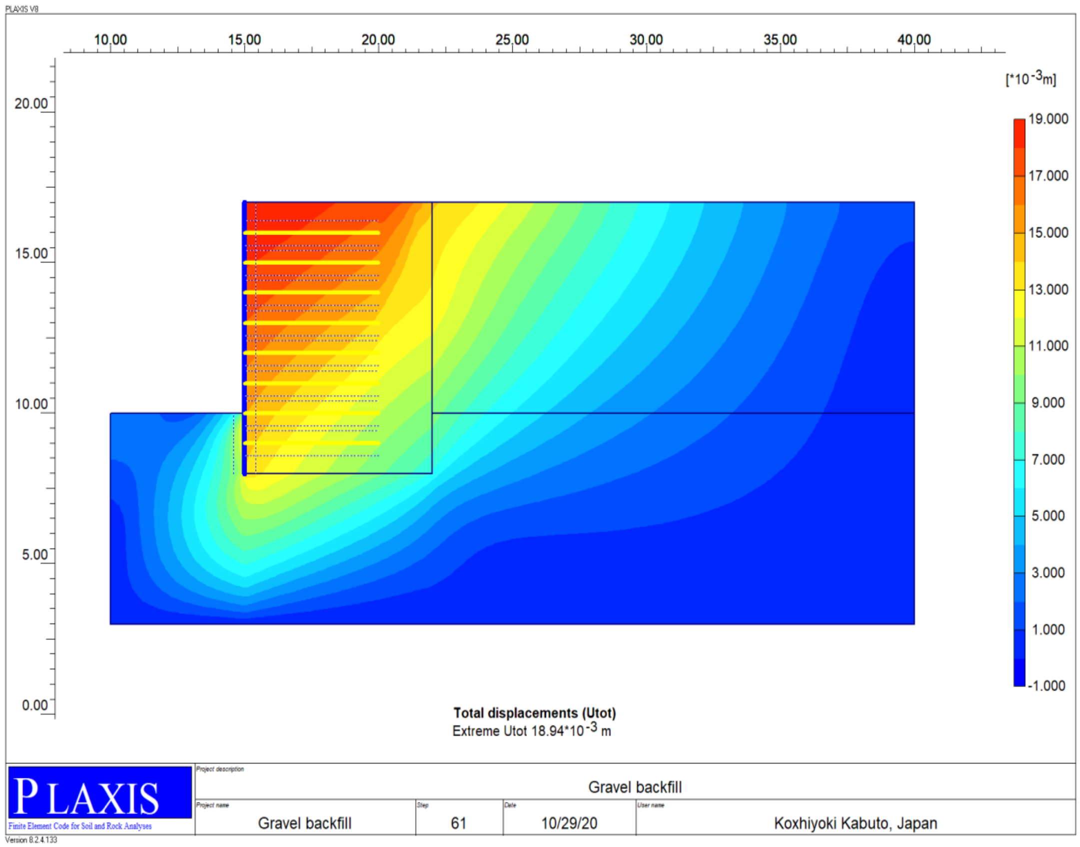

Figure B- 14 Total displacement of MSE wall

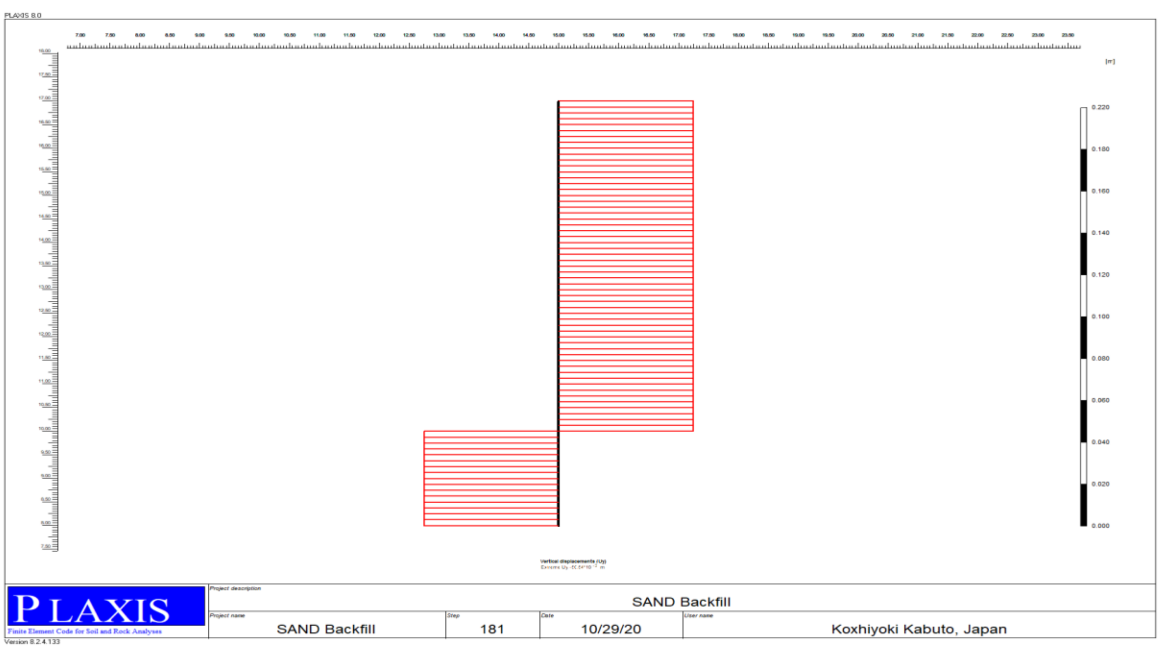

Figure B- 15 Vertical displacement of facing panel Gravel backfill MSE wall

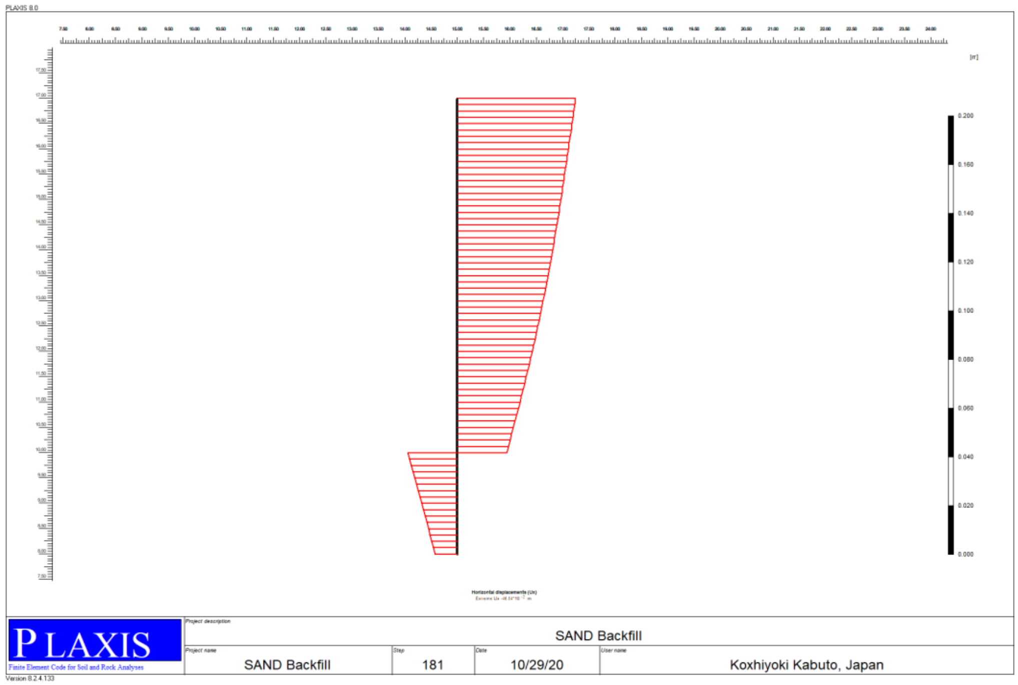

Figure B- 16 Horizontal deformation of facing panel for Gravel backfills MSE wall

