Pamukkale Univ Muh Bilim Derg, 25(3), 247-256, 2019

Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi

Pamukkale University Journal of Engineering Sciences

Parametric analysis of back-to-back reinforced earth retaining walls

Sırt sırta takviyeli toprak duvarların parametrik analizi

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Received/Geliş Tarihi: 08.09.2017, Accepted/Kabul Tarihi: 17.05.2018 doi: 10.5505/pajes.2018.22308
* Corresponding author/Yazışılan Yazar Research Article/Araştırma Makalesi

Abstract

In recent years, Reinforced Earth retaining structures have become more desirable for construction and civil engineering projects because of their suitable performance, variation of design and construction methods. In this article, the performance of back-to-back reinforced earth walls has been evaluated and analyzed. Throughout the article, the effect of different parameters such as angle of internal friction, soil unit weight, cohesion, using different materials in layers with 1.5 m thickness and reinforcing elements' specifications has been analyzed. For detailed information from the site of the wall, a borehole was drilled to a depth of 30 m and geotechnical tests were done in Hormozgan province (Iran). The results show that the lower length and tensile strength can be used with higher angle of internal friction and adhesion. Also, utilizing material in different layers produces a more favorable performance, optimization and decreases the strength of reinforcer elements.

Keywords: Geosynthetic reinforced soil walls, Finite element, Deformation, Stability

Öz

Son yıllarda, Takviye Edilmiş toprak yapılar, uygun performans, tasarım çeşitleri ve inşaat yöntemleri nedeniyle inşaat ve inşaat mühendisliği projelerinde daha cazip hale gelmiştir. Bu yazıda sırt sırta takviyeli toprak duvarların performansı değerlendirilmiş ve incelenmiştir. Bu bağlamda, iç sürtünme açısı, zeminin birim hacim, adezyon gibi farklı parametrelerin 1.5 m kalınlıktaki tabakalardaki farklı zemin malzemelerinin kullanımı ve takviye edici özellikleri gibi tanımlamalar değerlendirilmiştir. Duvarın temelinin geoteknik özelliklerinden ayrıntılı bilgi için, 30 m derinliğine varan bir sondaj yapılmış ve iranın Hormozgan ilinde geoteknik testler yapılmıştır. Sonuçlar daha az uzunluk ve Çekme mukavemeti daha yüksek iç sürtünme açısı ve Adezyon ile birlikte kullanılabileceğini göstermektedir. Ayrıca, farklı katmanlarda malzeme kullanma daha uygun bir performans üretir, takviye elemanlarının optimizasyon ve mukavemeti azalır.

Anahtar kelimeler: Güçlendirilmiş jeosentetik toprak duvarlar, Sınırlı eleman, Şekil değiştirme, Duraylılık

1 Introduction

Mechanically stabilized earth retaining walls (MSE), also known as reinforced soil walls, are widely utilized throughout the world because of simple construction techniques, aesthetics and also, they are cost effective too. In principle, MSE retaining wall is a composite system that consists of soil reinforcement, backfill material, facing element and foundation. Since the first Geosynthetic reinforced soil (GRS) retaining wall was built in 1970 in France, this system has been used successfully as earth retaining structures for more than four decades. Superiority of the geosynthetics over other reinforcements has made the geosynthetic earth walls one of the important options in designing the retaining walls. Qhaderi et al. (2005) examined the parameters influence on the sloped embankments reinforced with geotextile fibers. Their studies revealed that the stress distribution in the embankment height is independent of the geotextile layers' length. Also, the increase in the length and number of geotextile layers caused improved safety factor of the embankment against the slip[1]. Subaida (2008) investigated the experimental strength of the woven geotextile against tension and extraction of geotextile from the soil. The results showed that the strength of the geotextiles with narrowly woven fibers did not largely differ for the soils with different grain sizes. But for the geotextiles with wider woven fibers the extraction strength is greater for the finer soil grains than the coarse sand [2]. Bilgin (2009) using the ruling failure state tried to determine the minimum length and the minimum shortening possibility in the reinforced earth walls. For this purpose parameters such as the wall height, surcharge, the distance of vertical reinforcements, the backfill material properties and the foundation were considered. Results of the studies showed that the inner and outer failures are important criterions for determination of the minimum required length [3]. Siavoshnia et. al. (2010) evaluated the performance of the embankment reinforced with geotextile fibers constructed on the fine grain soil and modeled it using PLAXIS 2D software. The results showed that decreasing the embankment slope and its height from the bed while increasing the geotextile layers stiffness causes decrease in settlement of the embankment [4]. Huang et. al. (2010) evaluated the effect of the wall toe horizontal stiffness on the reinforced earth retaining wall performance under practical conditions. The numerical results indicated that wall toe stiffness in the bed is responsible for bearing a significant part of the loads resulting from the soil pressure in the system[5]. Fuente et. al. (2011) studied three new innovative models in precast concrete panels with experimental pull out potential of the strips. Results suggest that using such models can cause the increase in performance as well as facilitating the construction process[6]. Noorzad et. al. (2010) experimentally investigated clay reinforcing with geotextile. Results of their study show that, with the increase in the soil moisture, the maximum stress tolerated by the soil decreases for both with and without geotextile states, while some axial strain in the failure is observed. This is while the increase in the soil compaction results in escalation of the strength and axial strain of the soil in both states [7]. Abdelouhab et. al. (2011) investigated the numerical analysis of the earth wall behavior with different types of strip reinforcements including metal strip and strip made of synthetic Polymeri materials with moderate stiffness (GS50) and high stiffness (GSHA). Results showed that using geosynthetic strips caused more deformation and higher safety factor value [8]. Sengupta (2012) performed a numerical study using limit equilibrium and finite element methods for the failure of the reinforced earth walls. The deformation results predicated by the finite elements method can be compared with the actual data [9]. Esfandiari et al. (2012) carried out experiments on the galvanized steel strips with transverse members aiming to increase the pull out capacity. Results of their study show that using diagonal members ould cause increase in the pull out capacity as well as decrease of the length required by the steel strips [10]. Alam et al. (2013) studied the load-bearing mechanism of the steel-grid placed in the reinforced earth walls and its pull out capacity. The numerical results demonstrate that if constant values are considered for the soil friction angle and the coefficient of lateral earth pressure, the burden pressure will have no considerable effect on the load capacity [11]. Mirmoradi et al. (2016) studied the combined effect of toe resistance and facing inclination on the behavior of GRS walls. The results indicate that the values of ΣT_{max} (summation of the maximum load mobilized in the reinforcement layers)and ΣT_o (the summation of the connection loads) at the end of construction and at the beginning of the surcharge load applications were similar, but the values of ΣT_{max} were greater than ΣT_o for both walls at higher values of surcharge load and toe release [12]. Shehata (2016) performed a numerical study using finite element method for effect of attaching shelves to a cantilever retaining wall. The results showed that the shelves significantly decrease the maximum bending moment and the top movement of the wall. [13]. Tajabadipour et al. evaluated the performance of reinforced earth retaining walls when using tire chips sand mixture as backfill. The results indicate that the mixture, with the ratio of 30:70 under the condition of applying surcharge load or even without it, was found to be the most suitable filler material compared to the other mixing ratios [14]. Despite all of the effort the researchers have devoted to the performance of the geogrid reinforced earth walls, it seems there is no adequate practical data regarding the back-to-back walls' performance when using materials with different specifications and properties. Thus in this paper, influence of backfill type and material properties such as friction angle, adhesion, use of in different layers and etc, on the performance of reinforced soil segmental retaining walls under working stress conditions (end of construction) is investigated using a numerical model.

