FACING EFFECTS IN GEOSYNTHETIC-REINFORCED SOIL STRUCTURES

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ABSTRACT
This Paper outlines the Finite Element Method of analysis for simulating of Geosynthetic-Reinforced Soil Retaining Walls (GRS-RWs). Results of a parametric study to investigate the effect of facing including panel facing, segmental facing and wrapped facing on the behavior of GRS-RWs in terms of displacement of wall and forces in the reinforcements are presented. However this study is focused on the walls, because of the similarities to other forms of reinforced structures in facing such as slopes and abutments it can be applied to these structures too. This study shows that facing has a strong effect especially on the displacement of walls and should be taken into account in the design procedures which is not often concerned in analysis.

RÉSUMÉ
Ce Papier esquisse la Méthode d'Elément Finie d'analyse pour simulers de Murs De Soutènement de Sol Geosynthetic-Renforcés (GRS-RWs). Les résultats d'une étude paramétrique pour examiner l'effet de revêtement y compris le panneau faisant face à, segmental faisant face à et le revêtement emballé sur le comportement de GRS-RWs sur le plan de déplacement de mur et de forces dans les renforcements sont présenté. Cependant cette étude est convergée sur les murs, à cause des similarités aux autres formes de structures renforcées dans faisant face à tel que les pentes et les contreforts qu'il peut être appliqué à ces structures aussi. Cette étude montre à ce revêtement a un effet fort surtout sur le déplacement de murs et devrait être tenu compte de dans les procédures de conception qui n'est pas souvent concernée dans l'analyse.

1. INTRODUCTION

For the past several decades Geosynthetics have come to play a rapidly increasing role in a variety of civil and environmental engineering applications. The wide spectrum of the materials' characteristics enables the well-known, wide range of geotextiles functions that provide, in most cases, a very economic and ecologic alternative to conventional construction materials and methods.

One of the cases in which geosynthetics are used for reinforcement, is retaining walls. Geosynthetic-Reinforced Soil Retaining Walls (GRS-RWs) are the most popular structures that are often constructed to increase the stability of the natural or manmade fills. The proper performance of these structures is accepted by experts either in working loadings or in earthquake induced loadings (e.g. Ling et al. 2001).

On the other hand geosynthetics have a problem when they are used in retaining walls. In contrast with the common reinforced soil that steel bars are easily connected to the steel joints in concrete facing, geosynthetics cannot be attached like steel bars. To overcome this problem, three typical facing are used in this case. These facings which are shown in Figure 1 are as below:

(a) Panel facing
(b) Segmental (block) facing
(c) Wrapped (up) facing

For panel facing, a continues pre-cast concrete panel is used and geosynthetics are placed in the concrete before installation .Segmental facing uses some concrete blocks which are placed over each other through the height of the wall and geosynthetic sheets are situated between two blocks in the specified height. Wrapped facing does not have any separate elements and in each layer, the geosynthetic sheet is wrapped up to form the facing.

(a)

(b)

(c)

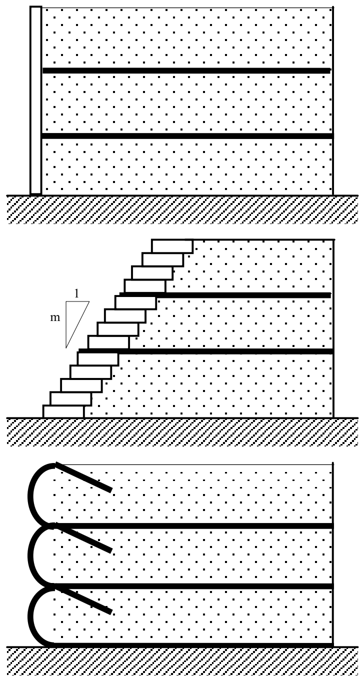

Figure 1. Typical Facings in RGS-RW: (a)Panel Facing; (b)Segmental Facing; (c) Wrapped Facing

Although GRS-RW is not an old technique, many attempts from experimental and laboratory tests to numerical simulation are carried out to study the behavior of this structure. The latest full scale laboratory tests have been taken by Bathurst et al. (2000) at RMC to have a better knowledge of GRS-RWs. This study had many valuable results and finally proposed a new design method called K-Stiffness (Allen et al. 2003, Bathurst et al. 2003). It showed that stiffness, of facing and reinforcements, is an important parameter that can affect the behavior of the structures and should be taken into account. This issue because of the limitations of Limit Equilibrium Method is not considered in the current design methods.

