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Araştırma / Research

EFFECT OF ECCENTRICITY FOR SHALLOW FOUNDATIONS SETTLING ON SLOPE CREST

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ABSTRACT

In this study, bearing capacities, settlement and stress behavior were determined for a shallow circular foundation inside and outside of a shear plane under eccentric loading conditions. For this purpose, unreinforced and reinforced slope models which were safe against collapsing, were used. Geogrids were fixed at some predetermined depths inside the slope. Loading values, displacements and additional vertical stress values which occurred as a result of the circular footing were measured by means of load cells, displacement transducers and pressure transducers, respectively. Finally, it was identified that eccentricity had an important effect in the determination of bearing capacity and soil stresses.

Keywords: Eccentric loading, reinforcement, geogrid, slope, soil stress

ŞEV TEPESİNE OTURAN SIĞ TEMELLERDE EKSANTİRİSİTENİN ETKİSİ

ÖZ

Bu çalışmada, dairesel bir temelin, şevin göçme yüzeyi içinde ve dışında inşa edilmesi durumunda meydana gelen taşıma gücü, oturma ve gerilme davranışları, eksantirik yük etkisinde araştırılmıştır. Bu amaç doğrultusunda, donatısız ve donatı ile güçlendirilmiş göçmeye karşı güvenli şev zemin modelleri kullanılmıştır. Şevli zemin içerisine belirlenen derinliklere geogrid donatı yerleştirilmiştir. Dairesel temelden dolayı meydana gelen yük değerleri, oturmalar ve ilave düşey gerilme değerleri sırasıyla yük hücresi, deplasman ölçerler ve basınç algılayıcıları yardımıyla ölçülmüştür. Sonuçta, eksantirisitenin hem taşıma gücü hem de zemin gerilmeleri üzerinde önemli bir etkisinin olduğu belirlenmiştir.

Anahtar Kelimeler: Eksantirisitik yükleme, donatı, geogrid, şev, zemin gerilmesi

1. INTRODUCTION

Soils differ vastly related to environmental conditions, their geological history and time besides of not being homogeneous and isotropic. For most of the construction materials, it is enough to use constant coefficients in the solution of design and application problems without thoroughly understanding the characteristic behavior of the materials in use. However, in the case of soils, it is not possible to determine constant material coefficients and general analytical models which define engineering properties of soils. It is a must to define the soil behavior for each project site along with thoroughly investigating the conditions that take place in a site. On the other

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hand, an insufficient understanding of the factors affecting the soil behavior may cause misleading results in most of the cases [1]. Therefore, it is only possible to obtain safe and economical engineering solutions in soil problems by understanding the conditions in which the material properties are defined and stay valid. In addition, it is very complicated to perform realistic stress-strain analyses in soils because of their highly complex materialistic properties. As a result, the following acceptations are used in the theory of elasticity:

- Soils are elastic materials with linear stress-strain relationships.
- A soil medium is homogeneous.
- A soil medium is isotropic which means that its properties are the same at a point in all directions.
- A soil medium is semi-infinite [2].

In the solutions which are obtained by the theory of elasticity, vertical stress distributions are free from the material properties of soils. On the other hand, parameters like soil type and stiffness are not taken into account and the same stress distributions are obtained for all types of soils [3]. However, in stress analysis of soils, soil types and the transferred stresses are of great importance. Therefore, a necessity arises for obtaining the values of vertical stresses experimentally which occur as a result of additional loadings.

In recent years, increasing rates in Earth's population and a concordantly expanding need for sheltering have caused an ascending demand for settlement issues [4]. As a reflection to this problem, site shortage and high costs have come into question and it has become a must either to settle on soils which have low bearing capacities and problematic consolidation properties or to improve existing settlement sites in the most optimized way possible. In accordance with these conditions, either an application of deep foundation should be considered or soil properties under a foundation should be improved. As being both an alternative technology and an economic solution, application of reinforced soil technology which is one of the soil improvement methods continues to gain popularity. It should be stated at this point that, one aspect that should highly be considered in the process of using reinforcement in the improvement of soil properties is to which depth the reinforcement should be placed right beneath the base of a foundation.

