A Real Approach for Numerical Analysis of the Road Embankments Reinforced by Geocell

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ABSTRACT: Geocells are one types of geosynthetics that have been recently used for soil reinforcement. Because of the unique performance of this type of reinforcement system (high confinement due to the three-dimensional geometry), their application is developing, and extensive studies are being carried out on these systems. Many laboratory studies have been conducted on geocell reinforcement systems, while few studies have been done on numerical analysis of their performance which is necessary for understanding their exact behavior. As a result, theoretical methods and the current design of these systems are less developed than their applications in various fields including road construction. Therefore, the present research aimed to study the performance of geocell reinforcement system in road embankments and the factors affecting it based on the numerical method of finite difference using a real more accurate approach. In addition, the effect of parameters of geocell infilled soil on the performance of these embankments were studied.

Keywords: Reinforced soil, Embankment, Geosynthetics, Geocell, FLAC^{3D}

1 INTRODUCTION

Geocells are one types of geosynthetics that have been recently used for soil reinforcement. Because of the unique three-dimensional geometry, they are able to provide high lateral confinement for its infilled soil and, as a result, significantly improve the strength and stiffness of the soil.

Since the major application of geocell is in road construction, extensive laboratory studies have been conducted in this regard. Yuu et al. (2008) comprehensively reviewed the technical literature on the application of geocell technology. They acknowledged that despite the high efficiency of reinforcement system with geocell, their application in improvement of road embankments is restricted because of inadequate theoretical studies. Edil et al. (2002) created some sections of paved road and studied the impact of geosynthetic reinforcers such as geocell on them. In addition, a study has been carried out on sections of unpaved roads and the results showed that the sections reinforced with geocell have a very good performance in seasonal cycles of freezing and thawing (Henry et al., 2005). Due to the high cost of field studies, some researchers conducted laboratory test of cyclic plate loading for simulation of traffic load (Mhaiskar and Mandal, 1994; Pokharel et al., 2010). However, cyclic plate loading cannot completely apply the loading effect of the wheel of the vehicle on the road surface. To resolve this error, researchers at Kansas State University carried out extensive studies on tests of applying the load of moving wheels on the road (Han et al., 2011; Pokharel et al., 2011; Yang et al., 2011).

Since the beginning of the studies in this field, due to the high cost and limitations of laboratory studies, there has always been a need for numerical studies. As a result, a limited number of studies were conducted by other researchers in the field of geocell reinforcement system. However, most of the numerical studies are based on an equivalent composite model for representing the strength and stiffness of geocell confined soil. In this model, the geocell reinforced soil is replaced by a soil with higher parameters which are selected based on test results performed on geocell reinforced soil. Since these tests have been carried out on limited number of soil specimens, these parameters are expected to be proportional to the same type of soil and generalizing them to other types in these numerical models will be associated with error. In addition, as previously mentioned, geocell has diverse and complex behavioral mechanisms due to its unique three-dimensional geometry that are not fully considered in such modeling.

Hence, the present research aims to model the embankment reinforced with geocell using a more accurate method based on reality in FLAC^{3D} software (modeling the soil and geocell separately), resolve the errors of previous models, and study the factors affecting the behavior and performance of this reinforcement system, including parameters of the soil placed inside the geocell.

2 NUMERICAL MODELING

In the present study, geocell and soil were three-dimensionally simulated separately. This method of simulation has given the capability to the numerical model to fully simulate all key behavioral mechanisms of geocell, in addition to eliminating the errors of composite method. In this method of modeling, the most basic step in the modeling of the geocell reinforced soil is the identification and selection of an appropriate structural element that is able to fully and accurately simulate the geocell behavior and its interaction with the soil.