Beside the laboratory tests, numerical modeling is a lower-cost method to study the reinforced soil structures. In this way, FEM and FDM are two main methods that are often used in analysis. For example, Ling et al (1995) used FEM to simulate GRS-RWs. They suggested deformation limits at the service condition as an alternative criterion for design. FLAC is a FDM program which was utilized by Hatami and Bathurst (2002) and Hatami et al. (2001) to predict the response of a well-instrumented, full-scale segmental retaining wall under staged uniform surcharge loading. A complete review of numerical modeling has provided by Hatami and Bathurst (2002).

Plaxis (1998), a finite element code for soil and rock analyses, was utilized in this study to investigate the effect of alternative facings for the GRS-RWs. Three different kinds of facings mentioned before were used with the typical properties of materials. In addition, to examine the effect of geosynthetic stiffness a parametric study carried out for each typical facing. Mohr-Coulomb as an elastic-plastic model for soil and a fully elastic model for other elements were applied to the model to simplify the process of analysis. This simplicity is the advantage of this study that avoids the usage of sophisticated models.

2. COMPARISON OF PLAXIS WITH PAST STUDIES

To control the validity of the model and to check the applicability of the FEM program, Plaxis, in this kinds of structures a simple model was compared to the past studies. Also it was carried out for achieving the best and accurate range of material properties.

2.1 Continues Panel Wall Models

Ho (1993) and Rowe and Ho (1993) reported the results of a FEM program for continues panel wall illustrated in Figure 2. A model with the same dimensions was produced here in Plaxis with almost the same properties for soil, wall and interface elements. The properties of the materials used in the model are presented in Table 1. The same model has been also carried out by Bathurst and Hatami (1998) using a FDM program, FLAC.

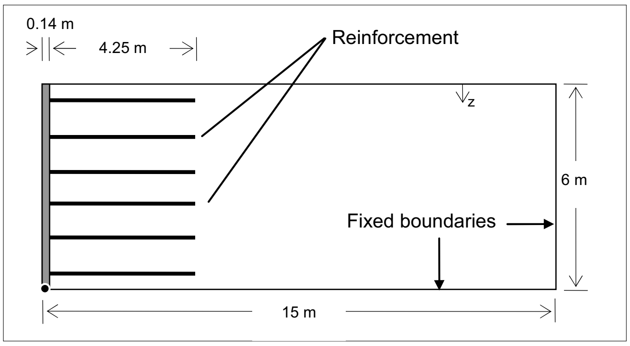

Figure 2. The model used for comparison

Table 1. Properties of the elements applied to the model.

Element		Model Properties
Soil (backfill)		• Mohr-Coulomb Model • γ = 20 KN/m^3 • c=0, ϕ=35°,ψ=6° • E=5+7.5z MN/m^2; z in meter • ν=0.3
Panel (wall)		• Linear Elastic • γ = 25 KN/m^3 • E=2.4E7 KN/m^2 • ν=0.15
Reinforcement		• Linear Elastic • $\gamma \cong 0$ • K (stiffness)=EA=2000 KN/m
Interface	Soil-Reinforcement	• Linear Elastic • E=5000 KN/m^2 • ν=0.3
Interface	Soil-Wall & Soil-boundary	• Linear Elastic • E=8000 KN/m^2 • ν=0.3

2.2 Comparison of Results

The values of lateral displacement of the wall face and normalized (axial) connection loads in the reinforcement layers are plotted in Figure 3. The corresponding results reported by Ho (1993) and Bathurst and Hatami (1998) are also presented in the same Figure. The displacement profiles from these three studies are in close agreement as illustrated in Figure 3a. The computed values of connection loads, T_c, in Figure 3b have been normalized with respect to the theoretical value of Rankin active soil pressure at the bottom of the wall. Connection loads are also in close agreement when compared to other studies. The differences may be due to calculation of soil elastic modulus and the treatment of the wall-soil and reinforcement-soil interface. This means that the linear relation used here to simulate the variation of Elastic Modulus through depth of the soil is not in good agreement with the relation has been used by two other studies. These two used the relation below for E:

$$E / P_a = K (\sigma_3 / P_a)^m \qquad [1]$$

Where K=460 and m=0.5 are constant coefficients; P_a=atmospheric pressure; and σ_3=minor principal effective stress in the soil.