2 Numerical modelling

Numerical modelling has been a useful tool for engineering design and it helps to better understand of different problems. The definition of modeling may vary depending on the application, but the basic concept remains the same.

By use of numerical modeling can be considered diffrerent changes created in stress, strain, displacement and other parameters in various locations of the structure.

The real position can be modelled using plane strain or axial symmetry models. In 2-dimensional analyses, it's possible to choose the two element types of 6-node and triangular 15-node. In six-node elements, the elements' displacement approximation function considered, is of second order and the stiffness matrix of this type of element is acquired using three stress points, but in the triangular 15-node elements, the displacement approximation function is of fourth order and 12 strain points are considered for it to determine the stiffness matrix.

2.1 Hardening-soil model (HS)

The Hardening-Soil model (HS) and Hardening Soil-small (HS-small) models are designed to reproduce basic phenomena exhibited by soils such as: densification, stiffness stress dependency, plastic yielding, dilatancy, strong stiffness variation with growing shear strain amplitude in the regime of small strains ($\gamma=10^{-6}$ to $\gamma=10^{-3}$). HS model was initially formulated by Schanz [15]-[18], Vermeer and Bonnier [19].

As for the Mohr-Coulomb model, limiting states of stress are described by means of the friction angle, ϕ, the cohesion, c and the dilatancy angle, ψ. However, soil stiffness is described much more accurately by using three different input stiffnesses: the triaxial loading stiffness, E_{50}, the triaxial unloading stiffness, E_{ur}, and the oedometer loading stiffness, E_{oed}. As average values for various soil types, we have $E_{ur} \sim 3E_{50}$ and $E_{oed} \sim E_{50}$, but both very soft and very stiff soils tend to give other ratios of E_{oed}/E_{50}.

$$E_{oed}= E_{50},\ E_{ur} =3E_{50},\quad Eoed = \frac{(1-\upsilon)E}{(1-2\upsilon)(1+\upsilon)} \tag{1}$$

In contrast to the Mohr-Coulomb model, the Hardening-Soil model also accounts for stress-dependency of stiffness moduli. In such situations there is also a simple relationship between the modified compression index λ^*, as used in models for soft soil and the oedometer loading modulus [22].

$$E_{oed}^{ref}=\frac{P^{ref}}{\lambda^*},\lambda^*=\frac{\lambda}{(1+e_0)} \tag{2}$$

Where p^{ref} is a reference pressure. Here we consider a tangent oedometer modulus at a particular reference pressure p^{ref}. Hence, the primary loading stiffness relates to the modified compression index λ^* or to the standard Cam-Clay compression index λ.

Similarly, the unloading-reloading modulus relates to the modified swelling index κ^* or to the standard Cam-Clay swelling index κ. There is the approximate relationship:

$$E_{ur}^{ref}=\frac{2P^{ref}}{K^*},K^*=\frac{K}{(1+e_0)} \tag{3}$$

This relationship applies in combination with the input value m=1.

Figure 1 shows the analysis of reinforced earth retaining wall with 6 m height for three constitutive model and specification of constitutive models are described in Table 1.

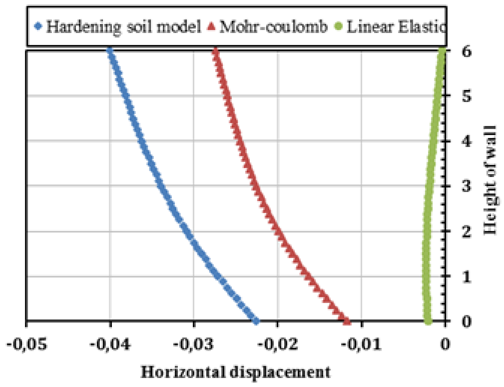

Figure 1: Three constitutive model for wall with 6 m height.

Table 1: Characteristics of different models uses in this study.

