Dirençlilik Dergisi
4(1), 2020, (117-128)
ISSN: 2602-4667
DOI: 10.32569/resilience.632301

Resilience Journal
4(1), 2020, (117-128)
ISSN: 2602-4667

-Araştırma Makalesi-

Farklı Dolgu Malzemesine Sahip Donatılı İstinad Duvarlarının Performanslarının Değerlendirilmesi

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Öz

İstinat duvarlarının yıkılması ölüm ve yaralanmalara yol açabilmektedir. İstinat duvarlarının yıkılması çevredeki binalara, araçlara ve altyapıya zarar vermekte ve ekonomik kayıplara yol açmaktadır. Bu nedenlerle, geosentetik donatılı istinat duvarlarına olan ilgi, bu yapıların sağladığı avantajlardan dolayı artmaktadır. Donatılı istinat duvarları hafif oldukları için deprem yükleri altında daha iyi performans sergilemektedirler. Ancak, bu yapıların tasarım ve inşası sırasında gerekli önlemler alınmazsa olumsuz sonuçlar ortaya çıkabilmektedir. Kullanılacak olan dolgu malzemesinin seçimi de oldukça önemlidir. Ekonomik olarak daha uygun olması nedeniyle tüm dünyada inşa sırasında şantiyede bulunan kohezyozlu zeminlerin kullanımı oldukça yaygındır. Kullanılan kohezyonlu zeminler ise donatılı duvarın karakteristiklerini oldukça etkilemektedir. Bu çalışmada, farklı zemin türlerinin geosentetik donatılı duvar dolgusu olarak kullanıldığı zaman, geosentetik donatılı duvarın performansına olan etkileri incelenmiştir. Bu nedenle kum ve kil tipi zeminler ile bunların karışımından elde edilen farklı tipteki zeminlerin gerekli özellikleri laboratuvar ortamında belirlendikten sonra, geosentetik donatılı istinat duvarları sonlu elemanlar yöntemi ile modellenmiştir. Karışımlar hazırlanırken, farklı zemin tipleri elde edebilmek için kum ile karıştırılan kil miktarı her bir karışım için %20 arttırılmıştır. Geosentetik donatılı istinat duvarlarının performansları ise yatay düzlemde meydana gelen yer değiştirme, oturma ve donatı üzerinde meydana gelen en yüksek kuvvet miktarları bulunarak değerlendirilmiştir.
Anahtar Kelimeler: Donatılı istinat duvarı, yer değiştirme, oturma

Performance Analysis of Geosynthetic Reinforced Earth Walls With Different Backfils by Finite Element Method

Abstract

Failure of retaining walls may cause loss of lives and injuries. Failure of retaining walls also has economical effects because of damaged buildings, infrastructure and vehicles. There have been some devastating cases regarding failure of retaining wall. Therefore, interest for construction of reinforced earth wall has increased in recent years due to several advantages they provide. Reinforced earth wall is more economical than ordinary retaining walls. They are lightweight structure which affects their earthquake performance positively. However, if necessary attention has not paid during design and construction, similar events may occur. Selection of backfill material is also important. In order to build an economical reinforced earth wall, constructors tend to use available soil on site instead of clean sand which changes behavior and performance of the reinforced earth wall significantly. Performance of geosynthetic reinforced earth walls is investigated in this study to find out effects of different soil types used as backfill. Locally available sand and clay is obtained for this purpose. Sand and clay is mixed at different proportions. Amount of clay is increased by 20%. Strength parameters of each mixture are determined by direct shear test. Experimentally computed Mohr-Coulomb material model parameters are used in finite element analysis. Performance of geosynthetic reinforced earth wall is evaluated by considering horizontal deformations, settlement, maximum forces acting on geotextile and its position.
Keywords: Reinforced earth wall, horizontal displacements, settlement

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Gönderim Tarihi / Received Date: 12.10.2019
Kabul Tarihi / Accepted Date: 11.06.2020

Bu makaleye atıf yapmak için- To cite this article
Balaban E. , Šmejda A., Onur M. İ. (2020). Farklı Dolgu Malzemesine Sahip Donatılı İstinad Duvarlarının Performanslarının Değerlendirilmesi. Resilience, 117-128..