A sand embankment was loaded by Scheidig and Kögler [5] and the pressures were measured which occurred at various points on horizontal planes at some specific depths. By using of a testing apparatus that was assembled with a special kind of oedometer, lateral pressures were measured by Hendron [6]. Displacement gauges were planted on the walls of an oedometer in order to accomplish the aforementioned measurements. The experimental study which was conducted by Selvedurai and Gnanendran [7] on a small scaled model was accepted to be the first work relevant to the subject. In the experiments, a model foundation was placed at a distance 1B (B: width of foundation) away from the slope crest. On the other hand, by placing a geogrid as a single layer to some specific depths, load and consolidation values were measured which occur as a result of the loading on the model foundation plate. At the end of the study, it was observed that by placing a single geogrid reinforcement layer to depths that were 0.5 and 0.9 times the width of the foundation, the final bearing capacity of the foundation increased approximately 1.5 times compared to the unreinforced case. Horizontal and vertical stresses were measured by Hanna and Ghaly [8] in sandy soils which had different stiffness degrees by using pressure sensors. By comparing the measured results to the values which were obtained by using the equation $K_0=1-\sin\phi$ given by Jaky [9], it was determined that being related to increasing degrees of stiffness, experimental and theoretical values of K_0 decreased. In addition, it was observed that the values of measured additional stresses were higher than the theoretical counterparts [8]. Behavior of a strip foundation settling on a sand slope was examined by Huang et al. [10] by using some small scaled laboratory tests for reinforced and unreinforced conditions. A model slope which had an angle of 30° with the horizontal was used in the experiments. In the study, the bearing capacity behavior of a strip foundation settling on reinforced and unreinforced sand slopes was investigated for various loading conditions and reinforcement placements. As a result, the final bearing capacity of the foundation was obtained to be 3.8 times higher for the case where reinforcement was placed 0.5B apart from each other than the unreinforced conditions. It was also found that bearing capacity was 1.17 times higher for the case of 0.3B reinforcement placement compared to the unreinforced case. The effect of reinforcement length on the value of the final bearing capacity of the strip foundation was examined and the optimum reinforcement length was obtained to be L=4B. Bearing capacities of a strip foundation settling on a sand slope which was improved by means of geosynthetics were investigated experimentally and numerically by Lee and Manjunath [11]. The study was carried out for both reinforced and unreinforced conditions. The bearing capacity behavior of the foundations was examined in the experiments for the case where a single reinforcement layer was placed into the soil. The effects of slope inclination, distance of the foundation from the slope crest, various types of geosynthetics and depth of the first reinforcement layer to the bearing capacity of the strip foundation were examined in the study. Eventually, it was seen that bearing capacity of the foundation increased 1.76 times in the case of using the geogrid type which had a higher tensile capacity. On the other hand, bearing capacity was observed to increase 1.58 times for the second geogrid type and 1.43 times for using geotextile compared to the unreinforced state. Another observation reached in the study was that the values of the bearing capacity of a strip foundation decreased with increasing slope angles and increased in the case of moving away from the slope crest. For the case where the foundation was settled at distances of 1B-2B away from the slope crest, the bearing capacity values increased and for the case where a settlement distance of 5B was used, the bearing capacity was not affected any more for both reinforced and unreinforced conditions. Pressure sensors were used by Hanna and Soliman-Saad [12] in an attemp to measure horizontal and vertical stresses in sandy soils in order to determine the effects of compaction to the stress values. K_0 values obtained by dividing the measured horizontal values to the vertical counterparts were compared with the values calculated by the equation $K_0=1-\sin\phi$. Eventually, it was observed that, as the angle ϕ increased, the K_0 values that were obtained by the expression $1-\sin\phi$ decreased whereas the K_0 values obtained as the ratio of the measured horizontal stresses to vertical stresses increased. A study was executed by Yoo [13] for the purpose to analyze the bearing capacity of a strip foundation settling on a slope with geogrid reinforcement by means of some small-scaled laboratory tests. It was observed at the completion of the study that in the case where a single reinforcement layer was used in the soil slope, the bearing capacity increased 2.2 times in comparison with the unreinforced condition. After completing the experiments, the optimum depth for the vertical distance between the reinforcement was obtained to be h/B=0.70 (u:depth of the first reinforcement layer, h:vertical distance between reinforcement, d:total reinforcement depth and L:reinforcement length). On the other hand, for the case where two reinforcement layers (N=2) were inserted into the soil at optimum u/B and h/B values, the bearing capacity values were observed to increase approximately 3.2 times compared to the unreinforced case. In addition, bearing capacity values for N=3 resulted in an increase of 5 times compared to the unreinforced case. An experimental study was implemented by Bathurst et al. [14] which was about obtaining the bearing capacity of a strip foundation settling on soil slopes which were improved by using geogrid. At the completion of the study, it was understood that the bearing capacity increased 2 times for the case where the slope model was reinforced with the geogrid which had a higher tensile strength compared to the unreinforced conditions. On the other hand, bearing capacity was observed to increase 1.6 times for the case with the geogrid reinforcement of lower tensile strength compared to the unreinforced case. A research was conducted by Sawwaf [15] by means of using some small-scaled laboratory tests in order to determine