	Hardening Soil Model	Mohr-Coulomb	Linear Elastic
TYPE	Drained	Drained	Drained
γ_d (kN/m^3)	18	18	18
K_x (cm/s)	1.00E-01	5*10E-6	5.5*10E-6
K_y (cm/s)	1.00E-01	5*10E-6	5.5*10E-6
c_{ref} (kN/m^2)	0.1	0.1	-
ϕ (°)	40	40	-
Ψ	10	10	-
E (Mpa)	41	41	-
E_{oed} (Mpa)	50	-	-
E_{50} (Mpa)	50	-	-
Eur (Mpa)	150	-	-

In this regard horizontal displacement of the wall has been investigated. Mohr-Coulomb model represents a'first-order' approximation of soil behaviour and in this study results are given less than hardening model.thus, It is recommended to use this model for a first analysis of the problem considered. For each layer one estimates a constant average stiffness. Linear elastic model is logical conclusions, so hardening model with consideration the stiffness for each layer of soil is more accurate [22]. In this study, for all simulations plaxis sofware and harding model was used with aforemention results.

3 Geometry of the modeled wall

Figure 2 illustrates the cross section of the studied models geometry. In modeling, the walls are considered with the identical height of H=6m. Statistical analyses have been performed in different states without surcharge on the walls with identical height and the underground water level for all the models is considered with attention to drilling that was performed in Hajiabad (located in the southern part of Iran) and water table 30 m under the foundation of wall.

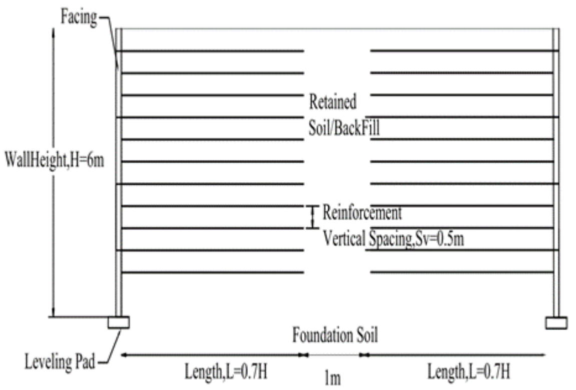

Figure 2: Geometry of the modelled wall.

3.1 Characteristics of material

The material predicted for the numerical modelling included the backfill material, precast concrete blocks and geogrid elements. The parameters used in the wall are briefly described in the following sections.

3.2 Backfill materials

In this study a specimen of granular soil with hardening (HS) behavioral model has been used. Table 2 represents the embankment specifications used in the modeled wall.

Table 2: Characteristics of different material.

	Dense Sand	Silty Sand	Clayey Sand
TYPE	Drained	Drained	Drained
γ_d (kN/m^3)	21	19	18
K_x (cm/s)	1.00E-01	5*10E-6	5.5*10E-6
K_y (cm/s)	1.00E-01	5*10E-6	5.5*10E-6
c_{ref} (kN/m^2)	0	5	15
ϕ (°)	41	33	38

3.3 Specification of facing materials and reinforcements

For numerical analyses precast concrete block type is used. The precast concrete panels are commonly square or rectangular in shape with typical dimensions of 125 to 200 mm thick and 1.2-1.5 m high and a front face width of 1.5 or 3 m.

In the study, blocks with a height of 1.5 m, thickness of 0.2 m, axial stiffness EA=7.5*10^6 kN/m and bending stiffness EI=2.5*10^4 kN.m^2/m have been used.

In this study two types of geogrids with different stiffness were used (Geogrid A 1000 kN/m and Geogrid B 1400 kN/m). Each interface has been assigned with a virtual thickness which is an imaginary dimension used to define the material properties of the interface. A typical application of interfaces would be to model the interaction between a sheet pile wall and the soil, which is intermediate between smooth and fully rough. The roughness of the interaction is modeled by choosing a suitable value for the strength reduction factor in the interface (R_{inter}). For the present analysis, a typical value of R_{inter}=0.67 is used for the fill soil. This factor relates the interface strength (wall friction and adhesion) to the soil strength (friction angle and cohesion).

3.4 Local geology of walls foundation (site reconnaissance)

Geotechnical drillings were performed in specified site to determine the subsurface layering characteristics. The depths of the bore-holes were limited with top 30 m. The bore-hole drillings were performed in Hormozgan province and in Hajiabad city (Figure 3).

Figure 3: Location of site (Hajiabad city).

Hormozgan Province is one of the 31 provinces of Iran. It is in the south of the country, in Iran's Region 2, facing Oman and the UAE. It has an area of 70697 km^2 and its provincial capital is Bandar Abbas. The province has fourteen islands in the Persian Gulf and 1000 km (620 miles) of coastline. Qeshm and

Hajiabbad are the important cities of Hormozgan province. Qeshm Island is located a few kilometers off the southern coast of Iran (the Persian Gulf), opposite the port cities of Bandar Abbas and Bandar Khamir. Hajiabad county is located about 100 km north of Bandar Abbas (the central city of Hormozgan province). The sediments in Hajiabad are coarse grain brown gravel (Figure 4).

Figure 4 and Table3, show characteristics of different soil layers and dynamic parameters. This profile has been used for wall-foundation modelling.

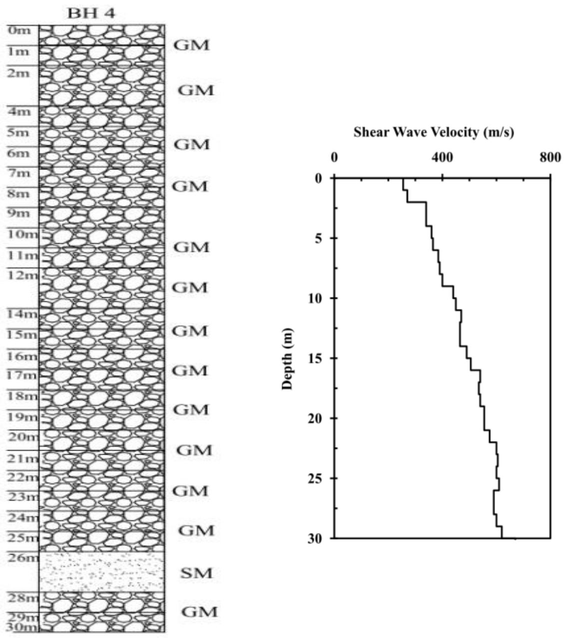

Figure 4: Site stratigraphy and maximum shear modulus.