1. INTRODUCTION

Construction of reinforced earth walls are getting more popular day by day. It is easier to construct reinforced earth walls. They are lightweight retaining structure when compared with traditional concrete retaining walls. However, as in traditional retaining walls, codes used to design reinforced earth walls by limiting content of fine particles of backfill. However, it may be seen that, backfill with a fine particles are used during construction of reinforced earth walls. The reason of using backfill with a fine particle is either economical or the construction site is in a remote area. Using cohesive backfill might yield to failure of reinforced earth wall which may result in either loss of lives or economic loss. Therefore, understanding behavior of reinforced earth walls with cohesive backfill is quite important in order to prevent failures during service life. Numerous researchers were studied the effect of cohesion up to limited values. Riccio et al. (2014) investigated behavior of reinforced earth wall constructed with a fine grained tropical soils. The wall is monitored for two months. Same wall is modelled using finite element method. Tension on reinforcement, load on instrumented block, vertical displacement, horizontal displacement and vertical stresses at wall base are measured. Researchers have drawn attention to the significant effect of cohesion of backfill. Increase of strains on geosynthetic observed when cohesion increases. Lopes et al. (2015) Conducted flume tests on walls which are used to protect saltpans from tidal effect of ocean. Walls are constructed by using traditional methods and reinforcements with fine backfill. It is concluded that, walls constructed with traditional methods are more stable than reinforced walls. Yang et al. (2012) conducted a study to determine the performance of reinforced earth with lime treated cohesive backfill. They concluded that, vertical pressures and lateral earth pressure decreases by time. This behaviour is attributed to strength gaining of lime treated cohesive backfill with time. Strains on reinforced remained constant by time. Liu et al. (2009) studied long term behaviour of reinforced earth wall constructed with marginal soil. Reinforced earth wall with 8 meter height is modelled for this study. Creep parameters of backfill soil and reinforced soil is varied. It is found out that, with constant creep rate of reinforcement, increasing creep rate of backfill resulted, increased lateral displacement of facing and reinforcement loads. If soil creep is lower than reinforcement creep, load is transferred to the soil which yield stress relaxation of reinforcement. While keeping soil creep rate constant, increasing reinforcement creep yields increased wall deformation. It also yields higher stress over the soil. Haddad and Shafabakhsh (2008) investigated possible reasons of failure of reinforced earth wall. In order to determine strength parameters samples are gathered. After that, wall is modelled in FEM programme. It is found out that backfill soil has significant amounts of fines which caused low permeability. FEM analysis showed that reinforcements have low factor of safety against pull – out capacity and rupture. Slope – stability analysis also yielded to low factor of safety for wet case which might led to failure. Rowe and Li gathered information about failed reinforced earth wall from the literature and classified them according to reasons. It is said in this study that, strains over reinforcement and creep forces are higher when clay is used as backfill. Post construction strains are higher in case of clay backfill. Koerner and Koerner (2011) focused on possible applicable drainage systems into reinforced earth walls, which are constructed using fine backfill soil. Several possible solutions for proper drainage of water are explained with their schematic drawings and reasons. Koerner and Soonb (2001) stated that, FHWA permits fine content in backfill up to 15% and NCMA up to 35% with PI equal to six. However, it is found out that, even these values may cause failure or extreme deformation of wall during the rain. Carlos and Lopes (2011) compared two differed design methods used in Aveiro Lagoon of Portugal. One of those methods rules out contribution of cohesion while another one does not. It is concluded that, the design method which rules out effect of cohesion yields more conservative results. Viswanadham et al. (2017) investigated the behaviour of geogrid reinforced walls subjected to seepage with and without chimney sand drain. They have concluded that, using high stiffness geogrid and chimney sand drain significantly improved horizontal displacement of wall facing. They also mentioned that, using chimney sand drain with low stiffness geogrid decreases pore water pressure. Zheng et al. (2018) conducted a parametric study on geosynthetic reinforced soil bridge abutments. Effects of geogrid reinforcement, backfill soil and abutment geometry is considered on reinforcement tensile forces at service load condition and failure condition. Researchers stated that, geogrid reinforcement parameters have little effect on Y-shaped locus of maximum tensile forces when no secondary reinforcement included, backfill soil strength parameters have moderate effects and abutment geometry parameters significant effect. Chen et al. (2018) proposed a 3D rational failure mechanism based on kinematic approach of limit analysis in order to assess stability of geosynthetically reinforced earth walls with cohesive backfill. They also considered 3D effects and pore water pressures to required reinforcement strength during design. They concluded that, required reinforcement strength increases as cohesion decreases, pore water pressure increases. Udomchai et al. (2017) analyzed a full scale bearing reinforcement earth wall with claystone backfill to propose a practical design method. Portelinha et al. (2013) investigated behaviour of reinforced earth wall constructed with non-woven geotextile using fine grained backfill under wetting conditions. They stated that, non-woven geotextiles are useful to reinforce fine grain soils under wetting conditions because they provide internal drainage. Therefore, non-woven geotextiles prevents from positive pore water pressures. Sukmak et al. investigated the horizontal displacements, bearing stress, settlement and lateral earth pressure of bearing reinforced earth walls. They have concluded that, as clay content increase, horizontal movements increase.