2.1 *Geocell and its interface with the soil*

In this numerical model, GeogridSEL elastic planar structural elements were used for simulation of geocell reinforcer. GeogridSEL (as one of the three planar elements existed in FLAC^{3D} software) is a membrane element which can resist membrane load but cannot bear the bending load. This element is suitable for modeling the flexible membranes which have shear interaction with soil. Therefore, it is used in this study for geocell simulation. In this modeling, an isotropic linear elastic behavior is considered for Geogrid element and at each geogrid node, the interface behavior is represented numerically by a rigid attachment in the normal direction and a friction-cohesion behaviour in the tangent plane to the geogrid surface.

2.2 *The initial model and verification*

2.2.1 *Reference model*

To verify the numerical model, the soil reinforced with a single geocell and the unreinforced soil were modeled using FLAC^{3D} software. This model, in fact, is the numerical simulation of the laboratory test conducted by Pokharel et al. (2010). Details of the box of this test have been shown in Figure 1.

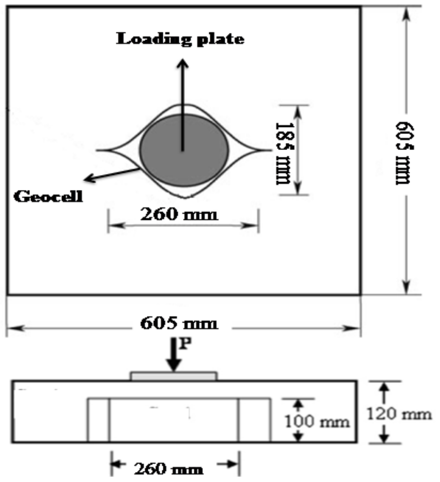

Figure 1: A schematic view of the test box for single geocell

in the middle of the box (Pokharel et al., 2010)

2.2.2 *The initial numerical model*

In this study, the model's geometry was created for two reinforced and unreinforced cases based on the test of Pokharel *et al*. (2010). In the reinforced state, the geocell was simulated and placed in the center of the model with the dimensions mentioned in that article (Height: 100 mm, diameter: 185 mm and 260 mm) and the nearest geometrical shape (diamond). In Figure 2, the numerical model of the soil reinforced with geocell and a schematic view of single geocell have been shown.

For full compliance of the numerical model with the test terms, the model dimensions were considered to be equal to those of the test box and then the obtained results were compared to the results of Pokharel et al. (2010) in order to verify the numerical model. The results of this comparison have been presented in Figure 3. As it can be observed, there is an acceptable consistency between the results of numerical modeling for the above-mentioned laboratory test.

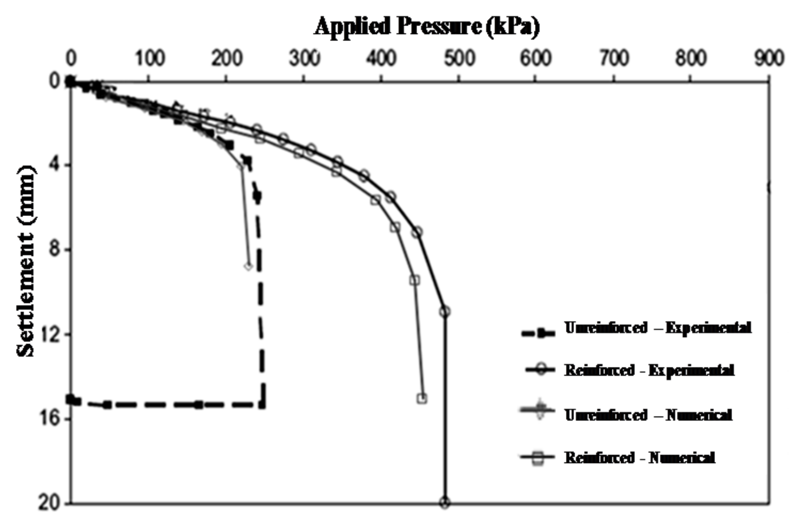

Figure 3: Soil settlement versus the applied load to reinforced and unreinforced soil (comparison of numerical model and laboratory test)