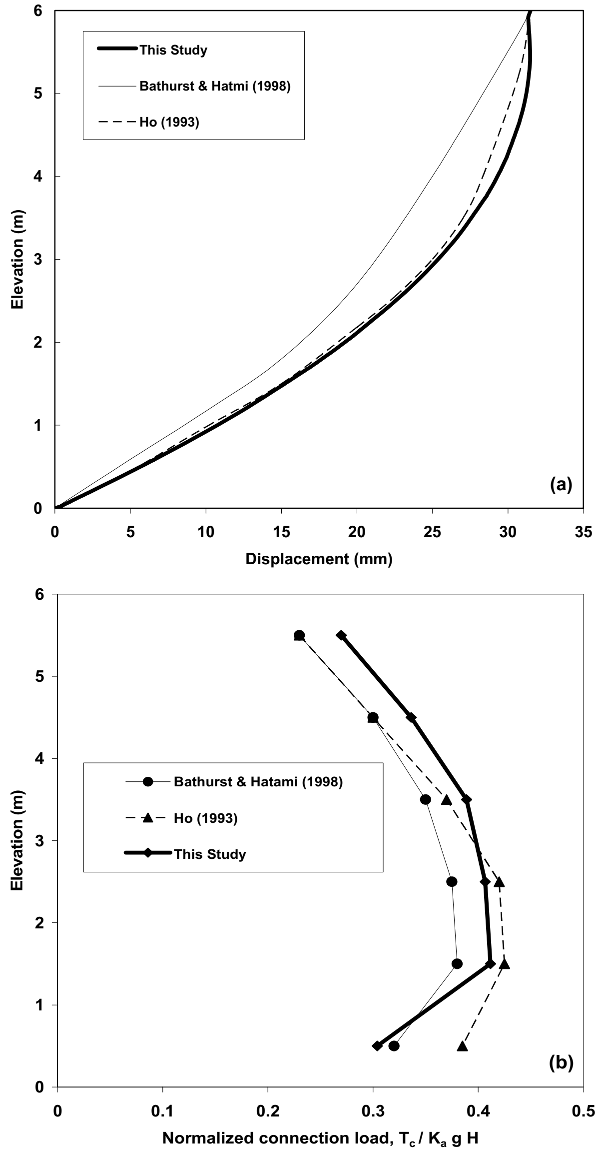

Figure 3. Comparison of three studies: (a) Displacement; (b) Normalized connection loads in the reinforcements

This comparison as mentioned before carried out mainly to assess the correct values for interface element properties that are modeled simply here by a linear elastic behavior of materials. The values in Table 1 are those that are obtained from this comparison.

3. MODELING

After the comparison, three fundamental models each has one of the typical facing of panel or segmental or wrapped, were prepared in Plaxis. Other characteristics are as below.

3.1 General Conditions

Plaxis has two types of elements for analysis; a 6-node triangular element and a 15-node triangular element. To increase the accuracy of calculations, the triangular elements with 15-node were applied in modeling. To simulate the concrete panel, segmental blocks, foundation, interfaces and backfill soil the "soil & interface" group of elements and for reinforcement layers the "geotextile" group of elements has been used.

The calculations were fully drained and no pore water pressure was considered. To improve the reality of the models a rigid foundation was added to the primary model which was used for comparison.

3.2 Dimensions

The reference problem is a wall of 6 meters height and 25 meters width. It seems that 25 meters is a far distance from the wall, but it could help the computational stage reach the minimum error.

The rigid foundation of 2 meters depth was placed beneath the wall as it shown in Figure 4. At the lower level of the model (horizontal boundary) two-direction (horizontal and vertical) fixities were used. However for the vertical boundaries the horizontal fixities were enough. According to the form of the segmental walls the value of 'm' (Figure 1b.) was chosen to be 20.