Although some studies are conducted related to reinforced earth wall with cohesive backfill, very few of them included transformation of behaviour of reinforced earth wall. Also, forces acting on the reinforcement is almost disregarded in the literature. Therefore, in order to determine the change of performance of geosynthetic reinforced earth walls with increasing cohesive part of the backfill, horizontal displacements of wall face and retained soil, settlement, pressure on foundation and maximum forces acting on reinforcement are considered. Analytical results are compared with the finite element model results.

2. ANALYTICAL DESIGN OF REINFORCED EARTH WALL ANALYSIS

Design of reinforced earth walls consists of two stages. First stage is called as external design and the second stage is called as internal design. In case of external design, safety of structure is determined by considering acting moments, resistive moments, sliding forces and resistive forces against sliding, eccentricity and maximum pressure to be exerted to foundation. When external design is completed, internal design is considered. In case of internal design, maximum horizontal force which will be carried by reinforcement determined and compared with the pull-out resistance. Pull – out resistance can be defined as the maximum force which can be transmitted to soil from reinforcement. Analytical analysis is conducted according to federal highway administration (FHWA) method.

In order to conduct this study, six different geosynthetic reinforced soil types are considered, while only one retained soil and foundation layers are considered. One type of reinforcement is also selected. Wall height is assumed to be 6 meters and length of reinforcement is equal to 6 meters. Backfill soils are varied from sand to clay by increasing clay content 20% in each case. Required material model parameters are determined by conducting laboratory tests. Standard proctor tests are conducted in order to determine unit weights of mixtures. Remaining material properties are determined by conducting direct shear tests. Unit weights and strength properties used in this study are provided in Table 1 below. φ, γ, c and E represents angle of friction, unit weight, cohesion and elasticity modulus in degree, kN/m^3, kPa and MPa respectively.

Table 1. Material properties of soils' used in finite element study

	Reinforced Fill				Retained Soil				Foundation Soil - 1				Foundation Soil - 2			
	φ	γ	c	E	φ	γ	c	E	φ	γ	c	E	φ	γ	c	E
Sand	47.4	17.4	0.5	64.02	20	15	1	15	20	15	1	15	20	18	35	60
%80 Sand + %20 Clay	42.4	20.7	11.6	55.72	20	15	1	15	20	15	1	15	20	18	35	60
%60 Sand + %40 Clay	41.2	20.5	24	90.22	20	15	1	15	20	15	1	15	20	18	35	60
%40 Sand + %60 Clay	38.8	20.6	25.8	59.48	20	15	1	15	20	15	1	15	20	18	35	60
%20 Sand + %80 Clay	36.5	20	34.4	85.54	20	15	1	15	20	15	1	15	20	18	35	60
Clay	32.4	18.5	37.7	85.67	20	15	1	15	20	15	1	15	20	18	35	60

2.1 External Design

In case of external design, sliding and resisting forces are computed. Dividing these force to each other gives capacity-demand ratio (CDR). If CDR is higher than 1 than the structure is considered safe against sliding. In case of sand and backfill CDR for sliding is calculated as 4.2 and 4.47 respectively. CDRs for all backfill soil types are provided in Table 2 below.

Table 2. Driving, Resistive Forces and CDR against sliding for different backfill types

	Driving Force (kN)	Resistive Force (kN)	CDR
Sand	86.02	361.65	4.2
80% Sand	86.02	430.24	5
60% Sand	86.02	426.08	4.95
40% Sand	86.02	428.16	4.98
20% Sand	86.02	415.69	4.83
Clay	86.02	384.52	4.47

When overturning moments are considered, it is seen that, overturning moments are equal to each other for all backfill types. This is due to that, forces creating overturning moments are same in all cases. However, resistive moments changes with respect to backfill type. In case of sand backfill resistive moment is calculated as 2070.25 kNm while it equals to 2189 kNm for clay backfill. Overturning and resistive moments are provided in Table 3 below.

Table 3. Overturning, Resistive Moments and CDR for different backfill types

	Overturning Moment (kNm)	Resistive Moment (kNm)	CDR
Sand	193.85	2070.25	10.68
80% Sand	193.85	2426.65	12.52
60% Sand	193.85	2405.05	12.41
40% Sand	193.85	2415.85	12.46
20% Sand	193.85	2351.05	12.13
Clay	193.85	2189.05	11.29

The last stage of external design consists of determination of eccentricity of reinforced wall and maximum pressure which will be exerted to foundation. Maximum pressure on foundation for sand and clay backfill is found as 171.06 kPa and 179.33 kPa respectively. Calculated eccentricity and pressures are given in Table 4 below.