Table 3: Characteristics of bore hole used in this study(foundation of wall).

Depth (m)	0-2	2-4	4-6	6-8	8-10	10-12	12-14
γ_d (kN/m^3)	18.2	18.4	18.3	18.6	19	19.2	19.6
ϕ (°)	35	36	36.25	38	41	43	45
c_{ref} (kN/m^2)	0.1	0.1	0.1	0.1	0.1	0.1	0.1
E (Mpa)	13	15	18	15	41	49	35
E_{oed} (Mpa)	20.8	24.1	28.9	24.1	65.8	78.6	56.1
E_{50} (Mpa)	20.8	24.1	28.9	24.1	65.8	78.6	56.1
Eur (Mpa)	62.4	72.3	86.7	72.3	197.4	235.8	168.5
Type(uscs)	GM	GM	GM	SM	GM	GM	SM

Table 4: Soil parameters experiment in Hajiabad.

Soil Properties	Standards	Values
Moisture content, ω (%)	ASTM D2216-80	0.4-2.8
specific gravity, GS	BS 1377	2.66
Plasticity index, PI	ASTM D424-59	0
AASHTO classification	AASHTO M145	A-3
optimum moisture content, ω_{opt} (%)	AASHTO T 180-A	14.2
Maximum dry density, γ_d (KN/m^3)	AASHTO T 180-A	16
cohesion, C (kN/m^2)	ASTM D3080-72	0
Friction angle, φ (°)	ASTM D3080-72	28

4 Problem layout

In this study, the effective parameters in the performance of the geosynthetic reinforced earth walls has been comprehensively and precisely analyzed. For this purpose a geogrid reinforced earth wall with the height of 6 m has been used. The reinforcement length has been considered by FHWA code [33]. The prefabricated blocks of 1.5 m height and 0.2 m thickness have been used as the surfacing elements (Figure 2). The parameters studied in this paper are as follows:

4.1 Effect of backfill material

In this section the effect of the geotechnical parameters including the angle of internal friction, specific unit weight and cohesion of the material has been considered. The unit weight and friction angle for soils ranged from 18 kN/m^3 to 22 kN/m^3 and from 32° to 42°, respectively.

For this purpose the sandy material with different geotechnical specifications has been used (Table 2). The execution of reinforced earth walls is carried out in layered form and from the same material. It seems like there is no adequate practical data regarding the walls' performance when using materials with different specifications and properties. Hencein this study a number of walls constructed using materials in different layers. In this regard the materials available in Hormozgan province and Hajiabad city were tested.

The sand samples used in the present experimental tests were obtained from the desert of eastern part of Hormozgan Province; Iran. Major parts of this area are covered with the sand which is characterized as poorly graded soil with high permeability. According to BS 1377, specific gravities of sand estimated 2.66.

The particle size distribution is as follows: average grain size, D_{10} = 0.22mm, D_{30} = 0.38 mm and D_{60} = 0.62 mm, uniformity coefficient, c_u=2.82; and coefficient of curvature, c_c=1.06, and the plasticity index (PI) was zero. This sand is classified as poorly graded sand (SP), according to the Unified Soil Classification System (USCS) (Table4).

Strength parameters of this sand at the optimum Moisture content, obtained from triaxial apparatus are C=0 and ϕ=28.

In order to obtain the optimum state and desirable performance of wall, the Hajiabad's material, sandy material with internal friction of 40 degrees and three other materials including Dense Sand, Silty Sand and Clayey Sand are used in 4 layers with 1.5 m thickness (Table 5, Figure 5).

Table 5: Characteristics layers of different embankment.

	H*	M*	E*1	E2	E3	E4	E5
Layer1	Sand	SW	SW	H*	DS*	SC	SW
Layer2	Sand	SW	DS*	DS*	H*	SW	Silty Sand
Layer3	Sand	SW	Silty Sand	SW	Silty Sand	H*	SC
Layer4	Sand	SW	SC	SC	SW	DS*	H*

Note: E* denote: Embankment; H*:Hajiabad material; M*: Main model (models with out cohesion and granular materials with friction angle of 40 degree)and DS*: Dense Sand. Layers are named from bottom to top see Figure 5.

4.2 Effect of reinforcing material

The effect of different parameters of reinforcing elements including tensile strength, the distance of the first reinforcing layer from the wall bed, as well as using two stepwise and sloped models (Figs. 6 and 7) for different materials has been studied. Figure 6 shows the stepwise model used for the geogrid reinforced earth wall. In this model a distance of 0.5 m has been considered between the geogrids and a geogrid length of 4.5 m has been divided into two part of three and one meters has been placed first and then a length of about 0.5 m of geogrid is transferred to a layer located at the height of 0.5 m from the previous layer. Next, the 1 m of the geogrid stretches along the soil and filling is performed for the next layer, then the same procedure goes on for the remaining layers (Figure 6). In this section two types of geogrids with different stiffness were used (Geogrid A 1000 kN/m and Geogrid B 1400 kN/m). Six types of soils with different properties and two types of geogrids have been used with the given specifications for assessment of the wall performance using the mentioned system.

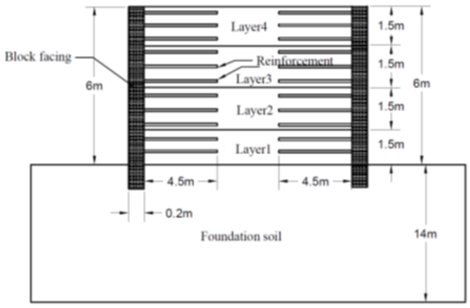

Figure 5: Schematic diagram of reinforced earth wall with different layers.