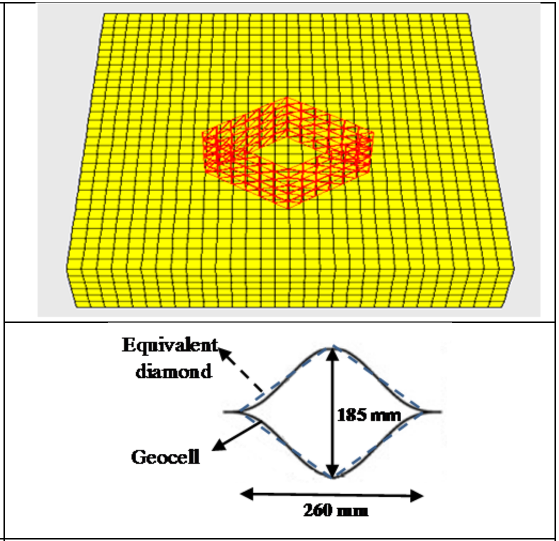

Figure 2: Numerical simulation of the laboratory model using FLAC^{3D} software

2.3 *Numerical model (modeling of embankment)*

Since the main objective of the present research is to study the application of the geocell reinforced soil in real scale, modeling was done for different layers of soil by applying real terms and creating the real number of cells.

2.3.1 *Selection of the embankment model dimensions*

In order to determine the dimensions of embankment model, a lane of a road with a width of 3.6 m was considered and the load of desired vehicle (the standard truck) was applied to it. Because of the symmetry along the lane and truck, half of this width (1.8 m) was selected for the model. On the other hand, due to the long distance between the front axle and the rear axle of the truck and lack of impact on the results, only the rear axle (tandem axle) was considered in this model.

2.3.2 *Selection of dimensions and surface of loading in the embankment model*

To apply load on the surface of the road, the load of the standard truck was considered. Dimensions, weight, and distance between the wheels were determined based on the standard truck proposed in Bridge Loading Regulations, Publication 139 (Figure 4). In this regulations, a truck with a load of 400kN, a length of 10m, a distance between the front axle and the rear axle of 6m, and an axle width of 3m has been introduced. As previously mentioned, only the tandem axle of the truck was considered in the model. According to Figure 4, the distance between the rear and front wheels of this axle is equal to 1.4 m.

The contact area of wheels with the ground, according to this regulations, was determined to be 20*30cm. Considering this contact area and Figure 4, the distance between wheels next to each other on the tandem axle was determined to be 10cm. In these studies, load was applied to the surfaces which where coincident with the contact surface of wheels with the ground in two ways:

In the first case, the weight of the standard truck, according to Bridge Loading Regulations, was constantly applied to these surfaces and a sensitivity analysis was performed for various parameters. The load imposed by the truck on tendon axle, based on this regulations, was equal to 320kN and the share of each of the wheels was 40kN. To consider the effect of impact caused by the truck passage and the applied dynamic load, according to AASHTO Regulations, an incremental coefficient should be applied to the static load. The maximum value of this coefficient has been recommended to be 30% of applied static load (AASHTO; 1996). Accordingly, the impact coefficient in the present study was considered to be 1.3.

In the second case, to evaluate the results with a different approach (applying the increasing loads until failure, instead of applying constant loads), loading was applied on the mentioned surfaces in a way that they were gradually increased until failure.