the bearing capacity of a strip foundation settling on an embankment of sand slope laying over a soft clay layer. The experiments were performed for both reinforced and unreinforced conditions. In the tests without reinforcement, the height of the sand layer which was placed on soft clay was increased from 0.5 times to 3.0 times the foundation width. Afterwards it was observed that in the case where the height of the sand layer was 3B, the bearing capacity increased 4 times compared to the case where the height of the sand layer was 0.5B. At the completion of the tests with reinforcement, it was obtained that the values for the optimum depth of the first reinforcement layer was u=0.6B, optimum vertical distance between the reinforcement was h=0.5B, optimum reinforcement length was L=5B and optimum reinforcement number was N=3. Behavior of additional vertical stresses that were generated from the effect of shallow foundations on soils with and without reinforcement were investigated by Bağrıaçık and Laman [16] by performing model tests. As a result, it was observed that the additional vertical stresses which were originated from shallow foundations on sandy soils with geogrid reinforcement were reduced at a ratio of 27% compared to that for the unreinforced case. Laboratory model tests were performed by Bağrıaçık et al. [17] in an attempt obtain the first optimum reinforcement layer depth in soils under a reinforced square foundation in terms of load and stress. For this reason, the values of additional vertical stresses which were originated from geogrid reinforcement embedded at specific depths in a soil were measured by means of using pressure sensors. In the experiments, a sand layer with a constant depth was prepared. Afterwards, stress values were measured under a square foundation without reinforcement at a depth two times the width of the square foundation. Eventually, it was observed that, beginning from the base of the square foundation, specific reductions occurred in the values of the stresses at depths of up to 0.40 times the width of the foundation. On the other hand, at depths which were more than 0.40 times the width of the foundation, no additional stresses took place. In accordance with this observation, the optimum depth of the first reinforcement layer in the case of using square foundations was specified as being 0.40 times the width of the foundation. In the study which was performed by Davarcı [18], the bearing capacity and settlement behavior of multilateral shallow foundations settling on reinforced-unreinforced loose-dense sand soils were examined. In order to perform the study, model tests which were constructed in a laboratory medium were used. In the study where a total of 170 tests were conducted, the effects of some parameters as foundation geometry (H, +, T and square cross-sectioned), soil type (loose-dense sand), placement of geogrid reinforcement (the first reinforcement depth, distance between the reinforcement, the number of reinforcement) on bearing capacity and settlement characteristics of multilateral shallow foundations were examined and collapse mechanisms were determined. It was observedvthat the addition of geogrid reinforcement resulted in an increase in the bearing capacity of loose and dense sand soils. In addition, it was seen that reductions took place in the settlement values. Eventually, the conclusion was reached that the test results were in a close agreement with the data obtained from the relevant literature. In this study, it was determined that there was no significant difference in the collapse loads of multilateral shallow foundations which had different geometries but approximately the same surface areas. By Kılıçel [19], the behavior of multilateral (H, +, T and square cross-sectioned) shallow foundations settling on sand soils were investigated numerically (PLAXIS 3D Foundation). The values which were obtained by the analyses performed on the multilateral foundations were compared with the bearing capacities of square foundations which had approximately the same areas. Eventually, it was observed that the bearing capacities increased as the foundation area for each foundation model was increased. In addition, it was seen that the multilateral foundations had the same behavior which was expected from a square foundation and the bearing capacity values increased as the surface areas were increased. On the other hand, it was determined that the bearing capacity values increased by an increase in length or width of any foundation which had the same geometric model and had different dimensions. Very close values were obtained to each other in the bearing capacities of multilateral foundations which had approximately the same areas compared to a square foundation. Some laboratory model tests were performed by Örnek et al. [20] for examining and determining the behavior of eccentrically loaded strip foundations on sandy soils. Consequently, in this study, it was realized that as the eccentricity of the applied loads increased, the values of the ultimate bearing capacity decreased. Laboratory model tests were used by Türedi and Örnek [21] in order to specify the vertical stresses which were originated from rectangular foundations settling on soils under various loading conditions. In addition, the results of the performed experiments were compared with the theoretical counterparts by using the methods in the relevant literature. Eventually, decreases observed in the values of bearing capacities as eccentricity values increased. Additionally, stress values were observed to decrease as the distance from the centre of the foundation increased. On the other hand, it was specified that the results obtained from model tests and theoretical methods were compatible to each other. Additional vertical stresses which occurred in a soil as a result of uniformly loaded circular footings resting on sandy soils reinforced by geogrids were investigated by Bağrıaçık [23]. Additional vertical stress values that occurred on horizontal planes at particular specified depths were measured by means of pressure transducers. In all tests, a sandy soil layer was prepared at a fixed depth (Z=2.0D). By regulating the depth of geogrid, additional vertical stresses were measured at the fixed depth. Finally, geogrid’s optimum depth was determined in terms of stress and loading by Bağrıaçık [23]. According to the test results, it was seen that the optimum depth of geogrid was approximately U=0.35D.