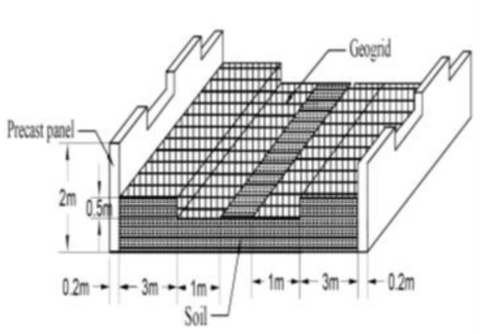

Figure 6: Schematic diagram for the step model used in this study.

Figure 7 shows sloped models used in wall. A total of eleven reinforcement layers with 0.5 m distance and two geogrid strengths (Geogrid A 1000 kN/m and Geogrid B 1400 kN/m) are used to make this model (Figure 7).The first 3 meters are parallel to the ground and the other 1.5 meters are sloped.

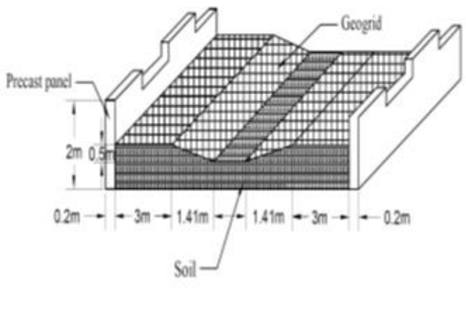

Figure 7: Schematic diagram for the slope model used in this study.

5 Results and discussion

In this study, the effective parameters in the performance of back-to-back geosynthetic reinforced earth walls have been analyzed. For this purpose a geogrid reinforced earth wall with the height of 6 m has been used. The reinforcement length has been considered by FHWA code [33]. The prefabricated blocks of 1.5 m height and 0.2 m thickness have been used as the surfacing elements (Figure 2). Hence, in this study anumber of walls were constructed using different materials (Table 2).

5.1 Effect of reinforced soil friction angle

Figure 8 shows the effect of the friction angle for 3 different unit weights and tensile strengths at maximum horizontal displacement. As it is seen from Figure 8, the maximum horizontal displacements decrease with the increase in the internal friction angle. With the increase in the angle of internal friction, the geogrid length has a more limited effect, so that for the angles more than 38° the maximum horizontal displacement for the two 3.5 and 4.5 m lengths has been close to each other. The increase in the geogrids' tensile strengths caused the maximum horizontal displacement to decrease, but for the angles higher than 38° this difference was very slight. Using more geogrid tensile strength has limited the effect of the length in the wall performance. The increase in the unit weight has caused increase of the maximum horizontal displacement. Also, with the increase in friction angle, the increase in unit weight has less effect on the horizontal displacement of the wall so that the difference has been decreased for the angles higher than 40 degrees.

In general, the friction angles greater than 40° have produced better performance of the wall and for the angles higher than 40° the geogrid tensile strength and its length has limited impact on the horizontal displacement. For example, using an angle of internal friction of 40° for the specific weight of 16 kN/m^3 for the two 3.5 and 4.5 m lengths had about 0.2% difference in the maximum horizontal displacement. Also, the tensile strength of 1400kN/m in stead of 1000 kN/m for the 4.5 m length caused a difference of about 0.11% in the maximum horizontal displacement. It appears that it would be possible to use the angles of internal friction higher than 40° mentioned in this paper to benefit from geogrids of 3.5 m length and 1000 tensile strengths. This will result in a savings of about 11 m in the geogrid length in the wall.

Figure 9 shows the normalized graph of maximum vertical displacement (settlement) as per the angles of internal friction. With the increase in the angle of internal friction, the settlement is lowered so that this decrease for the friction angles higher than 40° has been considerably increased. For the angles of friction greater than 40° the settlement difference for the two 3.5 and 4.5 m lengths has been quite close and has sometimes been almost equal.

With the increase in the geogrid tensile strength, the maximum vertical displacement has decreased; such decrease has been lowered with the increase in the angle of internal friction of the soil and for the angles of friction higher than 40° the geogrid tensile strengths value has limited effect in settlement. It should be noted that with the increase in the strength and angle of internal friction value, the length will have lesser effect in the maximum settlement so that for the angles higher than 40° such difference for the 3.5 and 4.5 m lengths is very limited and sometimes almost equal. The increase in the amount of specific weight has caused the settlement increase. But the point is that such increase is limited by the increase in the angle of internal friction. With respect to the results obtained from Figs. (8 and 9), friction angles higher than 38° have caused favorable performance of the wall in maximum deformation. Also, the use of greater angles of internal friction has caused shortening of the reinforcement length and the tensile strengths.

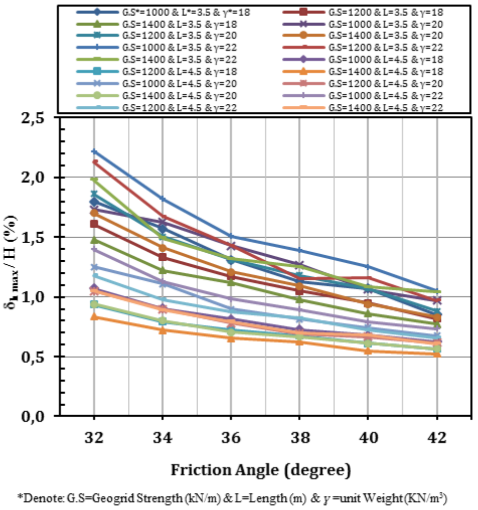

Figure 8: Effect of friction angle in Horizontal displacement.