Table 4. Calculated Eccentricity and Exerted Pressure for Different Backfill Types

	Eccentricity (m)	Limiting Eccentricity (m)	Exerted Pressure (kPa)
Sand	0.26	1.5	171.06
80% Sand	0.23	1.5	197.67
60% Sand	0.23	1.5	196.06
40% Sand	0.23	1.5	196.87
20% Sand	0.23	1.5	192.03
Clay	0.25	1.5	179.93

2.2 Internal Design

Internal design of reinforced earth walls consist of determining maximum force on reinforcement and comparing it if it can be transmitted to soil safely. Calculations showed that the highest forces are developed in case of sand backfill. The maximum forces computed for all backfill types are provided in Table 5 below.

Table 5. Calculated maximum forces on each reinforcement layers

Sand	%80 Sand	%60 Sand	%40 Sand	%20 Sand	Clay
F_h	F_h	F_h	F_h	F_h	F_h
1.95	-5.65	-25.29	-16.92	-24.63	-29.56
2.02	-2.68	-15.72	-10.01	-15.05	-18.20
2.59	-1.80	-14.81	-8.99	-13.95	-17.00
3.16	-0.93	-13.90	-7.97	-12.86	-15.79
3.73	-0.06	-12.99	-6.95	-11.76	-14.58
4.30	0.81	-12.08	-5.93	-10.66	-13.38
4.88	1.68	-11.16	-4.91	-9.57	-12.17
5.45	2.56	-10.25	-3.89	-8.47	-10.97
6.02	3.43	-9.34	-2.87	-7.37	-9.76
6.59	4.30	-8.43	-1.85	-6.27	-8.56
7.16	5.17	-7.52	-0.83	-5.18	-7.35
7.73	6.04	-6.61	0.19	-4.08	-6.14
8.31	6.91	-5.70	1.21	-2.98	-4.94
8.88	7.79	-4.78	2.23	-1.89	-3.73
4.65	4.22	-2.05	1.50	-0.53	-1.41

Since, all the maximum forces are calculated, pull – out resistance should also be calculated and compared with the forces. After calculations it is seen that, the highest pull-out resistance occurs on sand backfill and decreases as the clay content increases. Pull – out resistances are given on Table 6 below.

Table 6. Pull-out resistance for each type of backfill

Sand	%80 Sand	%60 Sand	%40 Sand	%20 Sand	Clay
25.14	23.19	21.62	19.18	16.39	11.98
52.33	48.70	45.51	40.58	34.86	25.76
81.58	76.53	71.67	64.18	55.41	41.34
112.88	106.68	100.10	90.00	78.04	58.72
146.24	139.16	130.79	118.04	102.75	77.89
181.66	173.96	163.76	148.28	129.54	98.87
219.13	211.08	198.99	180.74	158.41	121.65
258.66	250.52	236.49	215.42	189.36	146.23
300.24	292.29	276.26	252.30	222.38	172.61
343.88	336.37	318.30	291.40	257.49	200.80
389.57	382.78	362.61	332.71	294.68	230.78
437.33	431.51	409.19	376.24	333.94	262.56
487.13	482.57	458.03	421.97	375.29	296.14
539.00	535.95	509.15	469.92	418.71	331.52
592.91	591.64	562.53	520.09	464.21	368.70

When the calculations are compared, it is seen that pull-out resistances are higher than maximum reinforcement loads. Therefore reinforced earth walls can be said as safe structures.

3. FINITE ELEMENT MODEL

Plaxis software is used in order to create finite element models. Finite element model is created by using four different soils such as reinforced soil, retained soil, foundation layer 1 and foundation layer 2. General view of finite element model is given on Figure 1 below.