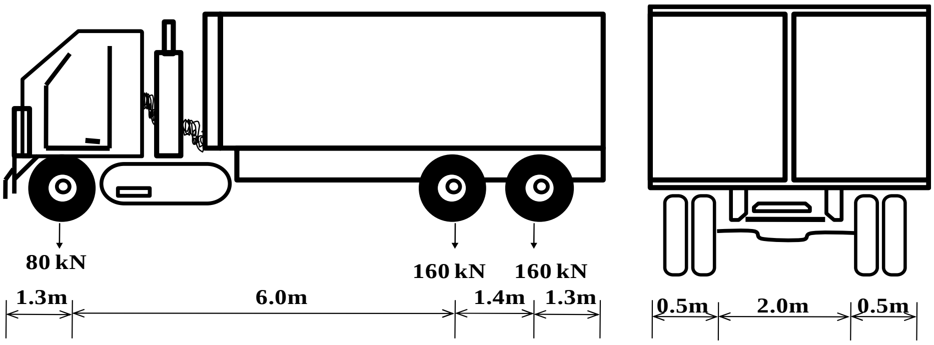

Figure 4: Selection of distance between axles and load of each axle

2.3.3 *Geocell material*

Parameters of geocell material and the type of polymer used have been presented in Table 1.

Table 1: Geocell material

Polymer type	Elasticity module (MPa)	Poisson's ratio
HDPE	200	0.45

2.3.4 *Soil type (base, subbase, and subgrade)*

In this stage, soil parameters in base and subbase layers appropriate for a highway with standard traffic load of 20 million axles per year and underlain by clay were considered (Huang; 1993). These parameters have been shown in Table 2.

3 RESULTS OF ROAD EMBANKMENT MODELING

Since the aim of this research was to study the performance of geocell reinforcement system in road embankments (as the most common area of geocell application), loading type and soil material were considered to be consistent with this objective.

3.1 *Applying the load to the model in reinforced and unreinforced states*

The model with the selected parameters were put under loading in reinforced and unreinforced states. In the reinforced case, geocell was placed in the base layer and 5cm below the ground surface. Figure 5 depicts the model of geocell reinforced embankment and the plan view of this model.

During construction of road embankments in areas where suitable materials are not available, the use of geosynthetic reinforcements system has been long considered as cost-effective way for reducing the thickness of the base layer and even subbase layer. Therefore, in order to eliminate the base layer, in addition to the model shown in Figure 5, a model without the base layer and only with subbase layer (considering a height of 30cm for subbase layer) was constructed. In the reinforced case, geocell was placed in the subbase layer 5cm below the ground surface. The results of loading in two mentioned cases have been given in Table 3.

Table 2: Soil parameters of the model

Layer	Thickness (cm)	Elasticity module (MPa)	Poisson's ratio	Special weight (kg/m^3)	Friction Angle (deg)	Cohesion
Base	20	200	0.37	2100	40	5
Subbase	30	75	0.38	2100	40	5
Subgrade	100	40	0.45	1900	0	100

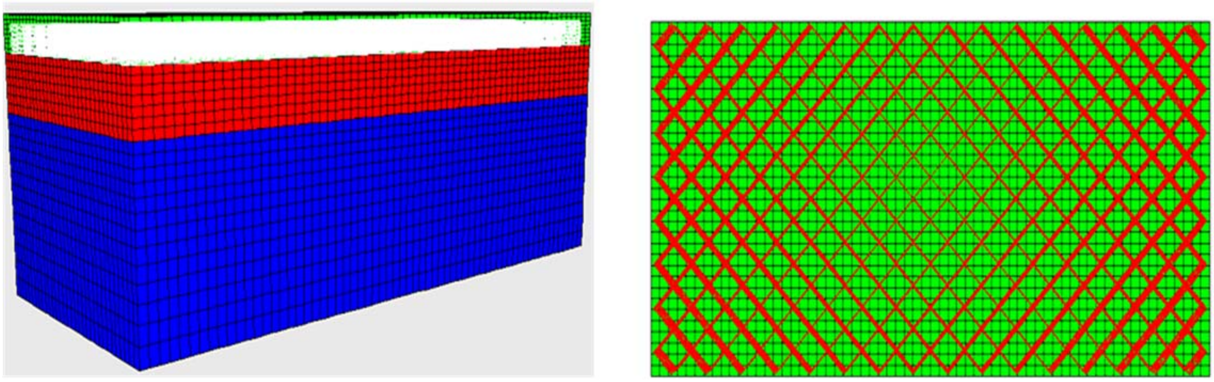

Figure 5: Three-dimensional model of the embankment reinforced with geocell and the plan view of geocell layer