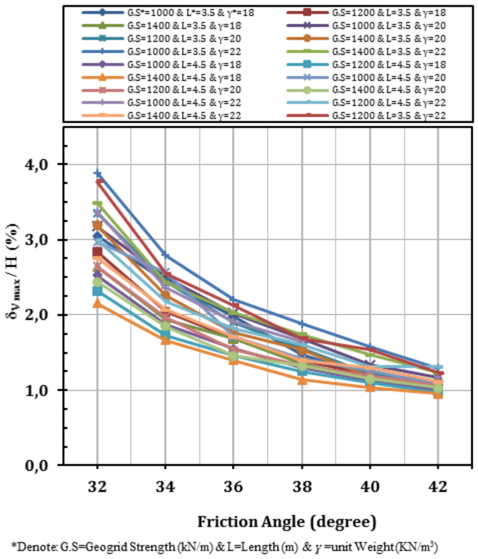

Figure 9: Effect of friction angle in vertical displacement.

5.2 Cohesion

Figure 10 represents the maximum horizontal displacement for the two lengths and three different cohesion values as per the angles of internal friction. As the cohesion tends to increase, the maximum horizontal and vertical displacement of the wall is decreasing (Figure10, 11). Also, the increase in the cohesion value caused decrease of the geogrid length effect, thus for the angles greater than 40° the maximum vertical and horizontal displacement values for the two 3.5 and 4.5 m lengths got very close to each other.

With the increase in the cohesion value to 5kN/m² the difference of maximum horizontal displacement value for the angles of internal friction has become considerable. However, the difference is less for the angles greater than 40° (Figure 10). Using more cohesion of material has caused the length of geogrid to have lower effect in maximum displacement of the wall, so that for the angles of internal friction greater than 40° the difference of results for the two 3.5 and 4.5 m lengths was very slight or there was almost an overlap between the two. In general, using sandy material with higher cohesion percentage has caused better performance of the wall; also, by the increase in the cohesion value for the angles of internal friction of more than 40° the results relevant to two lengths, 3.5 and 4.5 m have come closer to each other (Figure 10, 11).

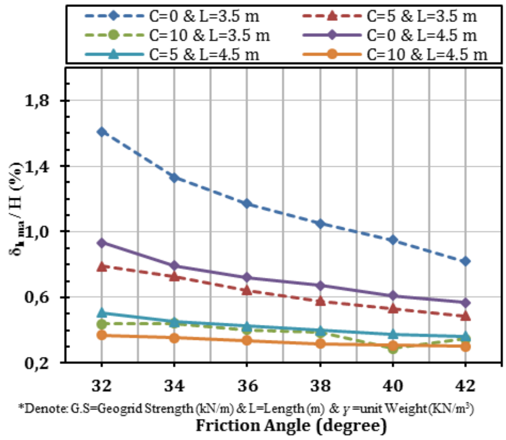

Figure 10: Horizontal displacement of wall for various friction angle and cohesion.

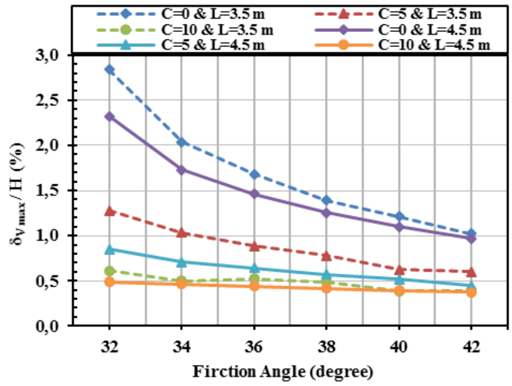

Figure 11: Vertical displacement of wall for various friction angle and cohesion.

This means decrease in the geogrid length, so that using the sand materials with 5kN/m² and friction angle of 40° has caused a difference of about 0.12% between the results of two 3.5 and 4.5 m length values and decrease of the geogrid length for about 11 m along the wall length.

5.3 Performance of reinforced earth wall using step model

Materials with higher angle of internal friction resulted in the decrease of the maximum horizontal and vertical displacements for all models. In stepwise model the utilization of materials with greater angle of internal friction and cohesion has caused closeness of the results compared with the normal state. Tensile strength of the geogrid plays a significant role in decreasing the maximum horizontal and vertical displacements in stepwise model application (Figure 12, 13).

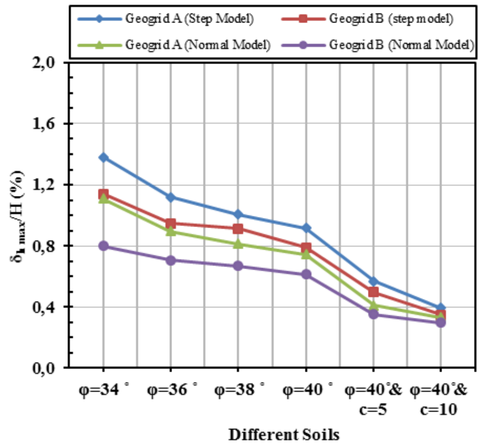

Figure 12: Horizontal displacemet for step model and two geogrids.

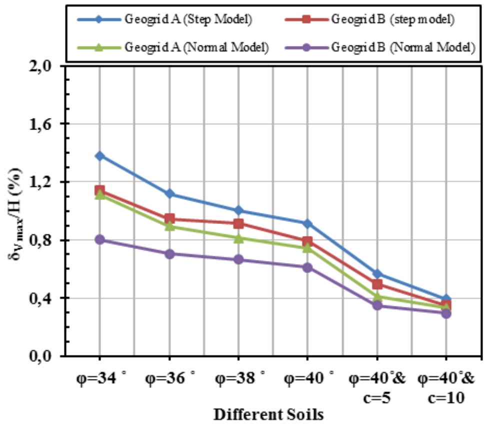

Figure 13: Vertical displacemet for step model and two geogrids.