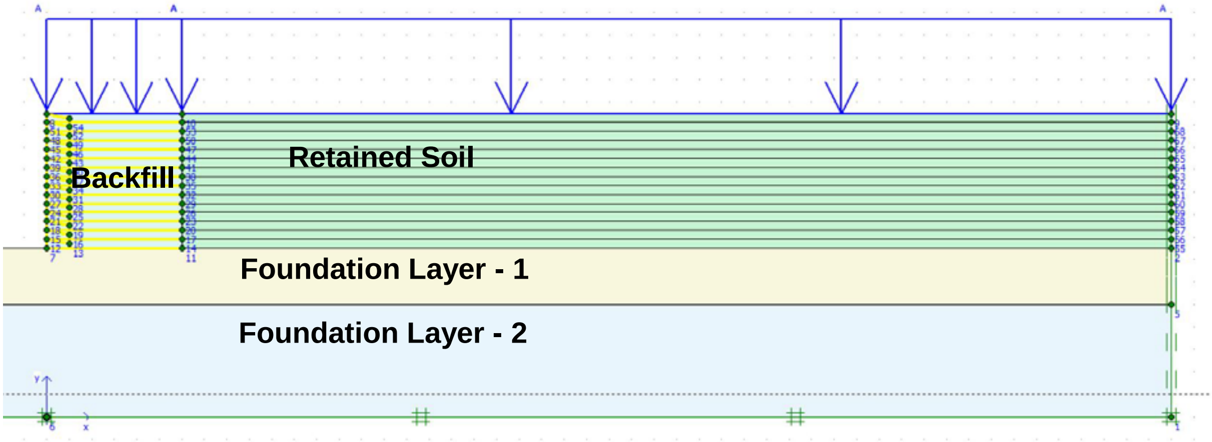

Figure 1. General view of finite element model

Mohr – Coulomb material model is selected in order to determine deformation characteristics of geosynthetic reinforced earth walls. Material parameters of other structural elements are chosen arbitrarily and kept constant throughout the study. Material properties are given in Table 1. Thicknesses of first foundation and second foundation layers are chosen as 2.5 meter and 5 meter respectively. Height of the wall is chosen as 6 meters for all cases. Stiffness of geosynthetic is chosen as 1048 kN/m. Wall face is assumed to be wrap around facing which is created by using geosynthetic. Surcharge load is calculated as 10.6 kN/m according to federal highway administration (FHWA) method. Distance between two consecutive geosynthetic layers are chosen as 0.4 meters which is defined as maximum distance by FHWA. Width of finite element model is carefully selected to eliminate boundary effects. Plane strain model is used during modelling process and 15 nodes elements with 14631 nodes and 21468 stress points. Average mesh size is computed as 0.868 meter.

4. RESULTS

Outcomes of the finite element analysis are presented in this sections. Performances of geosynthetic reinforced earth walls are assessed by comparing the horizontal displacements of wall face's, horizontal displacement of retained soil, settlements, forces acting on foundation, forces acting on reinforcements.

4.1 Horizontal Displacements at Wall Face

When horizontal displacements of different backfills are considered, the lowest displacements are computed for sand backfill when surcharge load is not applied. If computed horizontal displacements are compared with each other, the horizontal displacements can be put in order for cases whose backfills contains 80% sand content, 60% sand content, 40% sand content, 20% sand content, clay and pure sand from highest to lowest horizontal displacement. Displacements increase linearly with respect to increase of wall height. The highest and the lowest displacements at the top of the wall are computed as 144.98 mm and 86.92 mm respectively. Change of horizontal displacements are provided on Figure 2 below.

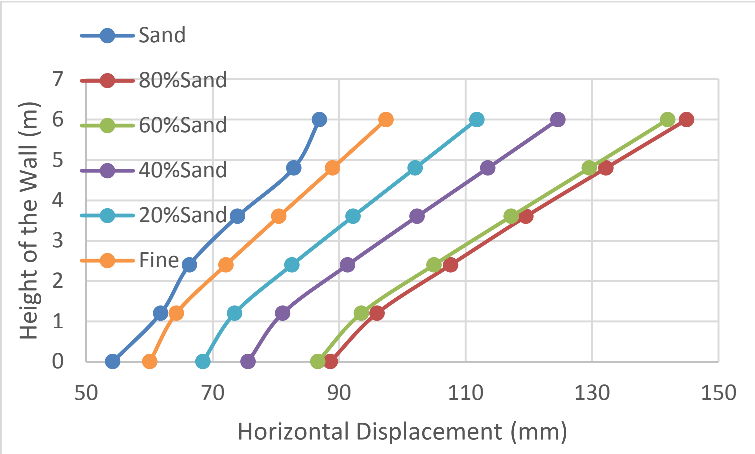

Figure 2. Horizontal displacement of wall face for different soil types without surcharge load

If the results obtained from this study is compared with results from the literature it is seen that, created finite element models captures the behavior very well. Horizontal displacements are reported as between 35 mm and 97 mm for height of 6 meter reinforced earth wall (Liu, 2012, Damians et al., 2014) without presence of surcharge load. It should be remembered that, horizontal displacement of reinforced earth wall is highly dependent on height of the wall, backfill properties, length of reinforcement and stiffness of reinforcement. Therefore, 35 mm horizontal displacement is reported for 2 meter height reinforced earth wall (Yoo and Jung, 2004), 70 mm horizontal displacement is reported for a wall 4 meter height with fine grained tropical soil (Riccio et al., 2014).