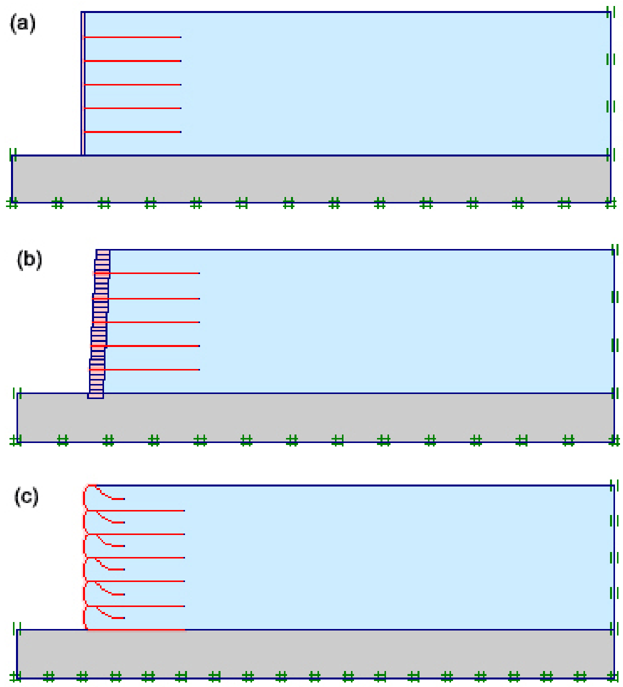

Figure 4. The models prepared using Plaxis; (a) Panel facing; (b) Segmental Facing; (c) Wrapped facing

For all of the models the same combination of reinforcements was used. Five layers of geosynthetics with 4.5 meter length have been placed in each 1 meter through the height of the wall. Exception is the wrapped facing model that needs an extra layer on the foundation and totally six layers are require to wrapped up and come back 1.5 meter in the soil.

The schematic shape and form of the three typical models are presented in Figure 4. However mesh generation is automatically produced by Plaxis, when necessary it is possible to generate meshes manually.

3.3 Material Properties

The same properties of backfill soil, interface elements and concrete panel in section 2 (Table 1) were used again here. However the elastic modulus of soil set to a constant value of 50 Mpa. The properties of segmental blocks interface between each two blocks and foundation, and more additional information are reported in Table 2.

As it is seen, the foundation is almost a rigid material with the elastic modulus 500 times greater than the soil elastic modulus. In this study, material and interface properties have been selected in a way to ensure that reinforcement rupture, pullout of reinforcements or sliding of segmental blocks on each other were not the failure mechanism. Although the accuracy of the results is important, using simple models is another goal here.

Table 2. Properties of the elements applied to the models.

Element		Model Properties
Soil (backfill)		• Mohr-Coulomb Model • γ = 20 KN/m^3 • c=0, ϕ=35°,ψ=6° • E=50 MN/m^2 • ν=0.3
Segmental blocks		• Size of each block 60×20 cm • Linear Elastic • γ = 16 KN/m^3 • E=500 MN/m^2 • ν=0.2
Panel (wall)		The same as in Table 1.
Foundation		• Linear Elastic • γ = 20 KN/m^3 • E=2.5E4 MN/m^2 • ν=0.3
Reinforcement		• Linear Elastic • $\gamma \cong 0$ • K=5000,15000, 45000 KN/m
Interface	Soil-Reinforcement	The same as in Table 1.
	Soil-Wall & Soil-boundary	The same as in Table 1.
	Block - Block	• Linear Elastic • E=10000 KN/m^2 • ν=0.25

3.4 Loadings

For the analysis the effect of static loading was considered only. On the other hand no kinds of surcharges or external loadings were applied to the models and the computational process carried out for the weight of materials, all at the end of construction in one stage.

3.5 Variable Parameters

In addition to the type of facing which is a variable factor, the stiffness of geosynthetics is another variable parameter in the models.

The geotextile element in Plaxis is a cable element with an elastic model of behavior that only carries the tension forces. The only parameter to define this element is stiffness which is equal to EA (product of Elastic modulus and section area).

To examine the effect of reinforcement stiffness (K), three different values of K were selected and applied to each facing model; that are 5000, 15000, 45000 KN/m.

4. RESULTS

The results are presented in three parts; deformation and displacement, maximum tensile force in reinforcements and the plastic zone in the soil. Following sections are related to each part.

4.1 Deformation and Displacement

The first thing that is observed from the analyzed models is that the deformation of each wall with similar types of reinforcement and soil properties varies with the type of facing. For each type of facing a unique form of deformation will occur. The three forms of deformation that are related to each facing type are shown in Figure 5. It is clear that the type of facing affects the general form of deformation of GRS-RW.