5.4 Performance of reinforced earth wall using slope model

The results show that the maximum horizontal does not show a constant trend by increasing the slope of the layers of geogrid; however, these changes are less and in some states equal in materials with higher angle of internal friction and cohesion. Therefore, it is possible to illustrate that the changes in slope angles in higher angle of internal friction have less effect on the wall performance.

Also, higher angle of internal friction made the sloped model results closer to the normal model and the sloped model for β=11.4 geogrid A or for β=11.4 geogrid B against normal model; horizontal displacements differ by about 0.065% and 0.055%, respectively (Figure14).

As the tensile strength of geogrid increases, the horizontal displacement decreases and for friction angle larger than 38 degrees and cohesive sand, the tensile strength does not significantly affect the results, thus the results for two geogrids A and B differ by about 0.04% (Figure 14). The slope model has little effect on the materials settlement behind the wall and provides the results for different slopes very close to each other. But the settlement for geogrid A is less than the normal model by about 0.02% (Figure 15). It should also be noted that geogrid B achieved 0.01% smaller settlement with cohesive materials than in the normal conditions.

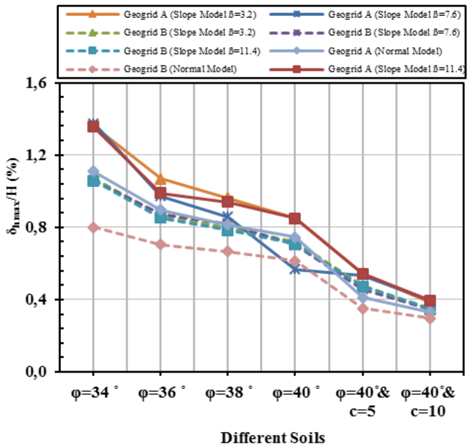

Figure 14: Effect use of Slope model in maximum horizontal deformations.

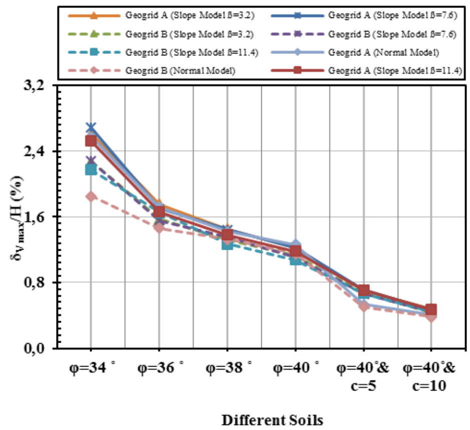

Figure 15: Effect use of Slope model in maximum vertical deformations**.**

Figure 16 and 17 shows horizontal and vertical displacement for sloped model in β=11.4° and two geogrid strengths A and B compared to other models (stepwise and normal mode).In all cases, the slope model leads to a better performance but for clayey sand and materials with more friction angle the results are closer together. Geogrid strength caused decrease in displacement of wall but the trend for cohesive sand is decreasing. Therefore, using desirable materials can utilize geogrid with less tensile strength.

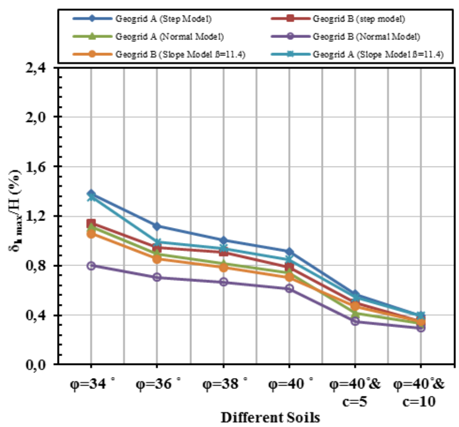

Figure 16: Effect of different suggested model in maximum horizontal deformations.

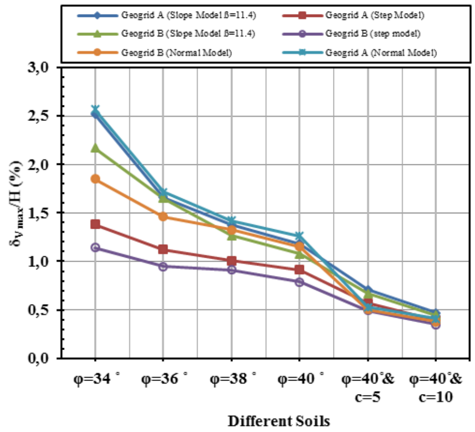

Figure 17: Effect of different suggested model in maximum vertical deformations.

5.5 Use of different soil in various layers

In this section, the reinforced soil walls using material with different layering is studied. Its purpose is to optimally use the material and to reduce the wall construction cost. To achieve this goal, the materials available in Hormozgan province and Hajiabad city were tested. Characteristics of these materials are described in Table 4.

In order to obtain the optimum state and desirable performance of wall, the Hajiabad's material, sand material with internal friction of 40 degrees and three other materials including Dense Sand, Silty Sand and Clayey Sand are used in 4 layers with 1.5 m thickness (Table 5, Figure 5).

Figure 18 shows the maximum horizontal displacement of reinforced soil walls for two tensile strengths of 1200 kN/m and 1600 kN/m and seven types of embankments. For the two states of Main Model (models with out cohesion and granular materials with friction angle of 40 degree) and Hajiabad the constant material throughout the wall height is used and for the five other types (E1–E5) the different layers with 1.5 m thickness are employed.

Using the materials available in Hajiabad results in large displacement of the wall, which is about 50 mm more than the main model with 0.76% difference. But when using the geogrid with more tensile strength, this difference will be halved.

Two embankments (E1 and E5) have the best performance among the other backfills and the difference between these two types of embankments has decreased tensile strength and is about 0.05%.