When surcharge load is applied to walls, displacements still increase linearly with respect to height of the wall. However, application of surcharge load changes order of magnitude of horizontal displacements. The order changes to 80% sand, 60% sand, 40% sand, 20% sand, pure sand and clay from the highest to the lowest. The highest and the lowest horizontal displacements increase to 472.16 mm and 366.62 mm respectively. Computed horizontal displacements under surcharge load is given in Figure 3 below.

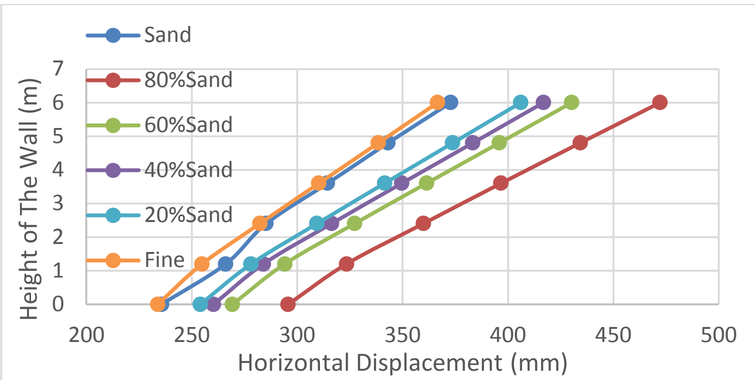

Figure 3. Horizontal displacement of wall face for different soil types with surcharge load

4.2 Horizontal Displacements of Retained Soil

Horizontal displacements of retained backfill increases with height, however decrement is seen at the surface for all type of backfills. The computed horizontal displacements can be put in order as sand, clay, 20% sand content, 40% sand content, 80% sand content and 60% sand content from the highest to the lowest respectively. The computed displacements at the bottom of the wall are equal to each other for 80% sand, 40% sand and 20% sand contents. Change of horizontal displacement of retained soil for without surcharge case is given in Figure 4.

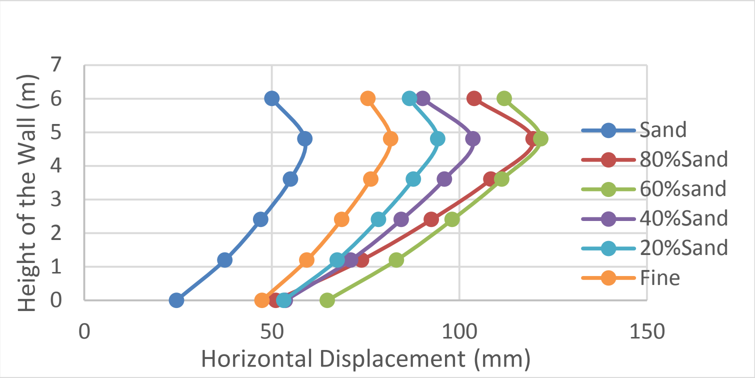

Figure 4. Horizontal displacement of retained soil for without surcharge load

When surcharge load is applied, the highest displacement is calculated for 80% sand content and 60% sand content. The order remains for other sand – clay contents as mentioned above. The decrease of horizontal deformation is reduced or even vanishes for clay, 20% sand and 60% sand contents at the surface when surcharge load is applied. The computed horizontal displacement of retained soil under surcharge load is given in Table 7.

Table 7. Computed horizontal displacements of retained soil under surcharge load

H (m)	Sand (mm)	80% Sand (mm)	60% Sand (mm)	40% Sand (mm)	20% Sand (mm)	Clay (mm)
6	286.81	415.47	395.21	372.99	375.44	339.25
4.8	320.85	424.25	390.10	375.26	367.61	332.57
3.6	294.78	387.43	357.43	344.68	337.94	307.34
2.4	263.59	345.08	321.51	309.69	305.18	279.54
1.2	228.81	297.90	282.92	271.20	270.25	249.99
0	184.76	240.23	236.50	223.11	229.27	214.90

4.3 Settlement of Geosynthetic Reinforced Earth *Wall*

When the settlement of wall is investigated for different soil mixtures, it is found out that, settlement is higher at wall face and decreases linearly as the distance increases from wall face. The highest settlement is computed for 80% sand content and it is followed by 60% sand content, 40% sand content, 20% sand content, clay and pure sand at toe of the geosynthetic reinforced earth wall. However, the settlement computed for 20% sand content is insignificantly higher than 40% sand content at the end of reinforced soil zone. It should also be noted that, computed settlements at the end of reinforced zone are almost equal to each other different backfill type. Application of surcharge load does not change the behavior but increases computed settlements. Change of settlements with respect to different backfill type under surcharge is given in Figure 5.