In this study, bearing capacities and additional soil stresses were determined which occurred as a result of shallow foundations located inside and outside of a shear plane. In order to accomplish the study, reinforced and unreinforced slope models were used for eccentric loading conditions.

2. MATERIAL AND METHODS

2.1. Finite Element Method (FEM) Analysis for the Determination of the Failure Surface of a Model Slope

In the classical slope stability analyses, since the analysis of stresses within a soil mass is approximate, it is quite difficult to carry out the computations for various loading conditions and geometries. With the increasing usage of computers in geotechnical engineering as well as in other sectors, finite element method has been used in an increasing rate in slope stability analyses. Finite elements method is a numerical method which is being used effectively nowadays in the precise solution of complex engineering problems. It has been understood in the later years that, this method, which was developed to be used in the analyses of the stresses that take place at the airframes, can also be used in applied sciences and in the solution of engineering problems. It has become one of the most widely used methods for the solution of many problematic applications nowadays as rapid improvements have taken place in the solution techniques. The elementary idea in finite elements method is to find a value which is in a close agreement to the exact value by degrading a complicated problem to a simple one.

The advantage of finite elements approach over the other conventional limit equilibrium methods is that an acceptance is not needed for the coordinates and geometry of the failure surface of a slope and for the magnitude and direction of the slices. Finite elements method can be applied to all failure mechanism types in two or three dimensions for complex slope geometries, various soil, boundary and loading conditions. By using many soil material models in modeling a slope, very close constitutive behavior is obtained for materials and correct computations can be carried out for stresses and displacements that take place in a soil. There are generally two approaches in slope stability analyses which are performed by means of using finite elements method.

In the first approach which is the gravity increase method, the gravitational constant is increased until slope becomes unstable and equilibrium solutions no longer exist.

In the second approach is named as the strength reduction method. Computations of strength reduction are performed by means of PLAXIS program [24]. PLAXIS is a computer program which is used to solve complex problems in geotechnical engineering projects by means of finite elements method. This program is able to perform analyses of deformation, stability, dynamic and time dependent behavior. The analyses are carried out as two dimensional axially symmetrical or plane deformation states or as three dimensional geometrical conditions in this program. In PLAXIS program, stress-deformation behavior of materials are modeled by means of non-linear solution methods. In the slope stability analyses performed by this program, a method called "phi-c reduction" is used (strength reduction method) and shear strength parameters c and tan(ϕ) are reduced up to reaching a collapse state.

In this part, factor of safety and failure surface are obtained for a slope model which is used in a model test by means of Plaxis 3D Finite Elements Program [24]. In the analyses, Mohr-Coulomb Model is used in the process of defining soil material properties. Six parameters are needed for Mohr-Coulomb Material Model which are the internal friction angle ϕ, cohesion c, dilatancy angle ψ, modulus of elasticity E, Poisson's Ratio ν and specific gravity γ. The material parameters which were used in the analyses for different values of internal friction angle can be seen in Table 1.