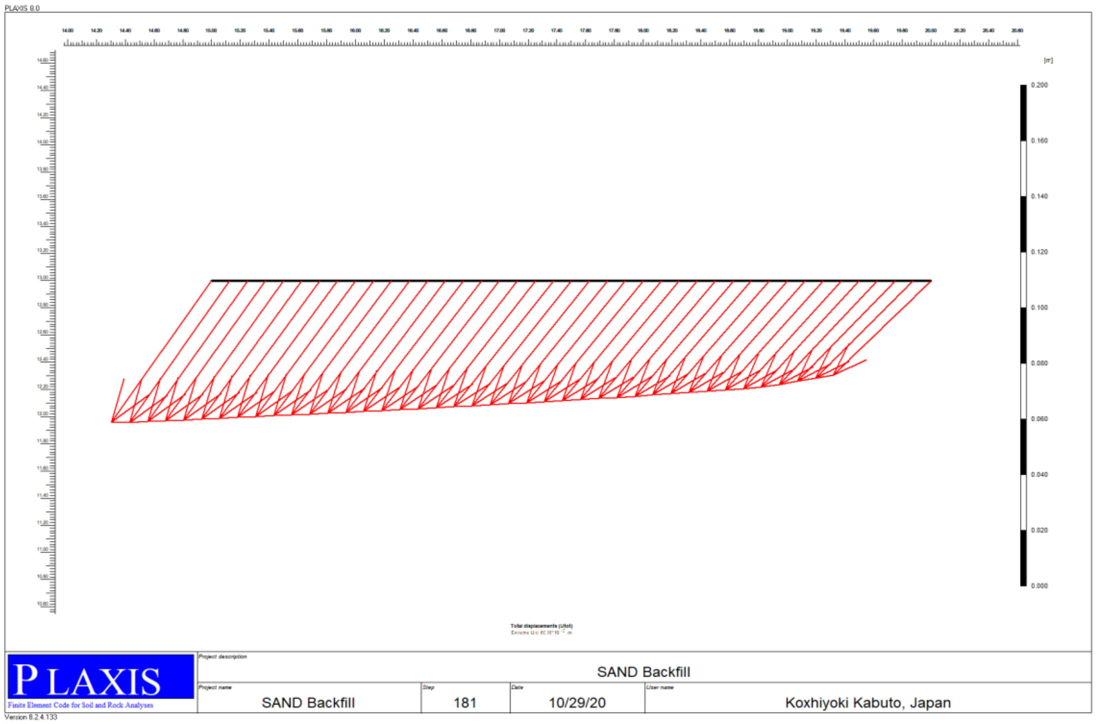

Figure B- 17 Tension force of geogrid reinforced for Gravel backfill MSE wall

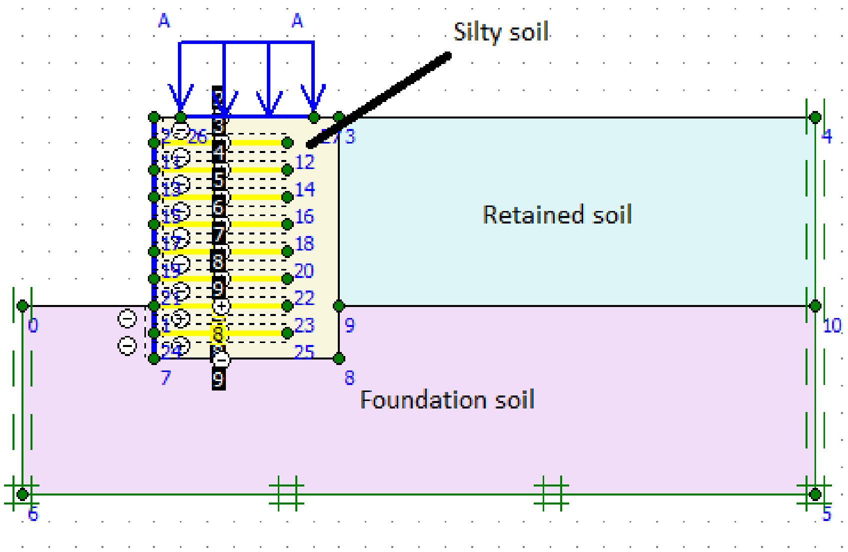

Figure B- 18 Silty backfill soil MSE wall model

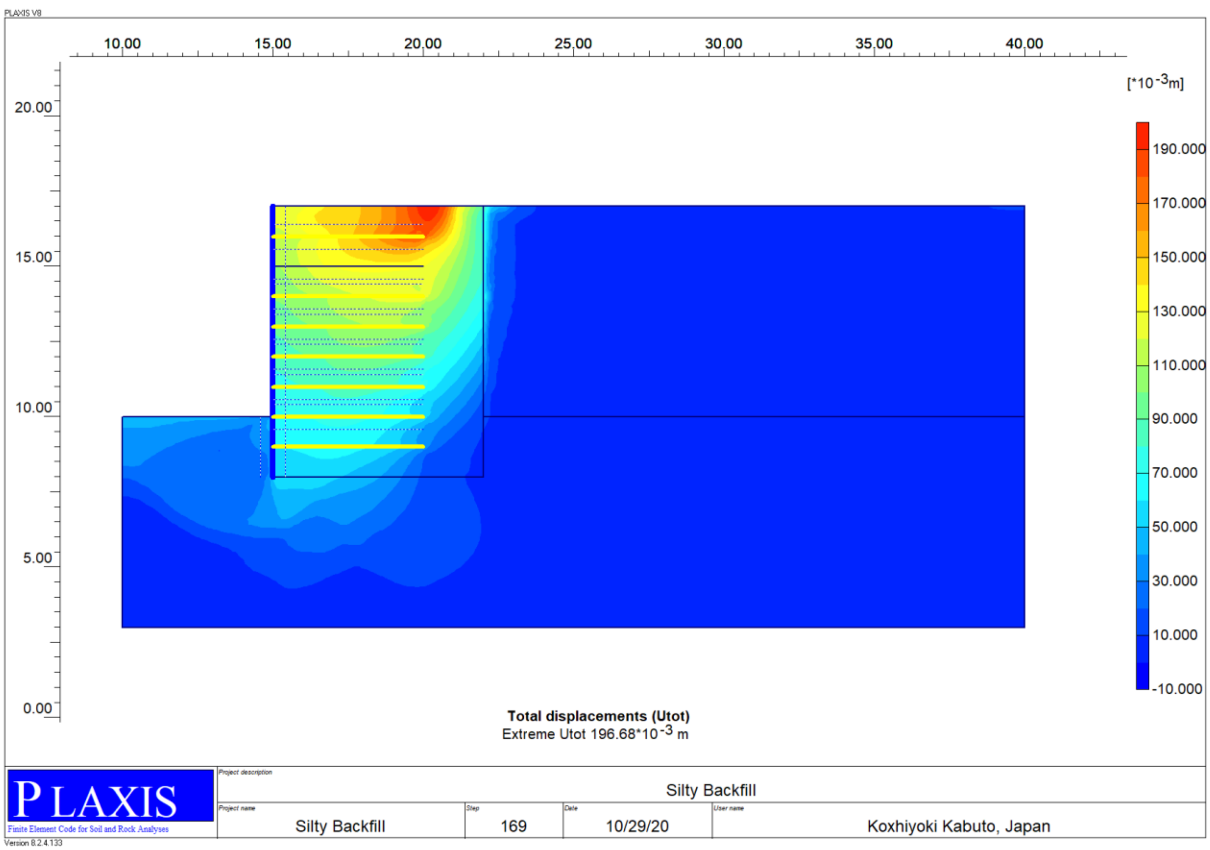

Figure B- 19 Total displacement of MSE wall

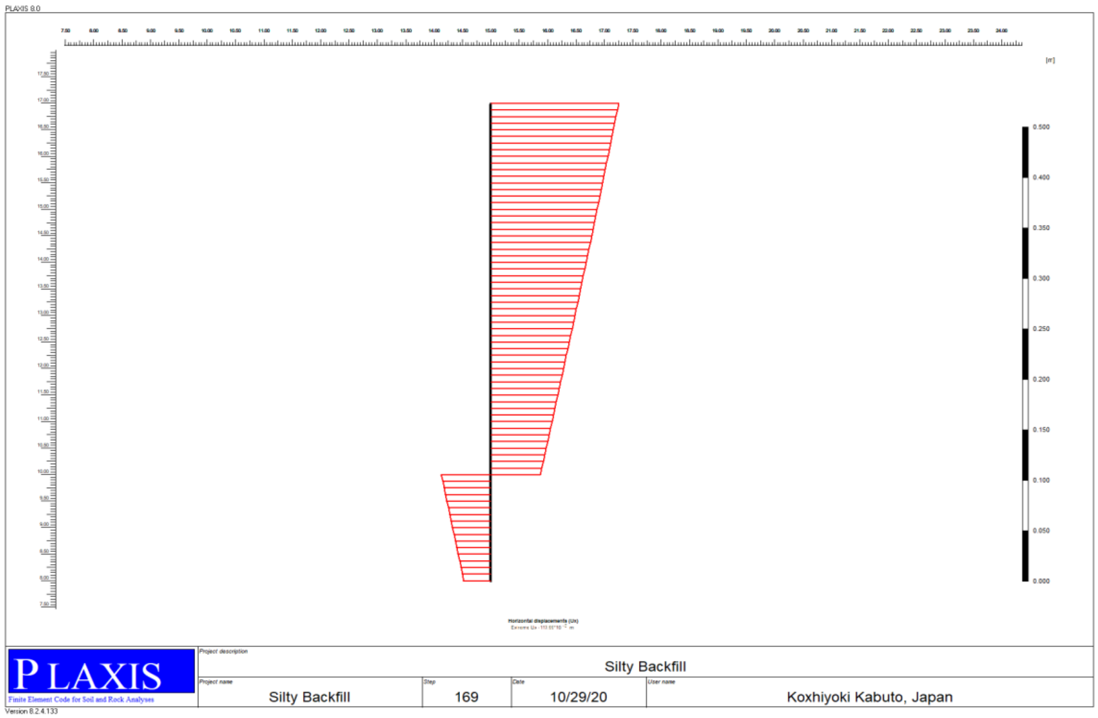

Figure B- 20 Horizontal deformation of facing panel for Silty backfills MSE wall