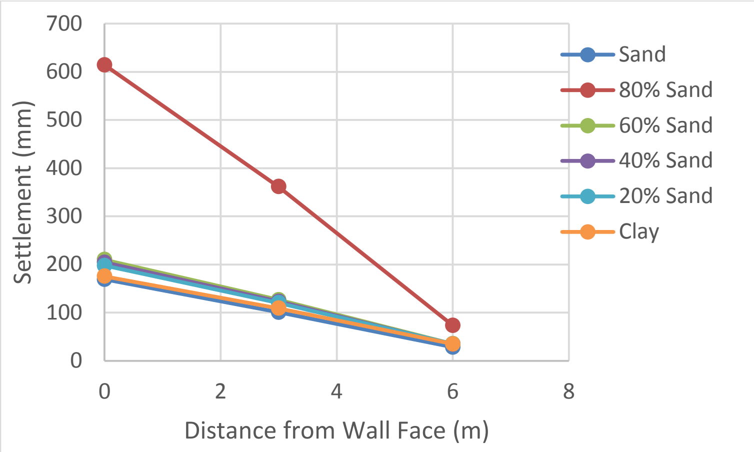

Figure 5. Settlement computed for different type of backfills under surcharge load

4.4 Forces Acting on Foundation

When the forces acting on foundation is investigated it is seen that minimum foundation pressure is computed for sand backfill as 145 kPa without surcharge load. As clay content increased foundation pressures increase up to 170 kPa for 80% sand, 60% sand and 40% sand. In case of 20% sand content and clay backfill, computed maximum foundation pressure decreases to 165 kPa and 160 kPa respectively when surcharge load is not applied to geosynthetic reinforced earth wall. If the surcharge load is applied, computed foundation pressures increases to 180 kPa for pure sand, 200 kPa for 80% sand content, 60% sand content and 40% sand content, 195 kPa for 20% sand content and 180 kPa for clay. It is seen that, surcharge load caused an increase for each type of backfill. However, the highest increment is calculated for sand backfill as 25%. Increment decreased to 18% in case as sand and clay mixtures. The lowest increment is calculated for clay backfill as 12.5%. Pressure distribution over foundation is given for sand backfill in Figure 6.

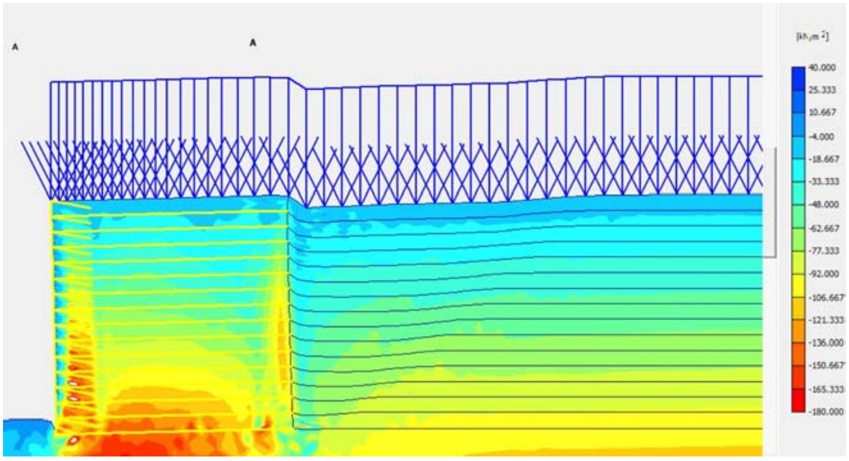

Figure 6. Pressure Distribution Foundation Soil for Sand Backfill

4.4 Forces Acting on Reinforcements

When the computed maximum forces are compared for different sand content in backfill, it is seen that computed maximum forces generally decreases as sand content decreases. However, in some circumstances, higher force is computed with lower sand content. These circumstances can be named as 40% and 20% sand contents for second layer of reinforcement, 80% sand content at 7th layer and 40% sand content for the 15th layer reinforcement. It should be noted here that, computed forces for 80% sand content backfill is higher than computed forces for sand backfill for the bottom four layers of reinforcement. It is also seen that, computed maximum axial forces decrease slightly at 2nd layer reinforcement for 80% sand content, 60% sand content and clay content, at third layer geosynthetic for pure sand, 40% sand content and 20% sand content. Change of maximum horizontal forces on reinforcement may be seen in Figure 7 with respect to height of the wall for without surcharge load case.