The variations of wall displacement through the height of each wall facing for three different values of reinforcement stiffness are shown in Figure 6.

Figure 6 shows that the wrapped facing has the greatest value of wall displacement. This maximum value of displacement is located at the top of the wall. It means that the maximum displacement in wrapped facing wall is occurred at the highest part of the wall. For two other kinds of facing this issue is not the same. It can be seen from Figure 6 that in segmental facing wall the maximum displacement is almost at the middle of the wall. This maximum value for panel facing is at 2/3 height of wall from the bottom however.

All of These features could affect the design method, especially for those kinds that are based on deformation and displacement.

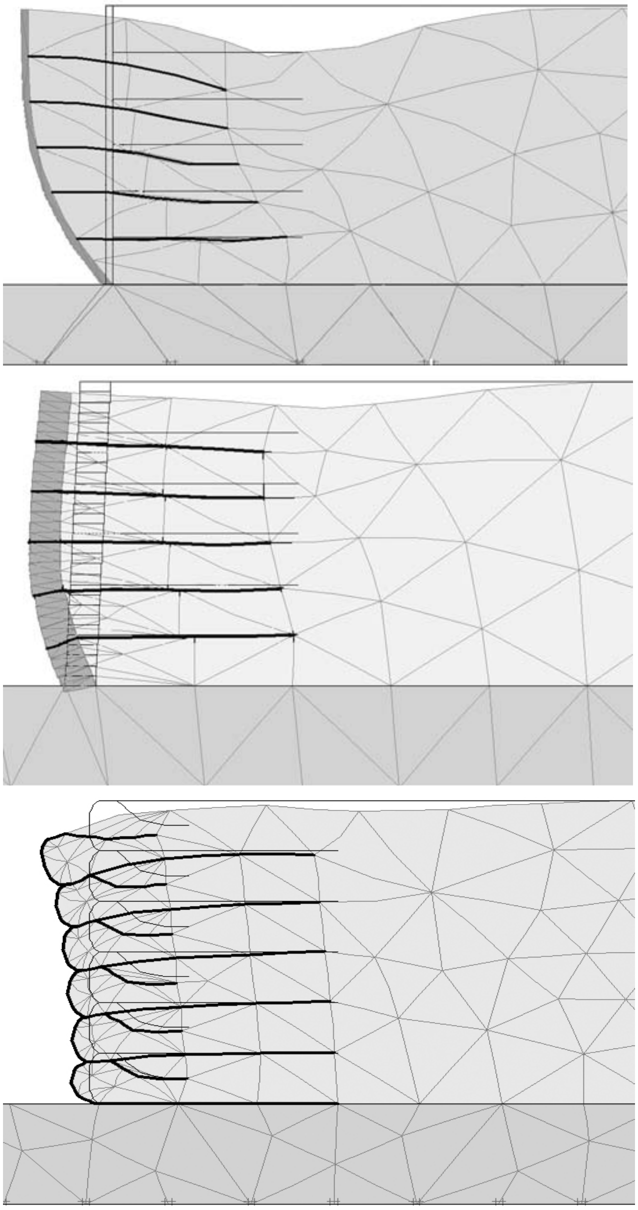

Figure 5. Three typical forms of deformation of GRS-RWs