Table 3. Comparison of results for two types of soil layering in reinforced and unreinforced cases

		Maximum settlement (mm)	Maximum swelling (mm)
Base-Subbase-Subgrade	Unreinforced	8.6	2.3
	Reinforced	7.7	1.5
Subbase-Subgrade	Unreinforced	9.6	3.7
	Reinforced	7.8	1.9

As can be seen in Table 3, maximum settlement in the reinforced and unreinforced states is 7.8 mm and 9.6 mm, respectively. Also, existence of geocell layer leads to the better performance of the reinforced soil of subbase-subgrade than the performance of the unreinforced soil of base-subbase-subgrade. This means that the use of geocell can be very helpful in areas where proper soil for base and subbase layers is not available and high costs may be imposed on the project for providing proper soil from other areas/sources.

3.2 *Evaluation the effects of the interface parameters on accuracy of geocell numerical model*

In order to evaluate the effects of the interface parameters on the results accuracy, a sensitivity analysis was performed on the interface parameters. As can be seen in Figures 6 and 7, sensitivity analysis showed that both parameters of interface (cs-scoh & cs-sfric) have relatively no effect on the results related to soil settlement. This result indicates that the performance of geocell, because of its unique geometry, is independent of the interface parameters and it directly reinforce the soil by confining.