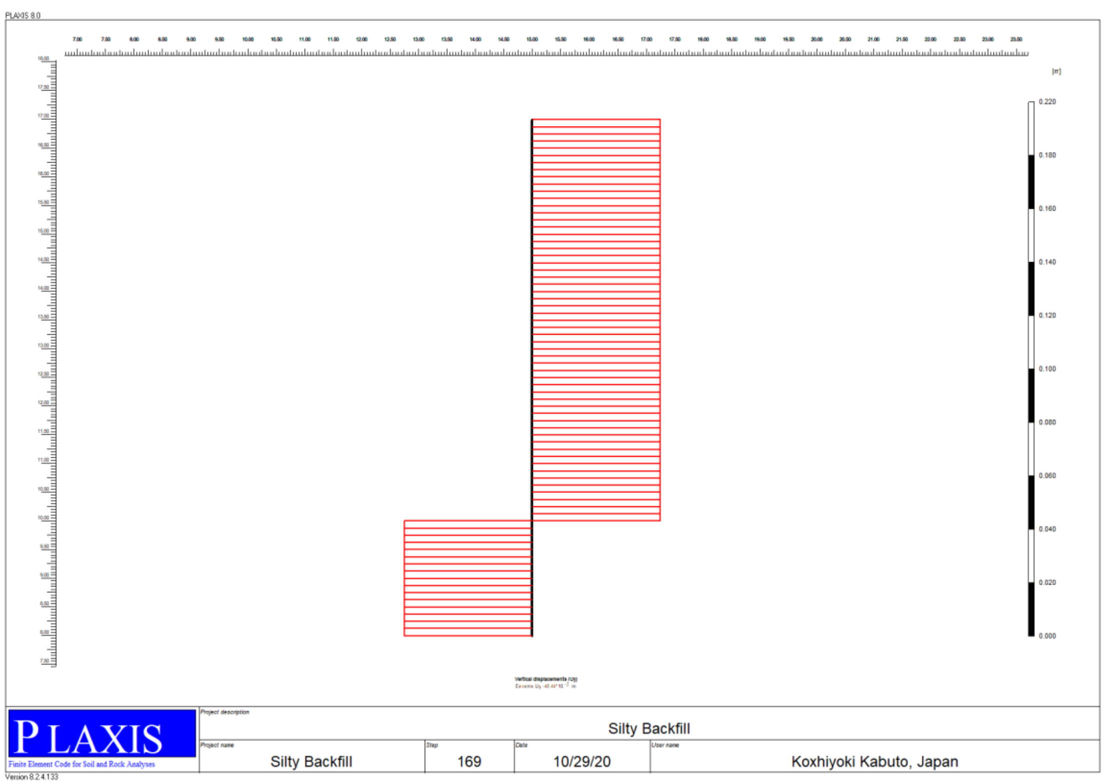

Figure B- 21 Vertical deformation of facing panel for Silty backfills MSE wall

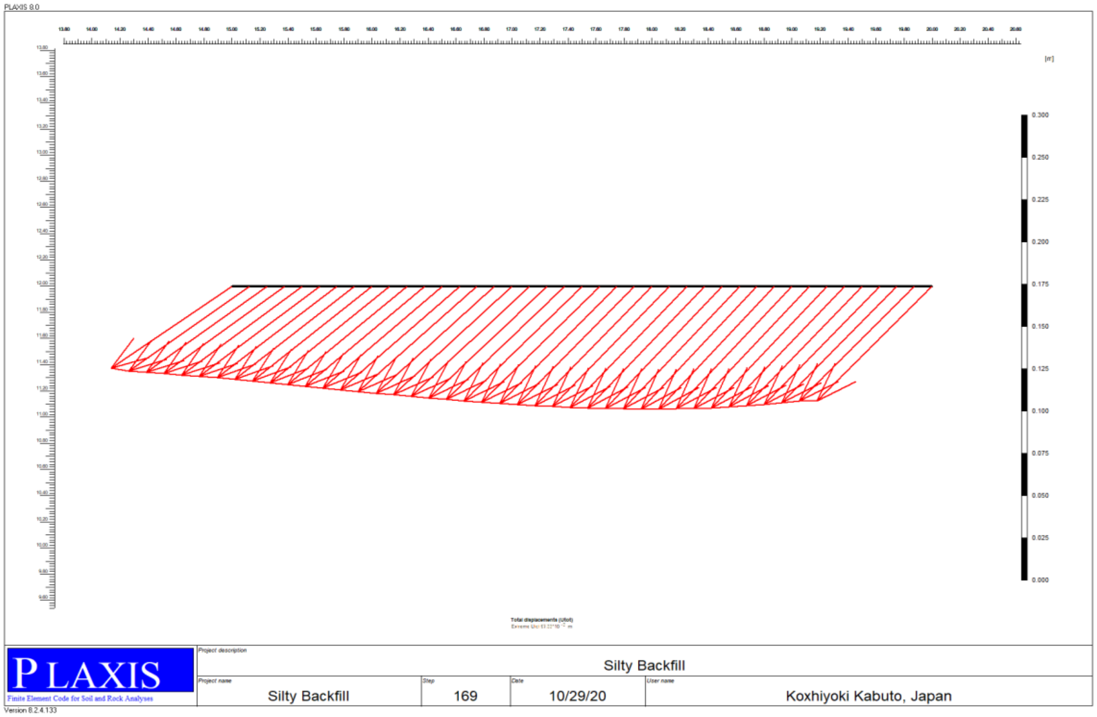

Figure B- 22 Tension force of geogrid reinforced for Silty backfill MSE wall

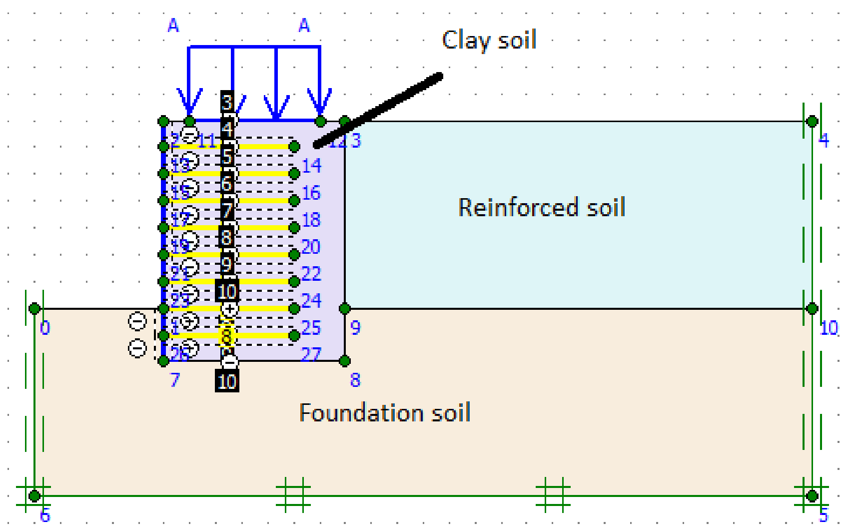

Figure B- 23 Clay backfill soil MSE wall model

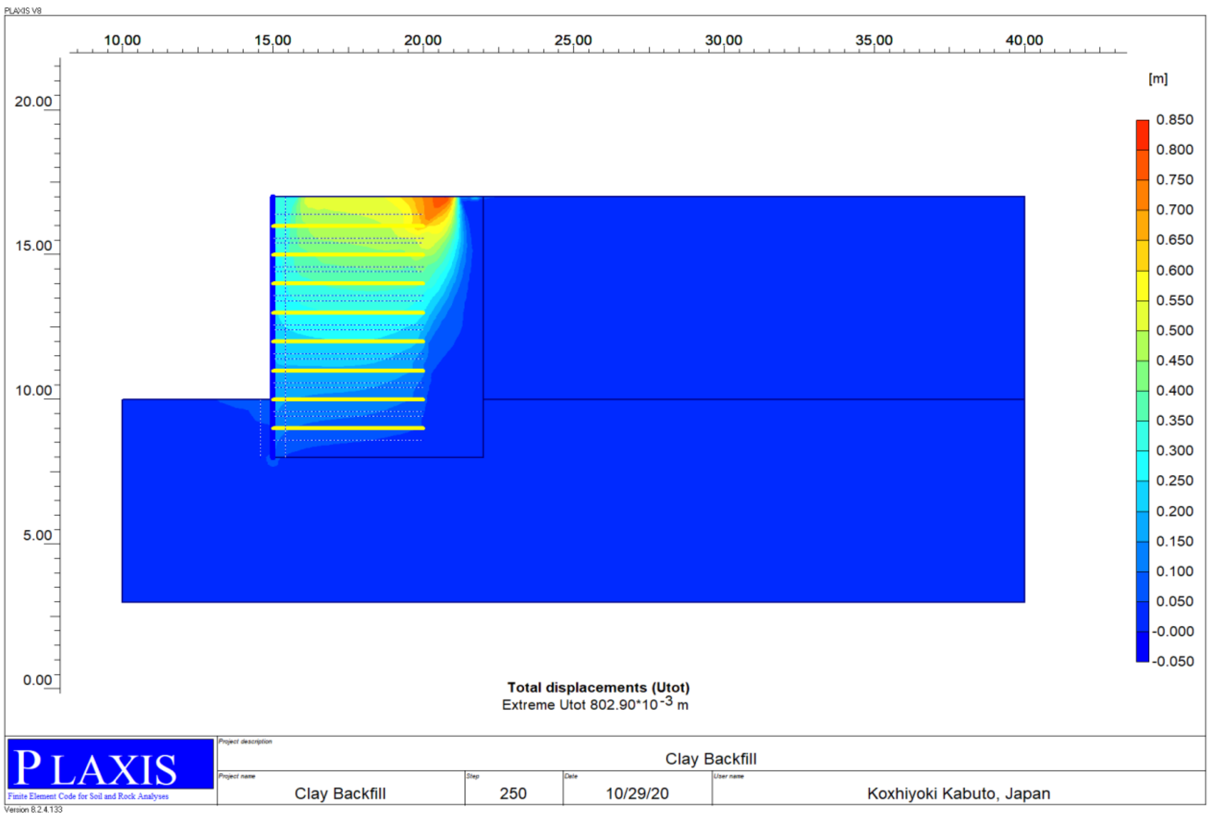

Figure B- 24 Total displacement of MSE wall

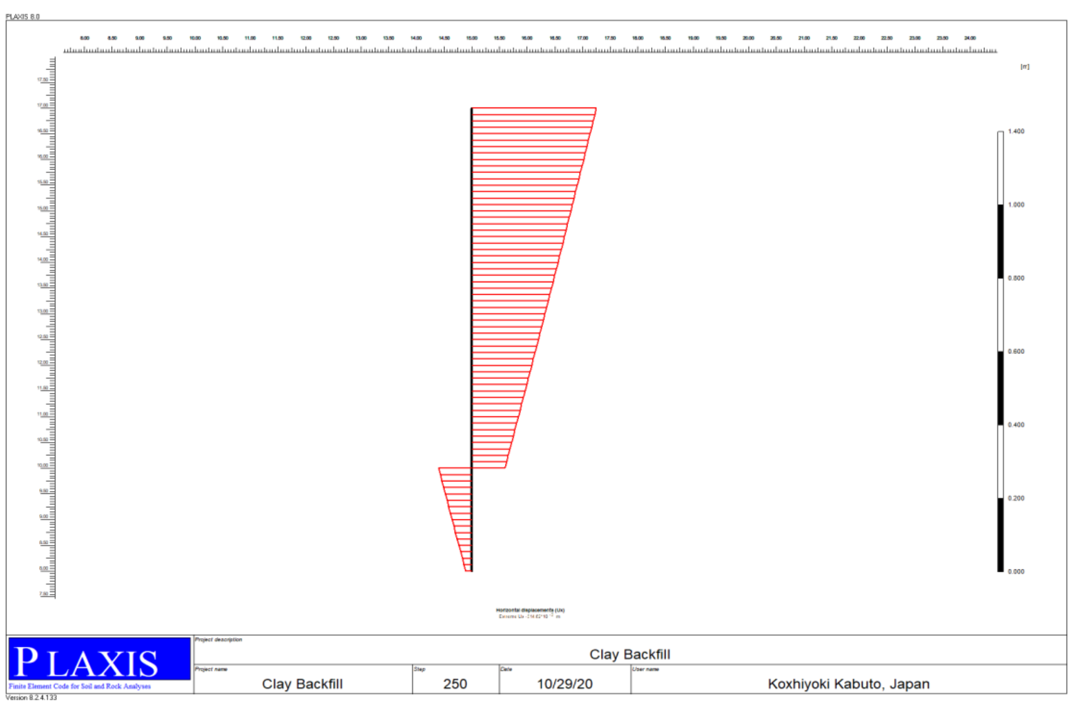