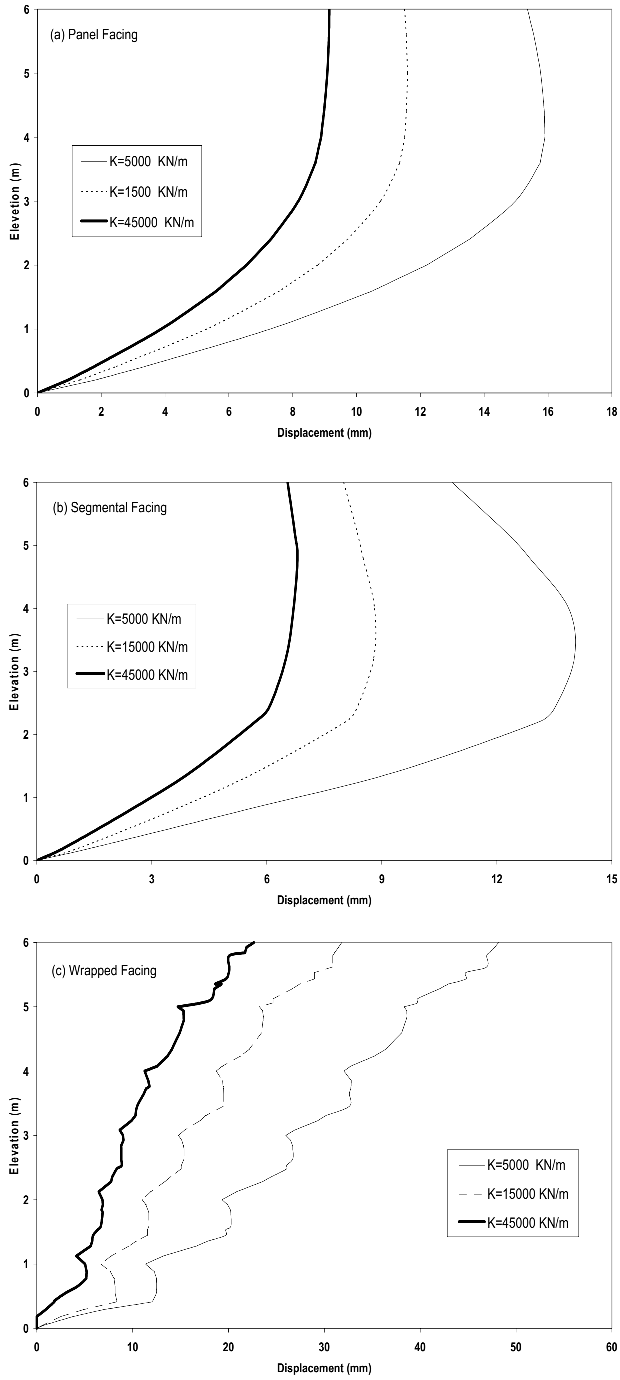

Figure 6. Variations of displacement with reinforcement stiffness for each wall facing

4.2 Reinforcement Force

Another factor considered in design is the maximum load that is produced in reinforcements. Figure 7 presents the variations of the maximum force in the reinforcement at five levels of segmental and panel facing walls and at 6 levels for wrapped facing wall. The increase of stiffness increases the reinforcement forces. Although this increasing is not equal in each level, but the curves has a parallel form. This is understandable that most of the increase is occurred at 1/3 height of wall from the bottom. However no increasing of reinforcement force is not seen at 2/3 of height of wall.

It is acceptable to say that the more the stiffness the more the force in reinforcement and the less the displacement. This also has meaning in the displacement based design methods.