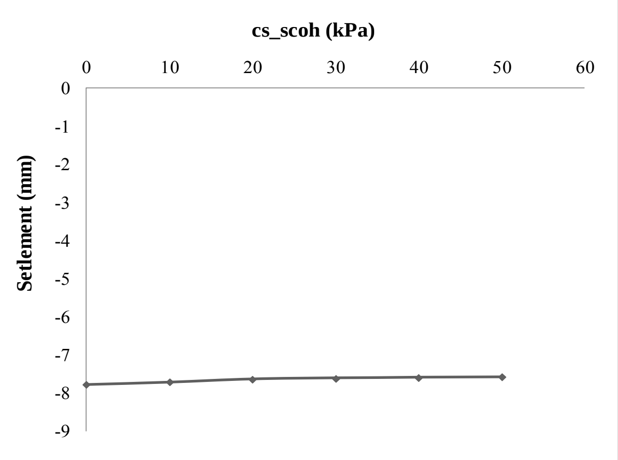

Figure 7: Effect of interface cohesion on geocell performance

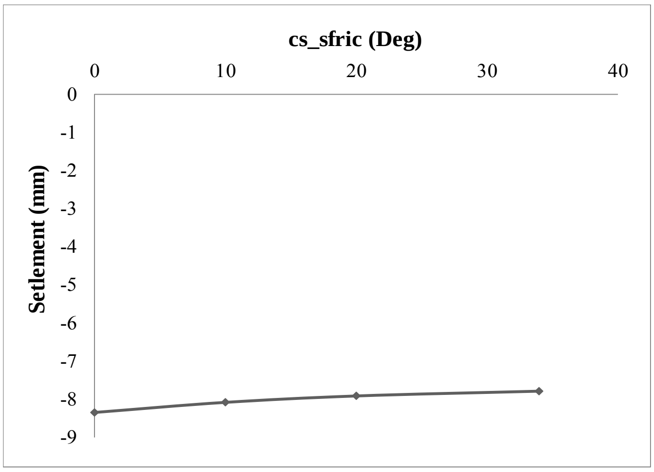

Figure 6: Effect of interface friction angle on geocell performance

3.3 *Effect of cohesion of geocell infilled soil on its performance*

To investigate the effect of parameters of geocell infilled soil on its performance, sensitivity analyses were conducted. Firstly, the effect of soil cohesion on behavior of the soil reinforced with geocell was studied. In the first stage, different amounts of cohesion were applied to the model under the constant load of the standard truck. The results of this stage have been presented in Figure 8. As can be seen, it seems that the effect of geocell on reduction of settlements decreases with the increase in cohesion amount. This is consistent with the findings of Pokharel et al. (2010). They put two types of cohesive and cohesionless soil under loading ***(Up to 900 kPa)***. The graph of settlement versus the applied load resulted from their tests has been shown in Figure 9. It seems that reinforcement with geocell has no effect on reduction of soil settlement in cohesive soils. They argued that since one of the mechanisms of geocell is the creation of apparent cohesion through lateral confinement in granular materials, this function becomes less effective by increase of soil cohesion and the advantage of using geocell decreases to minimum.

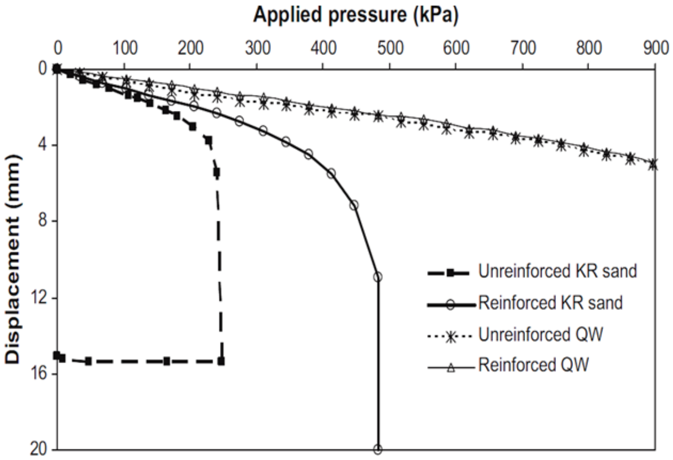

Figure 9: Results of the tests conducted by Pokharel et al. (2010)

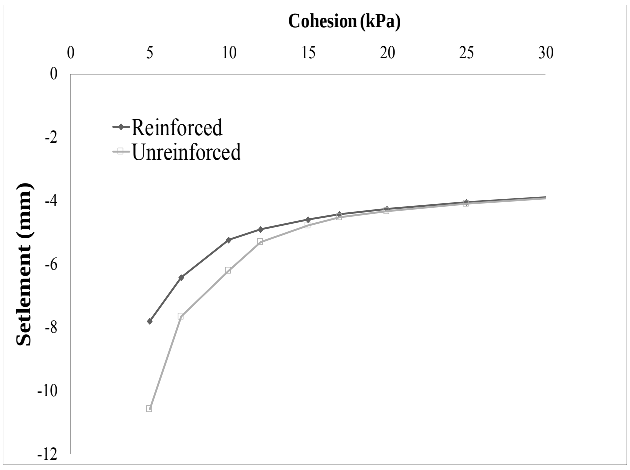

Figure 8: Effect of the cohesion of geocell infilled soil on behavior of the geocell reinforced soil under the constant load

In order to verify the authenticity and accuracy of these results, another kind of sensitivity test was carried out on soils with different amounts of cohesion. Unlike the previous method in which the load was constant, in this method load is increased until the soil failure. The results of these tests have been presented in Figures 10, 11, and 12. In this stage, all soil parameters were considered to be constant and only soil cohesion was increased in each stage.

As it can be seen in these figures, with increase in soil cohesion, under loads that are lower than the bearing capacity of soil, geocell does not have much influence on reduction of settlements. But with the increase of load and getting closer to the bearing capacity of soil, geocell influence is started and leads to improve the soil performance and increase the bearing capacity. In fact, the result obtained in studies of Pokharel et al. (2010) can be attributed to their constraint in applying the load (the device used in their experiment could apply a maximum load of 900 kPa) and since the applied load was much less than the bearing capacity of that cohesive soil, geocell was not activated in the soil.