Figure B- 25 Horizontal deformation of facing panel for clay backfills MSE wall

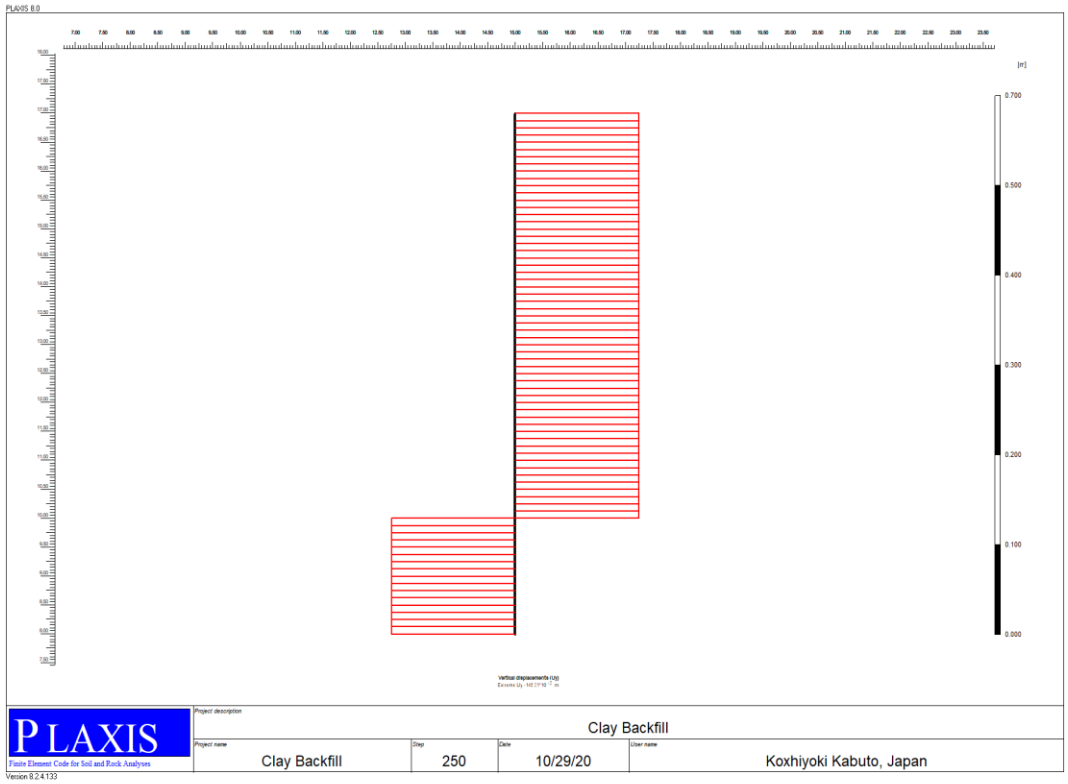

Figure B- 26 Vertical deformation of facing panel for Silty backfills MSE wall

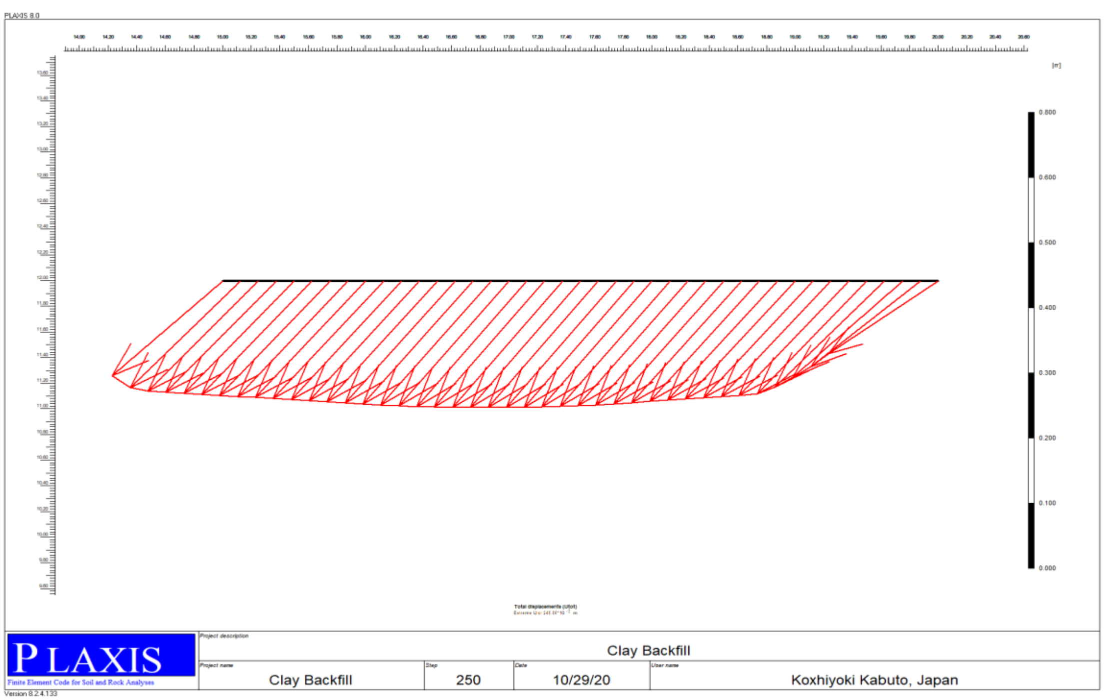

Figure B- 27 Tension force of geogrid reinforced for clay backfill MSE wall

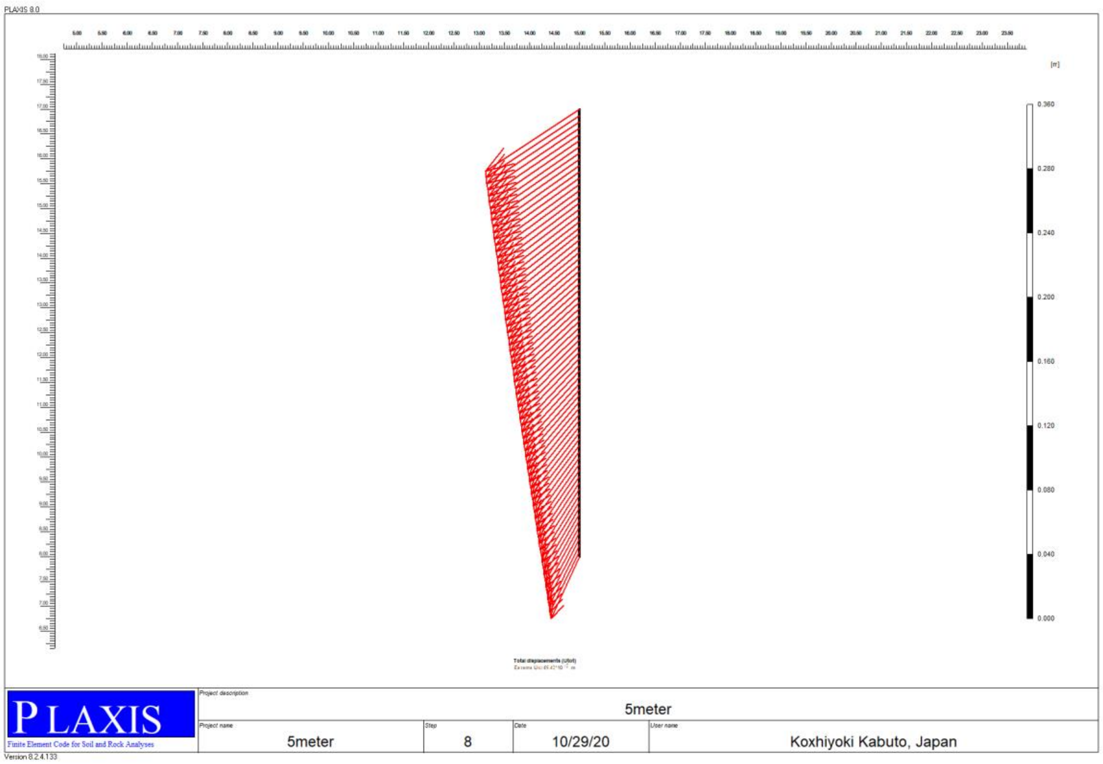

Figure B- 28 Horizontal deformation of facing panel for four meter length geogrid