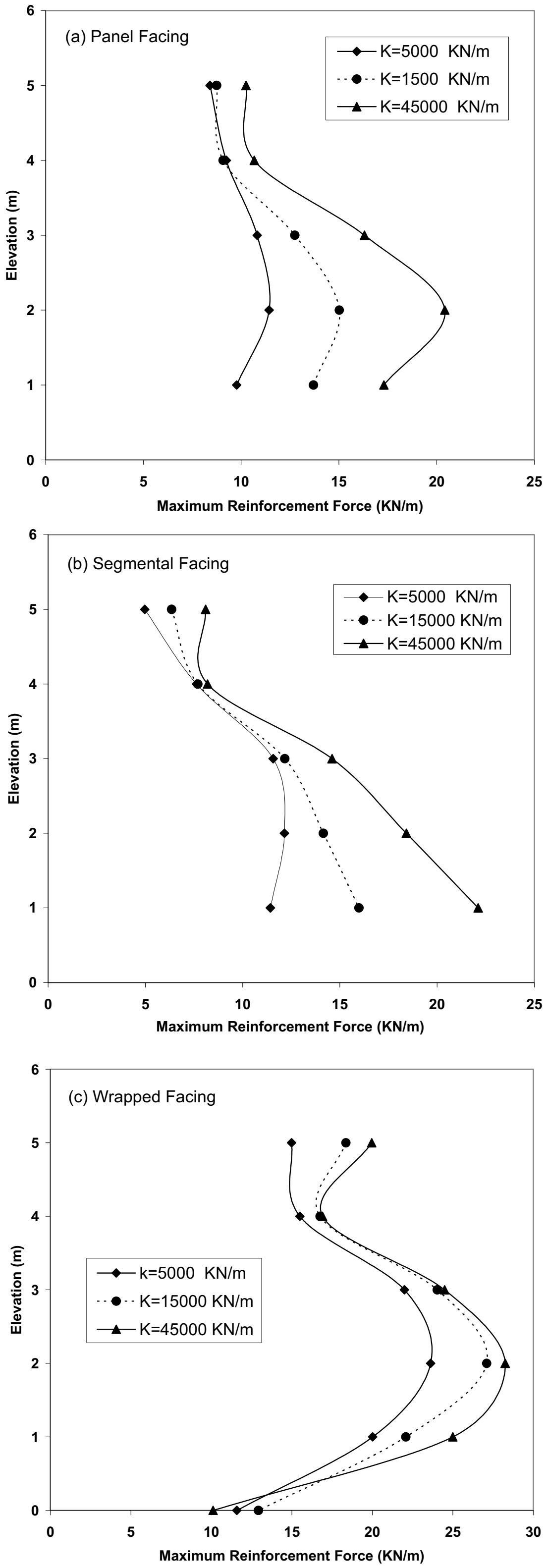

Figure 7. Maximum Reinforcement force for different value of reinforcement stiffness in each according to wall facing

4.3 Plastic Zone

According to the plastic analysis that was carried out for the models, plastic zones can be presented. It should be taken in mind that the plastic zones in these models are relevant to the Mohr-Coulomb elastic-plastic model.

The schematic forms of plastic zone in all of the models are as the same as what is illustrated in Figure 8. All of them have a plastic line with the slope angle equal to α. The definition of failure line and α have been shown if Figure 8. This definition is just for reporting the results and has no other meanings.

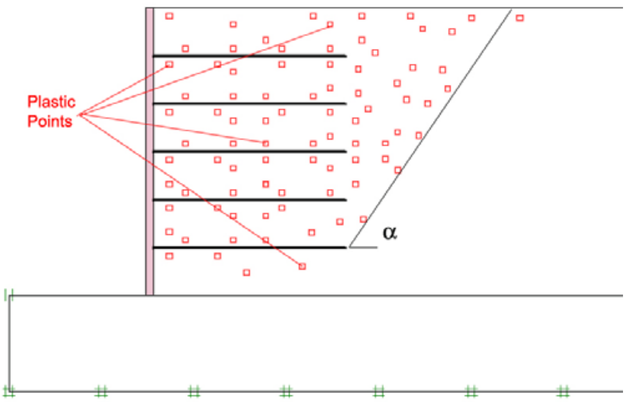

Figure 8. Schematic shape of plastic points in the models and the definition of plastic line and α

Corresponding values of α for each model are shown in Table 3. However there are no differences between α when K varies from 15000 to 45000 KN/m, it is seen that the strength of wall can affect the α. Simply it can be said that the value of α decreases with the increases of the strength of wall and stiffness of reinforcement.

Table 3. Values of α according to Figure 8

K (KN/m)	α in degree		
	Panel Facing	Segmental Facing	Wrapped Facing
5000	61.2	59.8	49.3
15000	45	43.9	42.7
45000	45	43.9	42.7

5. CONCLUSION

The results of parametric analyses of a geosynthetic reinforced soil wall using program Plaxis have been reported. At the first stage, the results of the program were compared to the past numerical studies. This study focused mainly on the effect of facing in a static analysis of a 6 meter wall reinforced with a range of reinforcement stiffness. Three types of facing were used to model a geosynthetic reinforced soil wall that are panel facing, segmental facing and wrapped facing. Qualitative features of these analyses are summarized below:

(a) Each type of facing (panel, segmental and wrapped) has a specific form of deformation and location of the maximum displacement is not the same in each wall with different facing.
(b) However the increase of the reinforcement stiffness decreases the displacement of the wall, the tension forces in reinforcement will also increases.
(c) The strength of the wall and the stiffness of reinforcements are two factors affect the area of plastic zone in the backfill soil. The more the stiffer the system, the less the area of plastic zone.
(d) However facing effect changes the behavior of GRS-RWs, current design methods that are based on limit equilibrium method do not consider the facing and stiffness factors.

6. ACKNOLEDGEMENT

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