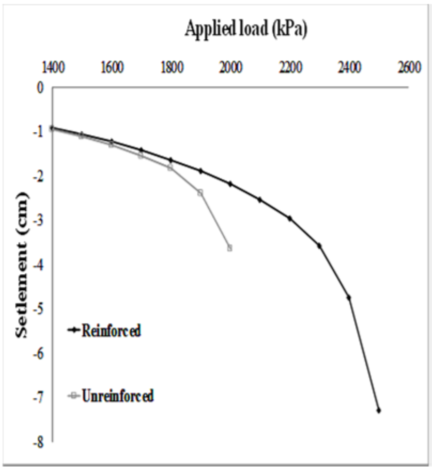

Figure 12: Load-settlement curve (soil cohesion= 80 kPa)

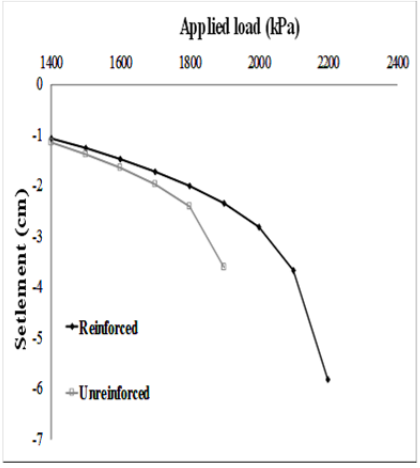

Figure 11: Load-settlement curve (soil cohesion= 60 kPa)

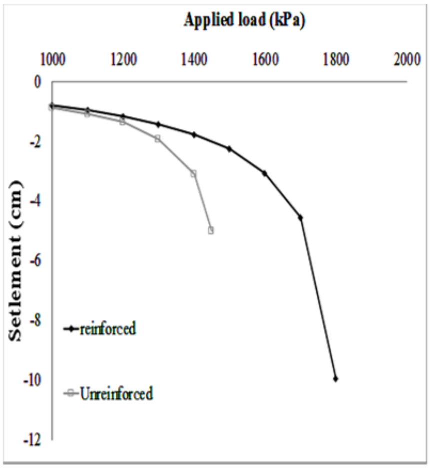

Figure 10: Load-settlement curve (soil cohesion= 30 kPa)

3.4 *Effect of soil friction angle inside geocell on geocell performance*

In the first stage, under constant load of the standard truck, different friction angles were applied to the soil model (Figure 13). As it can be observed, it seems that the impact of geocell on reduction of settlement decreases with the increase in friction angle. In order to verify the authenticity and accuracy of the results, sensitivity test was again performed until the soil failure (Figures 14 and 15). In this stage, all soil parameters were considered to be constant and only friction angle was increased in each stage. As it can be seen in these figures, similar to the effect of cohesion, with increase in soil friction angel, under loads that are lower than the bearing capacity of soil, geocell does not have much influence on reduction of settlements. But with the increase of load and getting closer to the bearing capacity of soil geocell influence is started and leads to improve the soil performance and increase the bearing capacity.

From the last 2 sections, it can be concluded that as long as adequate force is not applied to geocell, presence or absence of geocell has no impact on promotion of soil performance. The use of geocell would be effective and helpful when the stresses and strains applied to geocell are such that make it stretch and the created force in geocell leads to confinement in the soil and overcome the tensile weakness of the soil. Depending on the strength and stiffness of soil, these conditions may occur in different applied loads.