Table 1. Soil properties for Mohr-Coulomb Model (MCM) (FEM)

Material Parameters	Unit	Value
Angle of Shear Strength, ϕ	°	38
Dilatancy angle, ψ	°	8
Specific gravity, γ	kN/m^3	15.03
Cohesion, c	kN/m^2	0.001
Modulus of Elasticity, E	kN/m^2	22000
Poisson's Ratio, ν	-	0.20

According to the results of the analyses, the factor of safety graph of the slope that was used in the model tests is given in Figure 1. On the other hand, the distance of the shear plane to the slope crest was defined by considering Figure 2.

In accordance with the results, factor of safety of the slope model which was used in the model tests was obtained to be 1.5. In the analyses, the dimensions of soil medium were created according to the footing size in the D area. In the analyses, the boundary conditions were taken into account. So, the horizontal and vertical dimensions were taken as 13.0D and 5.5D respectively to eliminate boundary effects due to loading. A typical graded finite-element mesh composed of the soil, together with the boundary conditions and the geometry of the soil system used is shown in Figure 2. By considering Figure 2, distance of the shear surface to the slope crest was found as 0.075 m.

In this study, in a slope model which was reinforced and unreinforced by using reinforcement resistant to collapse, behaviours of bearing capacity-stress-vertical displacement of foundations within and out of a shear plane were examined which occur as a result of vertical loading conditions.

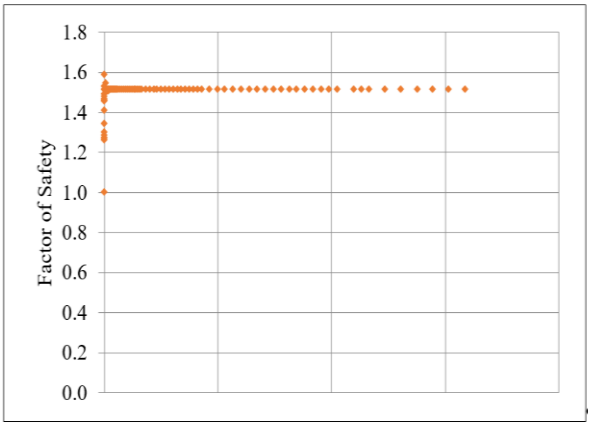


Figure 1. The factor of safety for slope

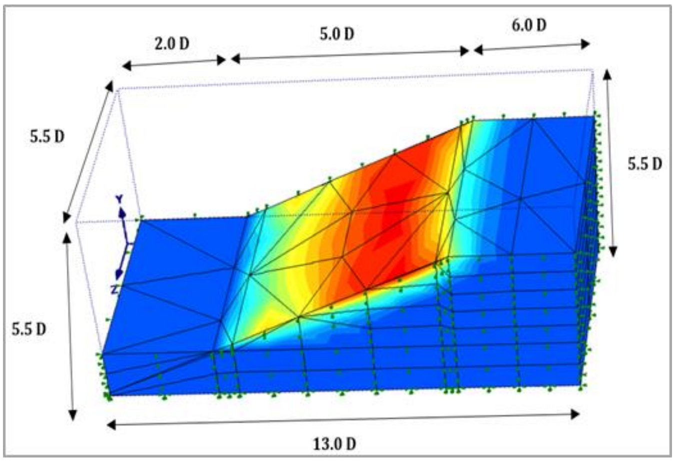


Figure 2. Typical mesh configuration for slope's shear surface

2.2. Experimental Studies

In the examinations, sand samples which were taken from Çakıt River bed in Çukurova District were used. Experiments were performed at soil mechanics laboratory of Çukurova University on oven-dried sand samples. The sand was classified as uniform clean sand (SP) according to TS 1500.

Test results of the sieve analysis are given in Table 2 [16]. Experimental studies were performed at the soil mechanics laboratory of Çukurova University bu using a box having a square cross-section and dimensions of 0.5 m width and 0.4 m height. The test box had a framework consisting steel profiles and its front and rear faces were made out of 0.006 m thick glass. The box's lateral surfaces and bottom were made from 0.02 m thick timber material [16].