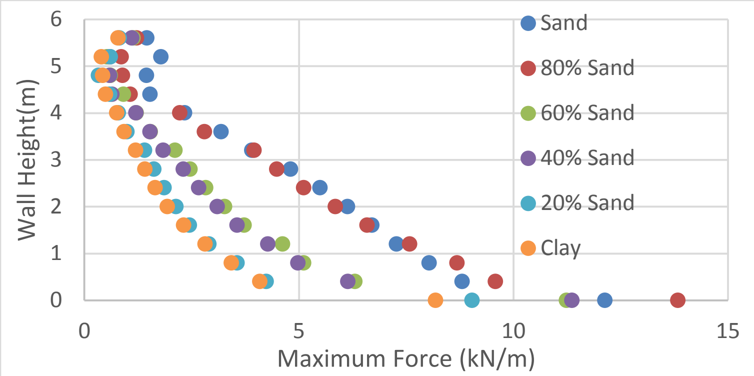

Figure 7. Change of Maximum Horizontal Forces on Reinforcement for Without Surcharge Case

When the maximum horizontal forces of each reinforcement layers is summed up to find resultant forces, the highest resultant force is obtained for sand backfill as 75.04 kN/m. The resultant force decreases as the sand content increases. Resultant forces is given on Table 3 below for all considered backfill types.

When surcharge load is applied to geosynthetic reinforced earth wall, computed maximum horizontal force increases especially at the first layer reinforcement. After the first layer, computed force decreases for the following 2 layer. After that, computed maximum force increases for following layers. The highest maximum forces are computed sand content except for last three layer at the bottom, where the highest forces are computed for 80% sand content. Other than that, higher maximum forces are observed for 40% sand content backfill except for 4th and 7th layer than forces computed for 60% sand content. The highest and the lowest horizontal maximum resultant forces are computed as 98.63 kN/m and 41 kN/m for sand and clay backfills respectively. Maximum horizontal resultant forces are given under surcharge load also on Table 8.

Table 8. Computed resultant maximum horizontal Forces on Reinforcements

	Sand	**80% Sand**	**60% Sand**	**40% Sand**	**20% Sand**	**Clay**
Resultant Horizontal Force (kN/m)	75.04	74.72	47.58	45.87	33.33	30.79
Resultant Horizontal Force (kN/m)	98.63	91.72	59.07	61.22	50.46	41

The highest and the lowest increment of resultant maximum horizontal force due to surcharge load is computed as 23.60 kN/m and 10.21 kN/m for sand and clay backfills respectively.

5. CONCLUSIONS

Behaviour of 6 meter height geosynthetic reinforced earth wall is investigated in this study. Effect clay content inside the backfill is taken into consideration to find out effect of cohesion increment to performance of geosynthetic reinforced earth wall. In order to conduct this study, analytical design of the walls are conducted according to FHWA method. Finite element analysis are made for each case. Horizontal displacement of wall face, horizontal displacement of retained soil, settlement of foundation soil, pressure on foundation soil and maximum horizontal forces are computed by finite element analysis. Following conclusions can be deducted from the results of this study.

- All geosynthetic reinforced earth walls are safe against sliding and overturning according to FHWA method.
- Unit weight of the backfill materials initially increases as the clay content increase. After some threshold value of clay content, unit weight of backfill decreases. Because of this, pressures on foundation also increase and decrease. Higher unit weight of backfill also yields to higher eccentricity.
- The highest maximum reinforcement loads are calculated for sand backfill at each reinforcement layer. Higher cohesion yields lower maximum horizontal force on reinforcement. Calculated maximum horizontal force also depends on the unit weight of the backfill. Therefore, there is not a linear relationship between increasing cohesion and decreasing maximum horizontal force. Pull – out resistance of backfills is higher than maximum horizontal forces in each considered backfill type. Forces calculated by FHWA method and computed by finite element analysis differs from each other only at top and bottom layers. Forces comply with each other at other on remaining reinforcement layers.
- The highest horizontal displacements are computed at the top of the geosynthetic reinforced earth wall. The lowest horizontal displacement is computed for sand backfill when there is not any surcharge load. When surcharge load is applied, the lowest horizontal displacements are computed for clay backfill. Horizontal displacements increases linearly with height of the wall.
- The lowest horizontal displacement values for retained soil is computed when only sand is used as reinforced backfill.
- The most important outcome of this study is that, as the cohesion of backfill increases, maximum horizontal force on reinforcement decreases. The decrement on maximum horizontal force on reinforcements yields higher horizontal deformations of the wall. This is observed, because load transfer mechanism is harmed due to cohesion which resulted higher horizontal displacements and reduced safety of the wall.

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