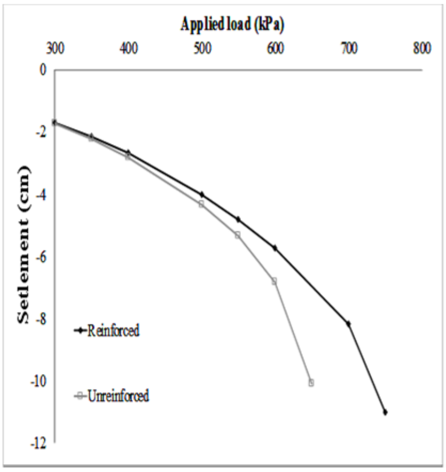

Figure 15: Load-settlement curve
(Φ = 40)

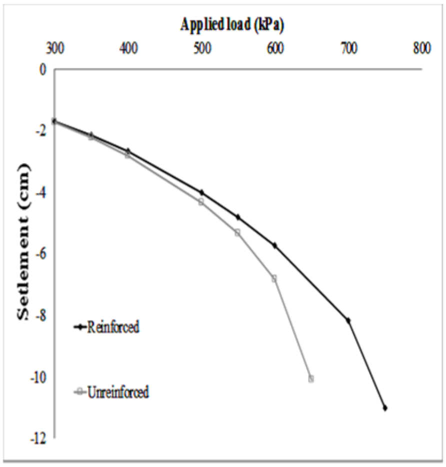

Figure 14: Load-settlement curve
(Φ = 25)

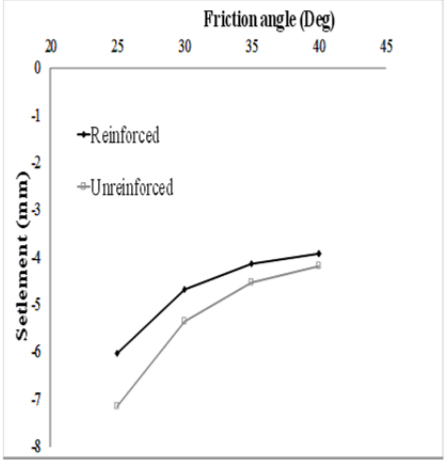

Figure 13: Effect of friction angle of the geocell infilled soil on behavior of the geocell reinforced soil under constant load

4 CONCLUSIONS

Since the beginning of the studies in this field, due to the cost and limitations of laboratory studies, there has always been a need for numerical studies. As a result, a limited number of studies were conducted by other researchers in the field of geocell reinforcement systems. However, most of the numerical studies are based on an equivalent composite model. Meanwhile, as previously mentioned, geocell has diverse and complex behavioral mechanisms due to its unique three-dimensional geometry that are not fully considered in such modeling. Hence, the present research aimed to model the geocell reinforced embankment using a more accurate method. The most important results of the present study are as follows:

1- Existence of geocell layer leads to the better performance of the reinforced subbase-subgrade than the performance of the unreinforced base-subbase-subgrade. This means that the use of geocell can be very helpful in areas where proper soil for base and subbase layers is not available and high costs may be imposed on the project for providing proper soil from other areas.

2- Sensitivity analysis of the effect of both friction and cohesion parameters of interface showed that interface parameters do not have much influence on modeling results. This indicates that the performance of geocell, because of its unique geometry, is independent of the interface parameters and directly reinforces the soil by confining it.

3- Analysis of sensitivity on soil cohesion revealed that, unlike the findings of Pokharel et al. (2010), geocell increases the bearing capacity and decrease soil settlement even in cohesive soils. The only difference between a cohesive soil with a soil with the same parameters but lower cohesion is the load in which the effect of geocell can be observed. The results obtained from analysis of friction angle were similar to the results of cohesion.

4- By evaluating the effect of cohesion and friction angle of the geocell infilled soil, it can be concluded that as long as adequate force is not applied to geocell, presence or absence of geocell has no influence on promotion of soil performance. The use of geocell would be effective and helpful when the stresses and strains applied to geocell are such that make it stretch and the created force in geocell leads to confinement in the soil and overcome the tensile weakness of the soil. Depending on the strength and stiffness of soil, these conditions may occur in different applied loads (In stronger soils, the effect of geocell can be observed in greater loads).

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