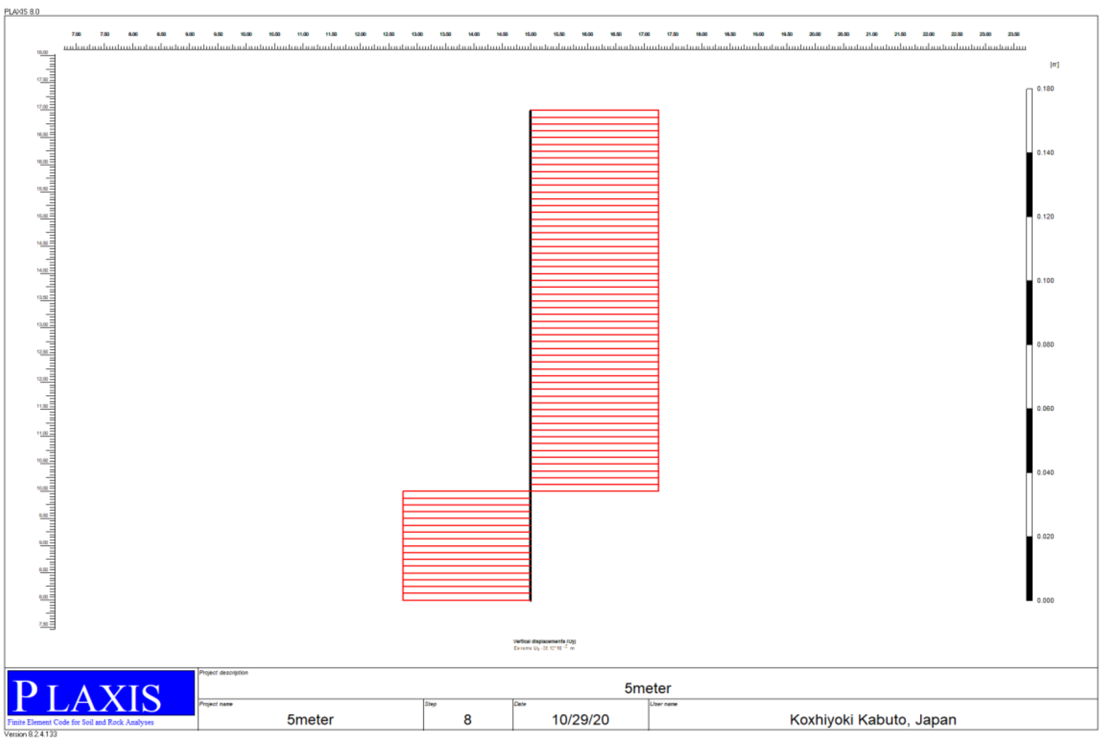

Figure B- 29 Vertical deformation of facing panel for four meter length geogrid

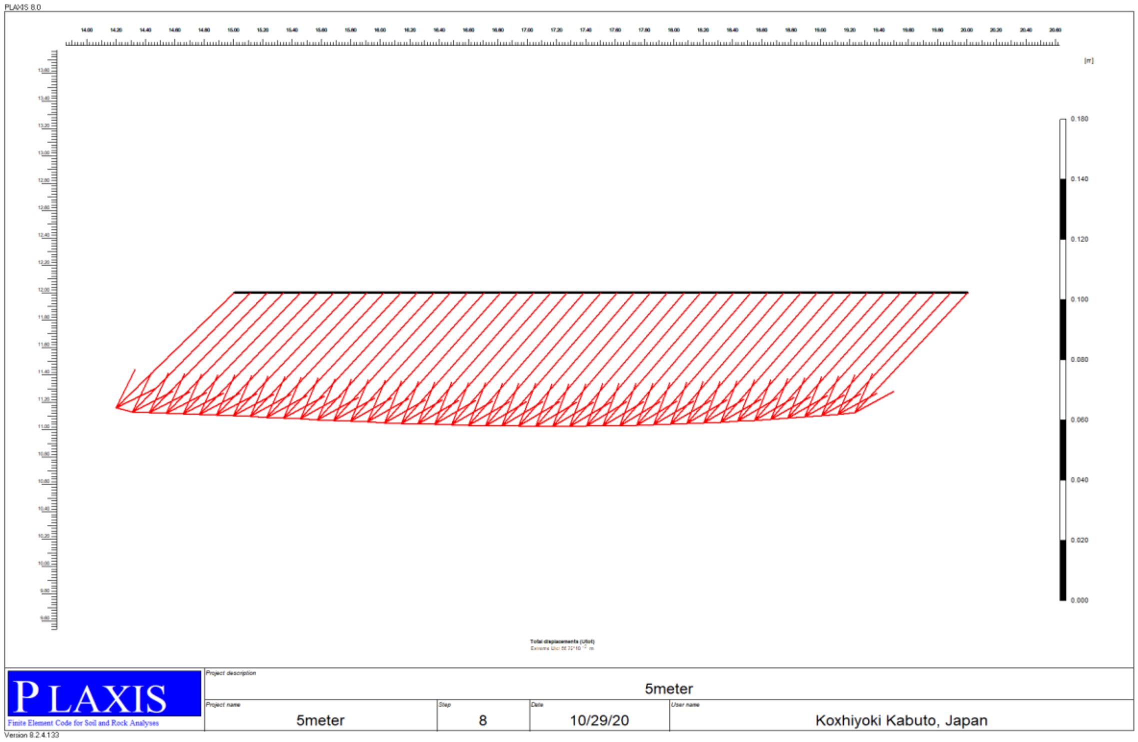

Figure B- 30 Tension force for four meter length geogrid reinforcement

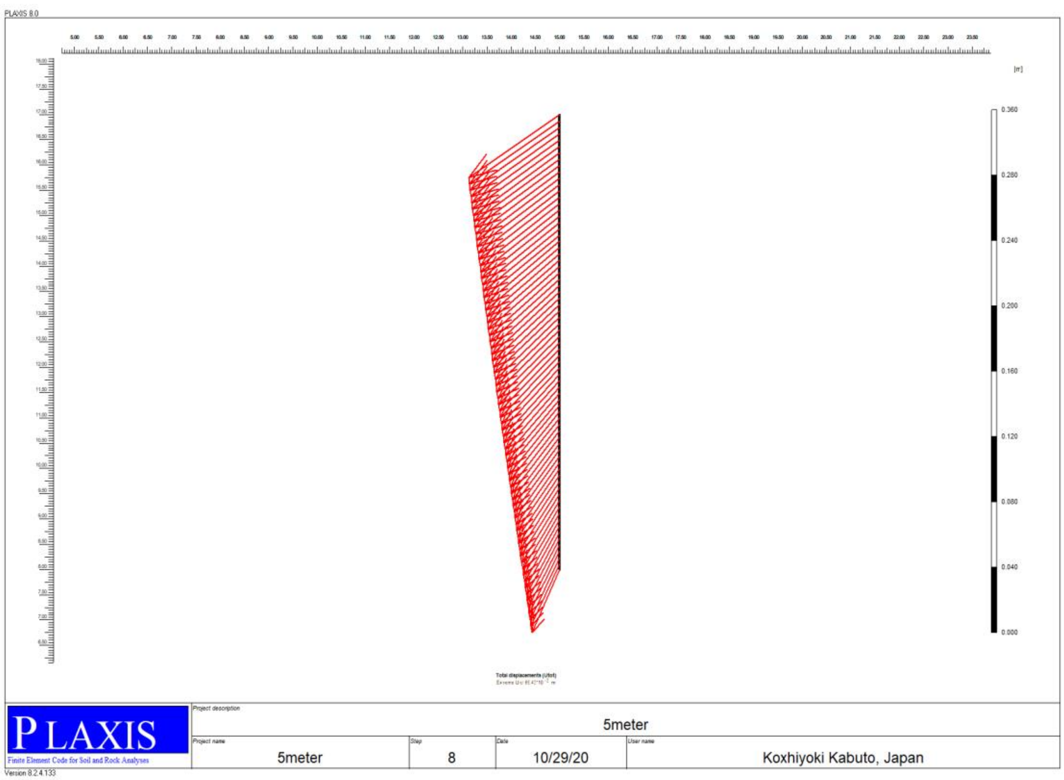

Figure B- 31 Horizontal deformation of facing panel for five meter length geogrid