As indicated, in Figure 18, the E1 and E5 have smaller displacement than the Main Model (when using the granular materials), while the three other suggested embankments (E2, E3 and E4) caused more values in comparison with the main model.

Using the locally available materials (Hajiabad) results in large settlement behind the wall which differs from the main model by about 1.5 %; also, there is no significant change in the results by increasing the tensile strength. Back fills E1 and E5 have smaller settlement than the other embankments so that the E1 embankment has experienced smaller settlement compared to E5 embankment by about 0.2%. Increasing the tensile strength does not result in any significant change (Figure 19).

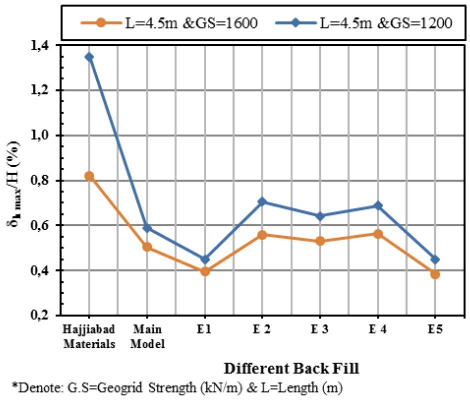

Figure 18: Maximum horizontal displacement for layered model.

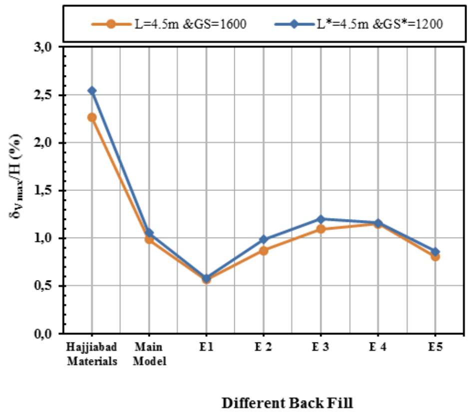

Figure 19: Maximum vertical displacement for layered model.

Figure 20 shows the safety factor for different models. Using Hajiabad's material results in safety factor of about 0.8, while it is 1.4 when using the main model and two geogrid types. The use of layered materials in embankments increased the safety factor for all models except E3. The greatest safety factor is related to E1. When using the tensile strength of 1600 kN/m, the safety factor is increased by about 0.2 (Figure 20).

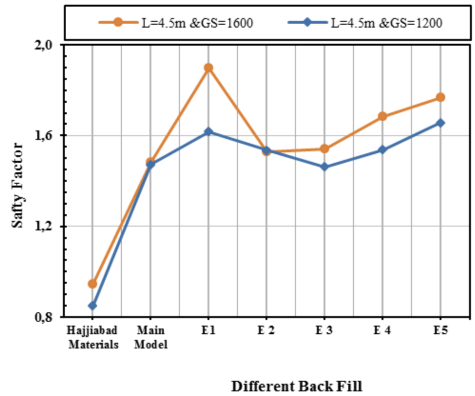

Figure 20: Safty factor for layered model.

Accordingly, the obtained results in this section used materials in different layers that caused higher performance of wall and less horizontal and vertical displacement than the main model and the safety factor is also increased.

It seems that employing different materials (for example E1) can optimize the wall and consequently reduce the construction costs because 1.5 m of the wall height in this study is produced from locally available materials.

5.6 Permissible displacement

Performance criteria for MSE structures with respect to design requirements are governed by design practice or codes such as FHWA,2009. With respect to lateral wall displacements, no method is presently available to definitively predict lateral displacements, most of which occur during construction. The horizontal movements depend on compaction effects, reinforcement extensibility, reinforcement length, reinforcement-to-panel connection details, and details of the facing system. A rough estimate of probable lateral displacements of simple structures that may occur during construction can be made based on the reinforcement length to wall-height ratio and reinforcement extensibility as shown in Figure 21 [40].

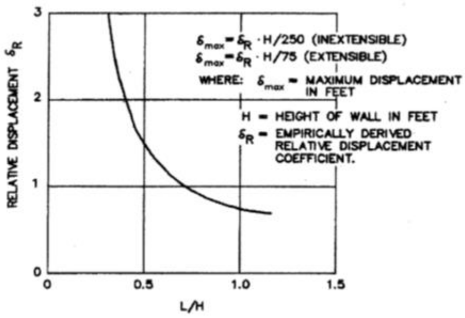

Figure 21: Empirical curve for estimating lateral displacement during construction for MSE walls (after FHWA RD 89-043 {Christopher et al. 1990})[40].

6 Conclusion

In the present study the influence of backfill, strength properties and reinforcement-soil stiffness on the performance of reinforced soil retaining walls under working stress conditions (end of construction) is investigated using a numerical model (Finite element method). The analyses presented in this paper led to the following major conclusions:

1. Friction angle of materials is one of the most important parameters in the wall performance. Less tensile strength and length can be used with more internal friction angle. Also, increased friction angle may reduce the adverse effects of materials specific unit weight increase,
2. Unit weight increase leads to an increased wall displacement and this increase reduces the effect of decreased displacement caused by geogrid tensile strength and adhesion,
3. Using materials with friction angles greater than 38 degrees and more adhesion leads to higher wall performance and decreases the tensile strength effect and geogrid length. Therefore, using such material may help reducing tensile strength and geogrid allowable length,
4. Building a wall with embankments in different layers with a height of 1.5m using in situ materials causes better performance than using only one kind of material. The use of materials different layers leads to the economization of the design and the reduction of the length of the geogrid,
5. The suggested model in different layers causes less horizontal and vertical displacement and increases in safety factor. Thus when materials are used in various layers the performance of wall is better and the design is more optimized,
6. The proposed sloped model has more favorable result than the stepwise model. The material type and geogrid~~s~~ tensile strength have important role in stepwise system.

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