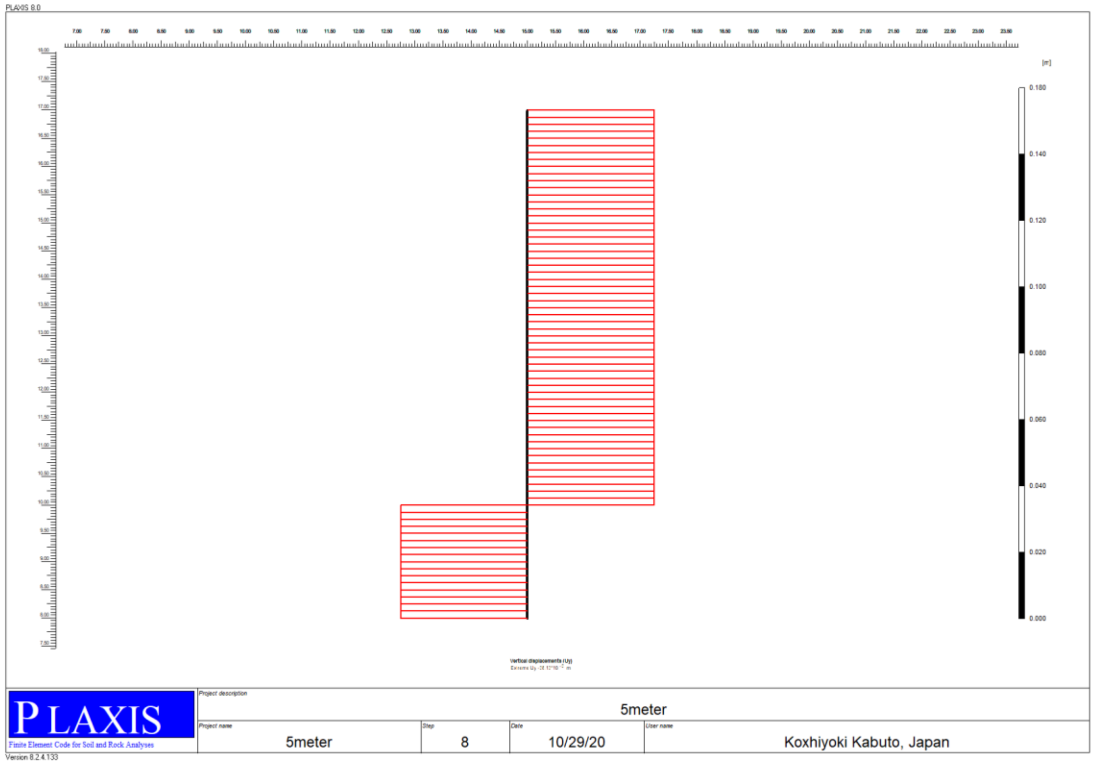

Figure B- 32 Vertical deformation of facing panel for five meter length geogrid

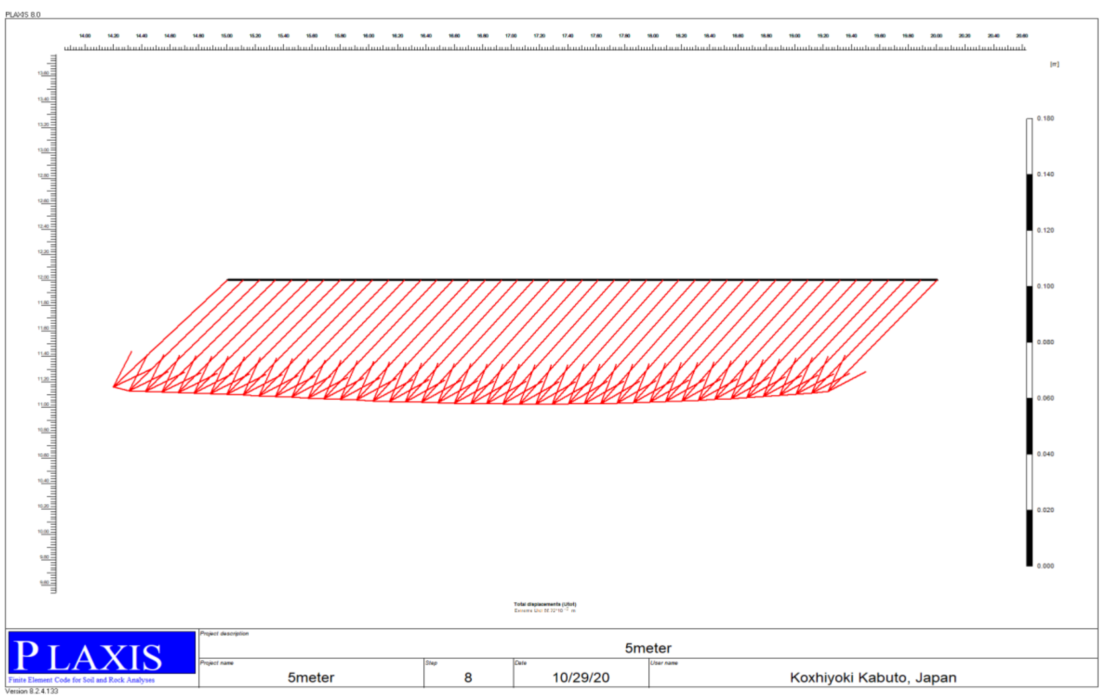

Figure B- 33 Tension force for five meter length geogrid reinforcement

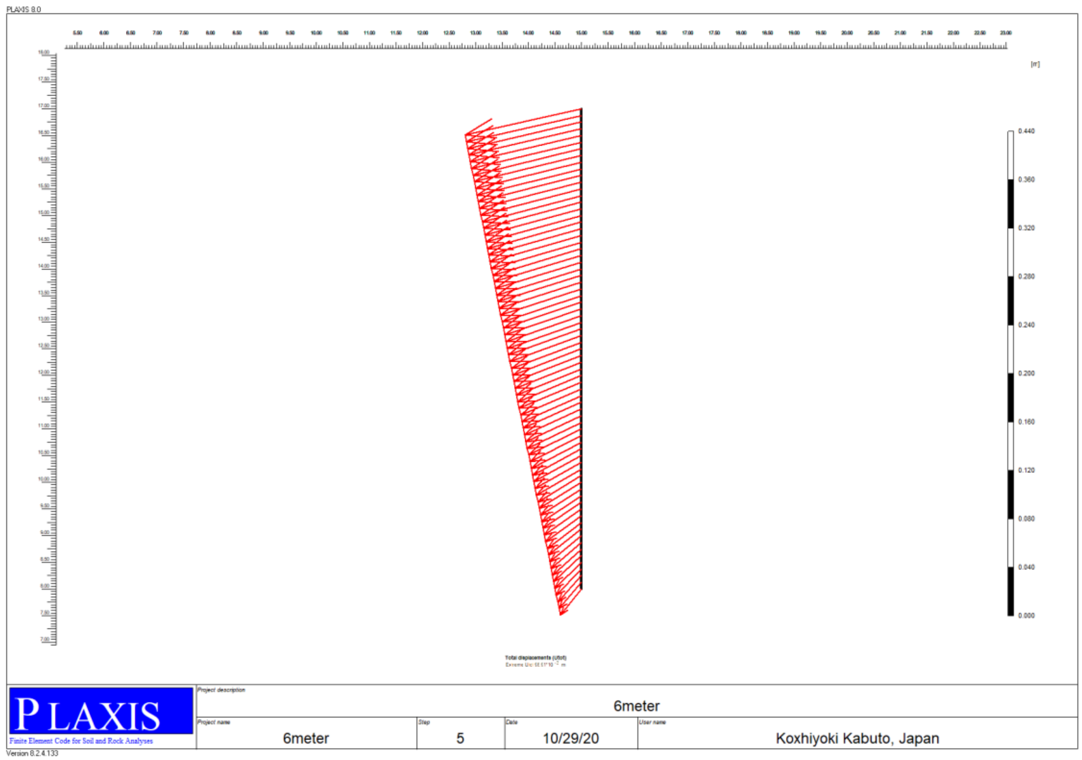

Figure B- 34 Horizontal deformation of facing panel for six meter length geogrid

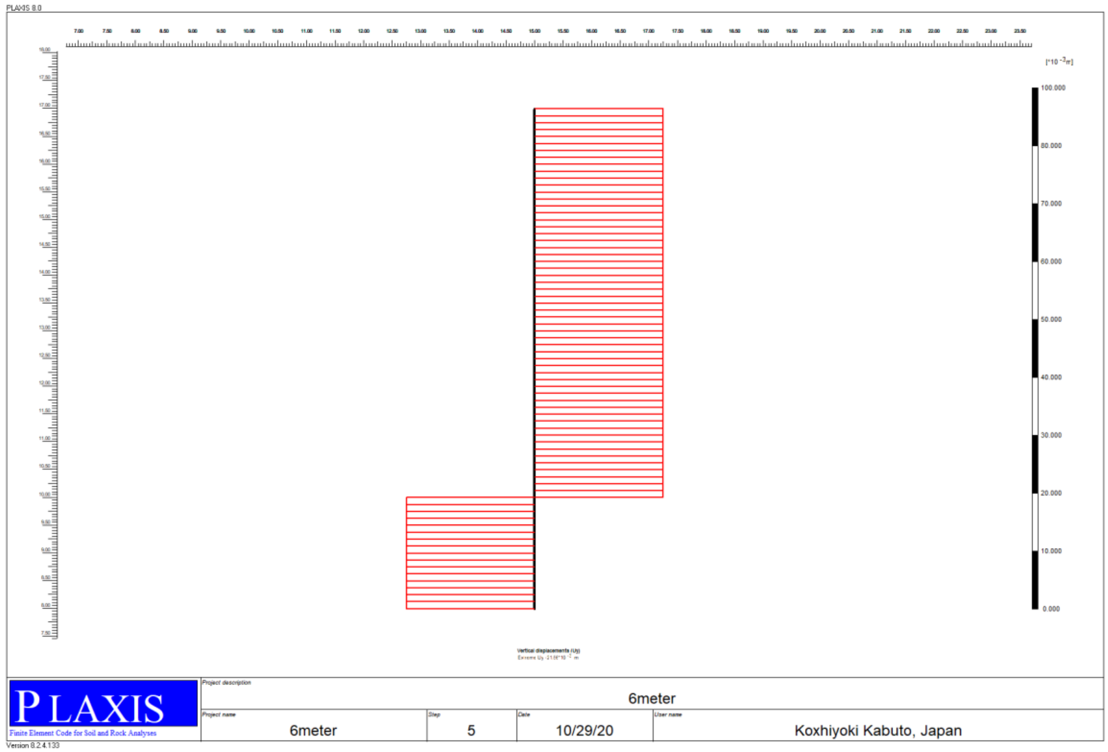

Figure B- 35 Vertical deformation of facing panel for six meter length geogrid

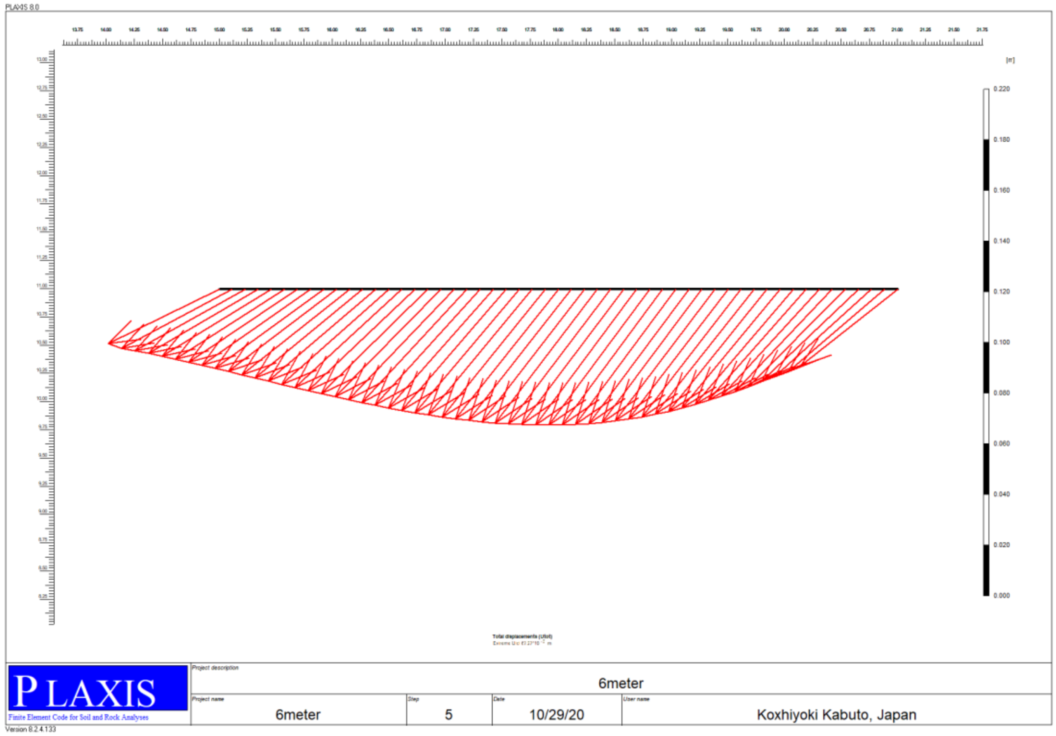

Figure B- 36 Tension force for six meter length geogrid reinforcement

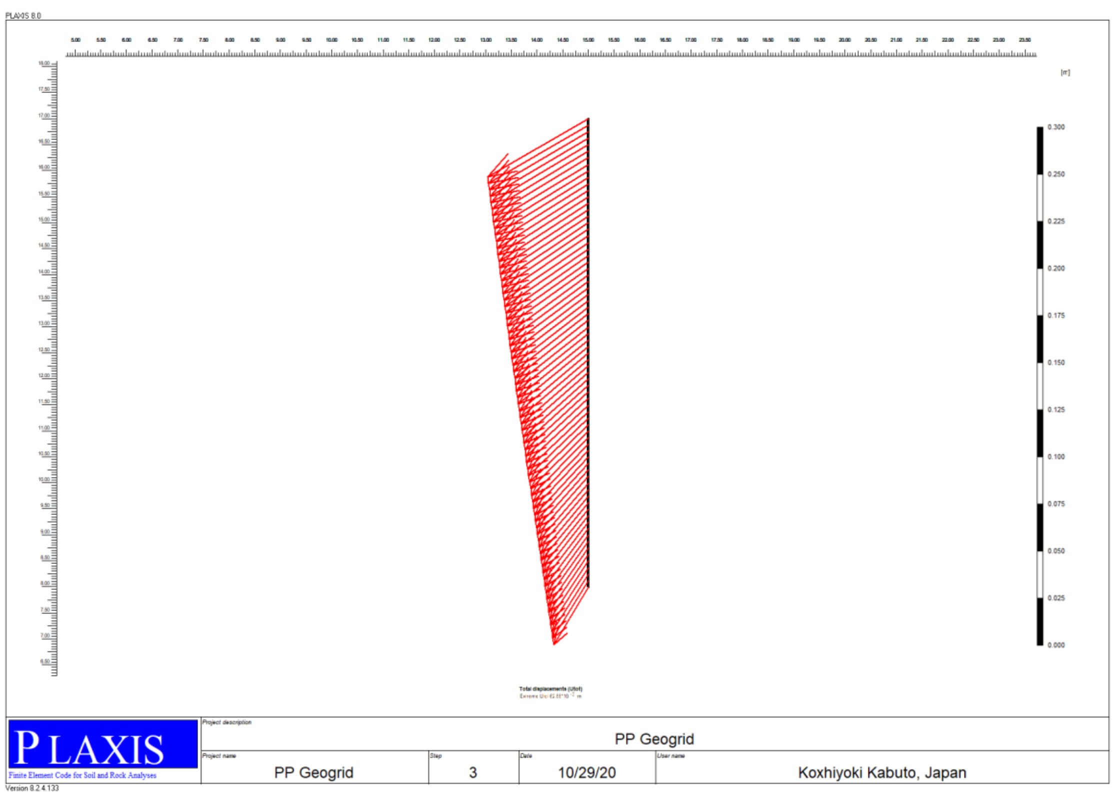

Figure B- 37 Total displacement of MSE wall for polypropylene geogrid reinforcement

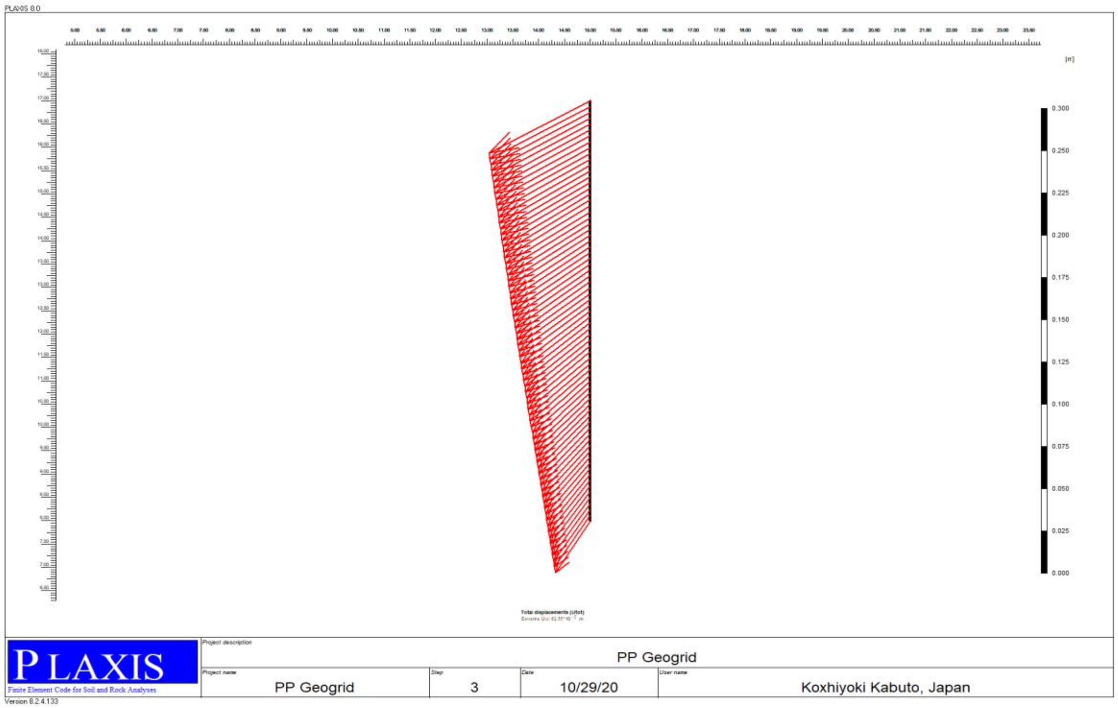

Figure B- 38 Horizontal deformation of facing panel for polypropylene geogrid

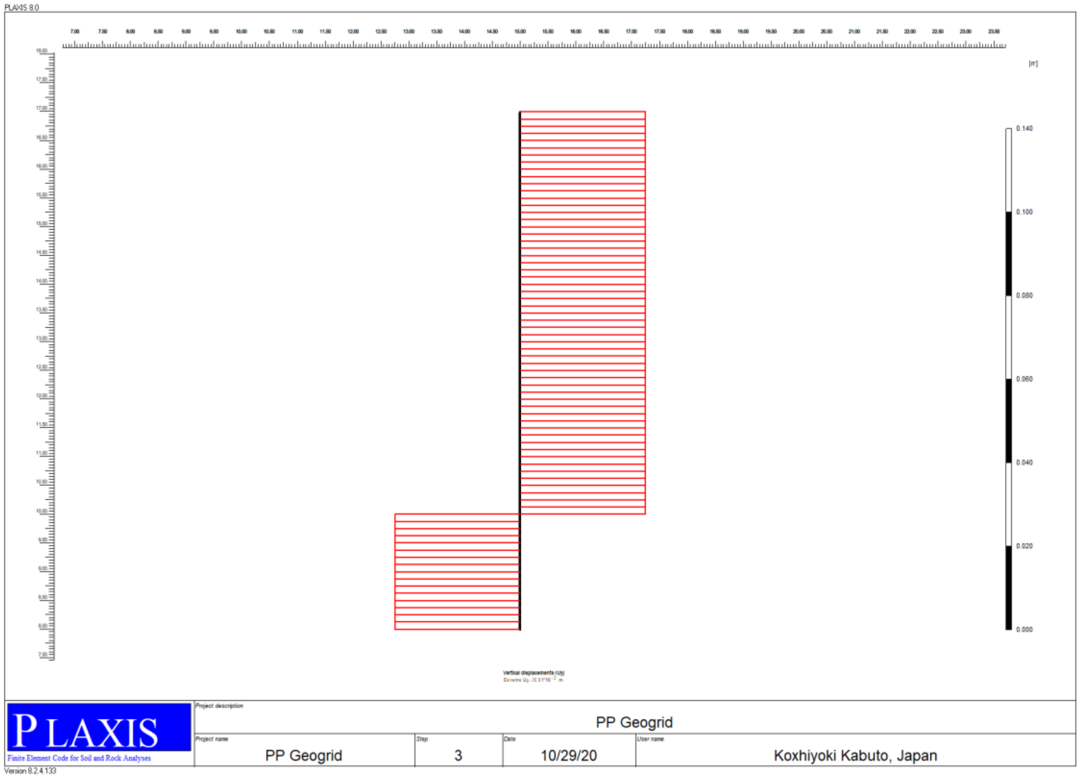

Figure B- 39 Vertical displacement of facing panel for polypropylene geogrid

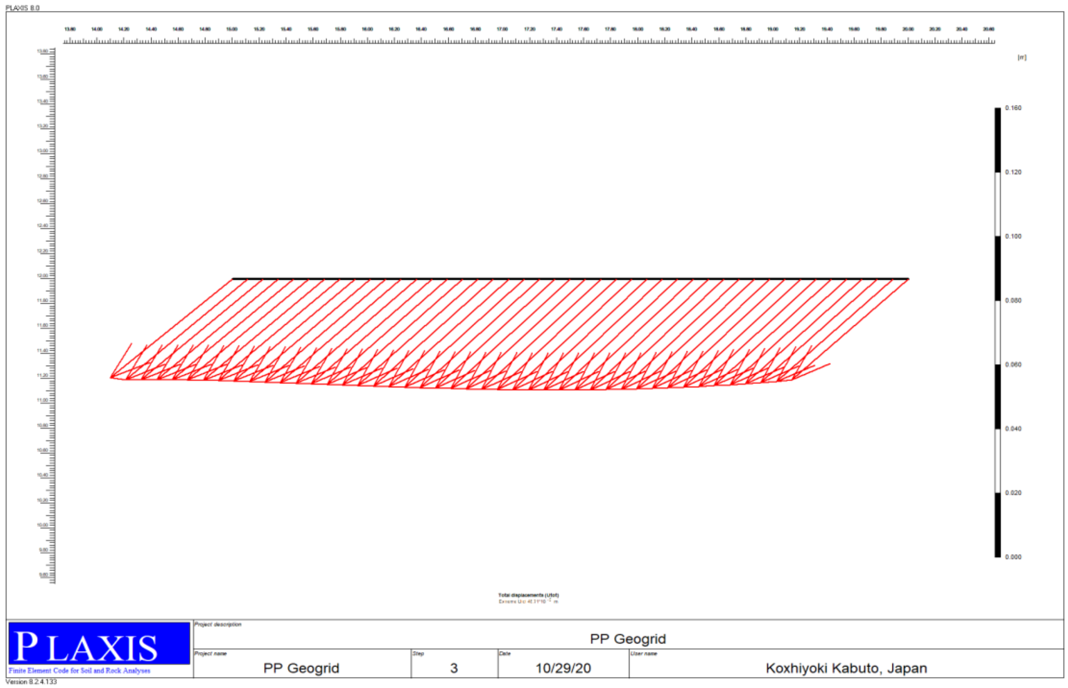

Figure B- 40 Tension force for polypropylene geogrid reinforcement

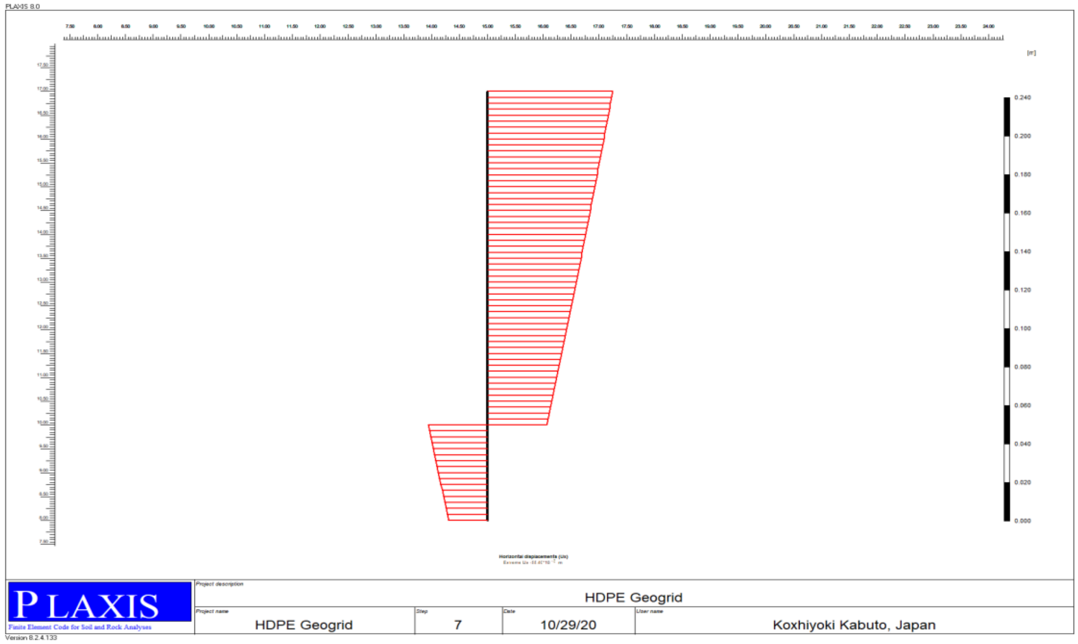

Figure B- 41 Horizontal deformation of facing panel for HDPE geogrid

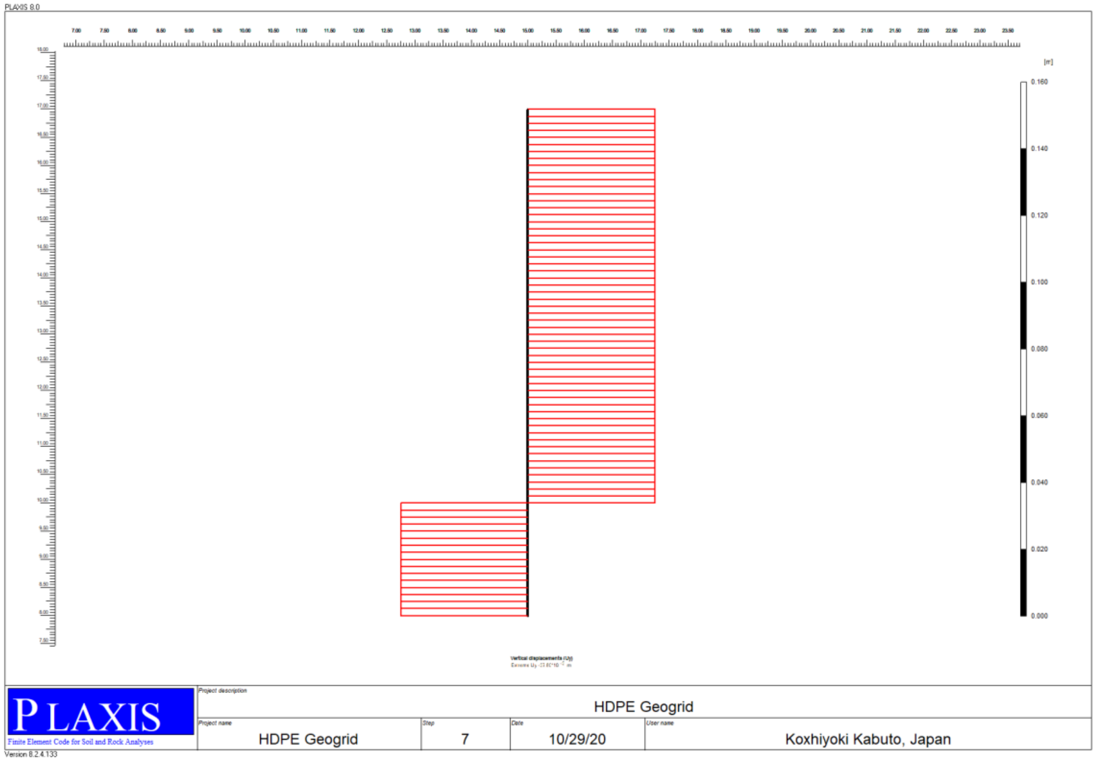

Figure B- 42 Vertical deformation of facing panel for HDPE geogrid

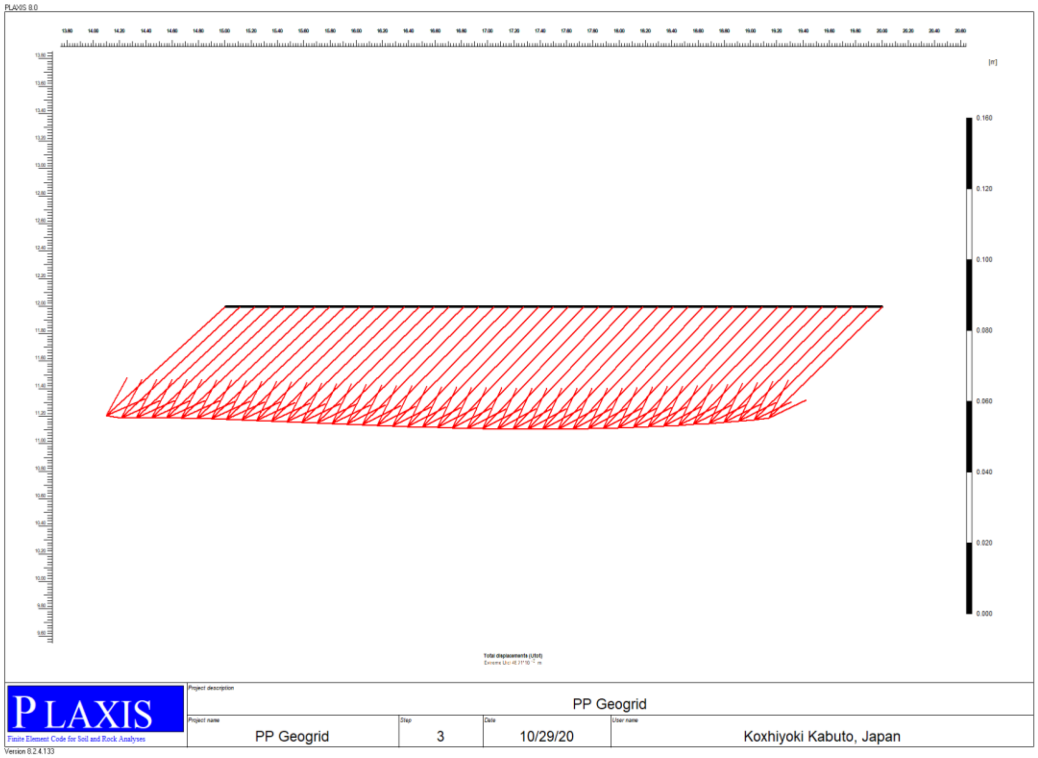

Figure B- 43 Tension force for HDPE geogrid reinforcement

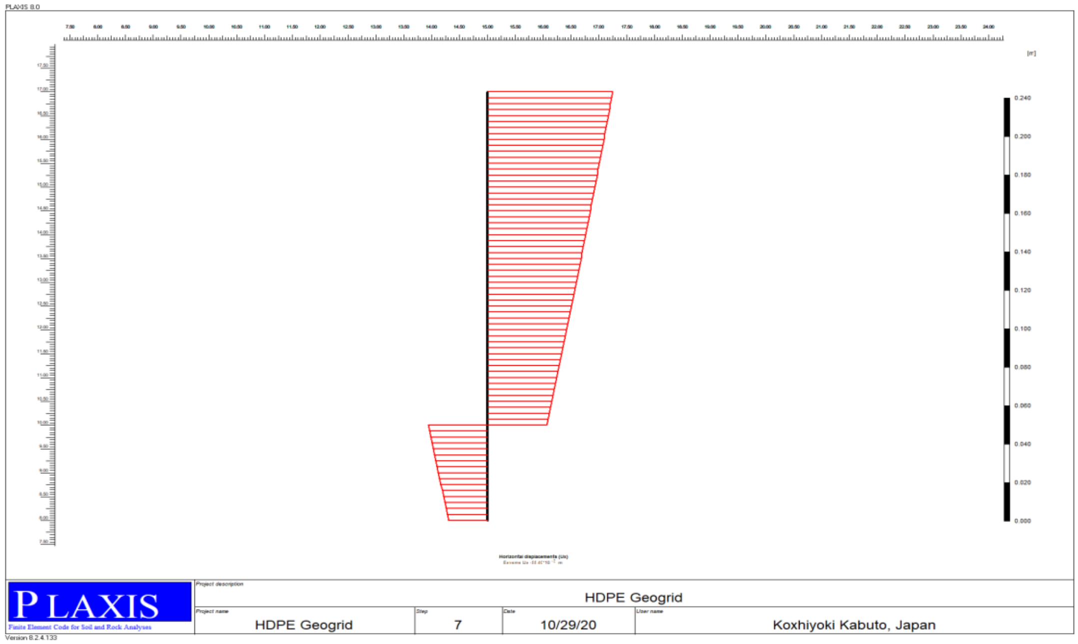

Figure B- 44 Horizontal deformation of facing panel for Polyethylene geogrid

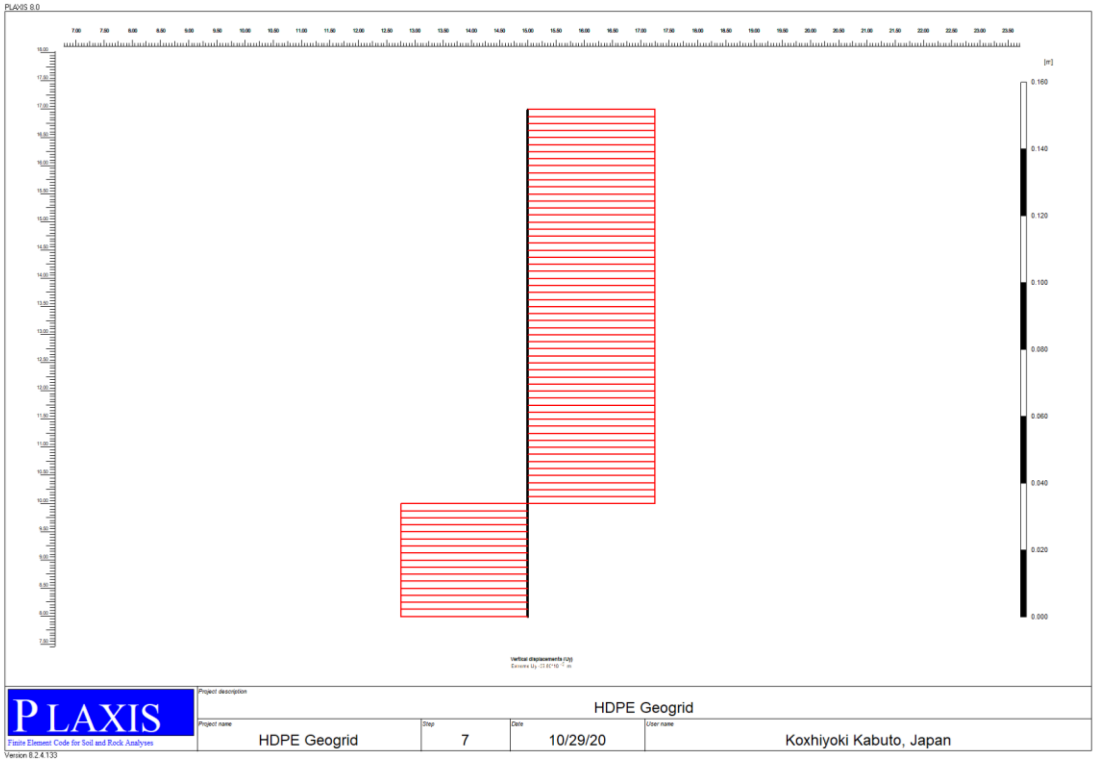

Figure B- 45 Vertical deformation of facing panel for Polyethylene geogrid

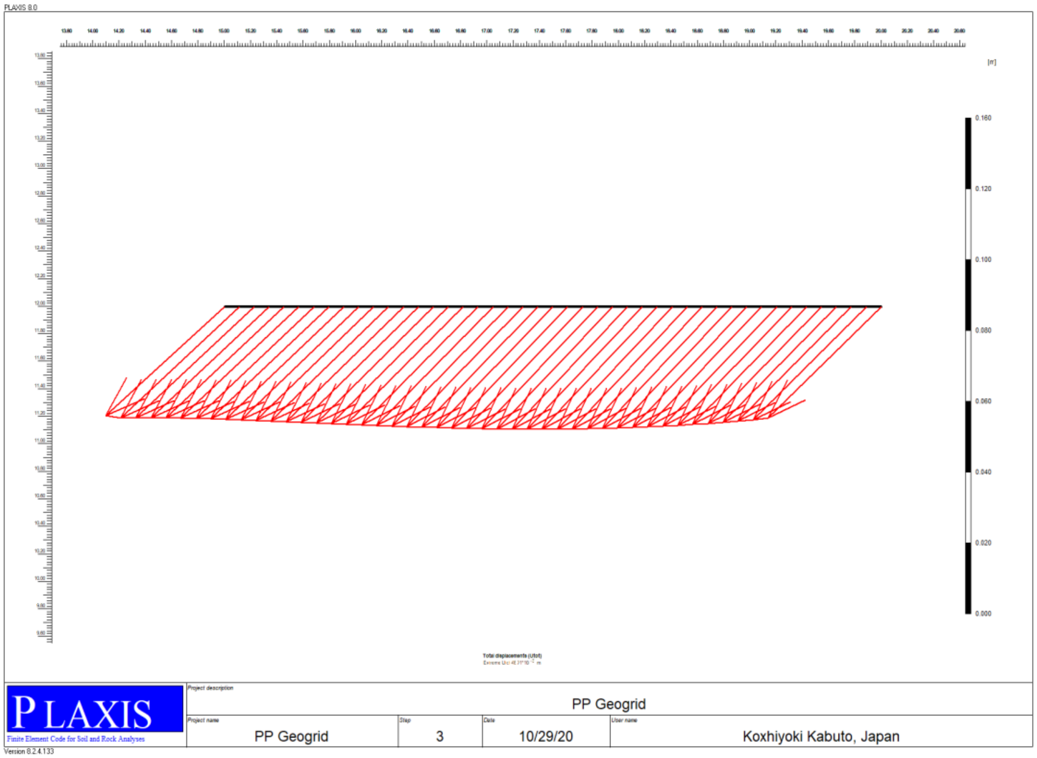

Figure B- 46 Tension force for Polyethylene geogrid reinforcement