Table 2. Soil properties [22]

Granulometric Parameters	Unit	Value
Percentage of Medium Grained Sand	%	46.40
Percentage of Fine Grained Sand	%	53.60
Effective Grain Size, D_{10}	m	0.0018
D_{30}	m	0.0030
D_{60}	m	0.0050
Coefficient of Uniformity, C_u	-	2.78
Coefficient of Curvature, C_c	-	1.00
Soil Class	-	SP
Maximum Dry Specific Gravity	kN/m^3	17.06
Minimum Dry Specific Gravity	kN/m^3	15.03
Specific Gravity	kN/m^3	26.80

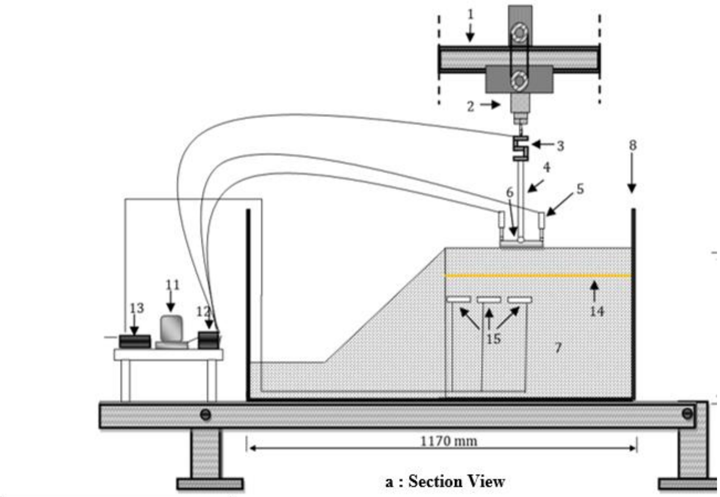
In the experiments, a circular foundation was used which had a diameter (D: diameter of foundation) of 0.09 m. The experiments were performed with a special testing device which was produced to be able to exert tension and compression at various time rates of loading. The loading apparatus was assembled onto the loading beam at the soil mechanics laboratory of civil engineering department. In order to determine the values of the load which were applied on the foundation plate, an electronic load cell was used which was produced by ESIT Company. The pressure sensor with a capacity of 200 kPa which was produced by Tokyo Sokki Kenkyujo Co. Ltd. was used to measure the vertical stress values which took place in the soil [16]. The geogrid reinforcement that was used in the experiment was placed at a specified depth (U=0.35D)[30] from the base of the foundation as shown in Figure 2. Afterwards, the stress values which took place at a depth of Z=2.0D were measured. In the experiment, the geogrid brand named as Secugrid (Biaxial Geogrid) which was provided by the producing company was used. The reinforcement properties of the Secugrid can be seen in Table 3 below.

Table 3. Properties of the geogrid [16]

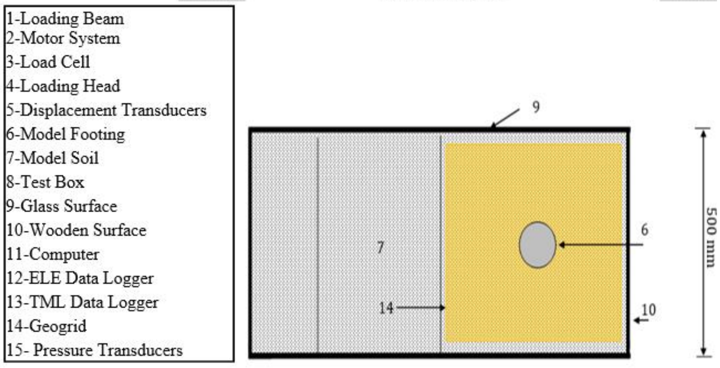
Technical Properties	Unit	Secugrid
Material	-	Polypropylene
Max. Tensile Strength, md/cmd[*]	kN/m	≥ 60 / ≥60
Tensile Strength at 2% stretching, md/cmd	kN/m	22 / 22
Tensile Strength at 5% stretching, md/cmd	kN/m	48 / 48
Span, md × cmd	m x m	0.031 × 0.031
Roll width / length	m x m	4.75 × 100

[*] md = machine direction, cmd= cross mach

The applied vertical loads were transferred via the load cell to the data logger device (ADU) which had 8 channel entries. Afterwards, these data were converted into numerical values in a computer environment by using the program called DIALOG. The vertical stresses which occurred as a result of the applied vertical loads were obtained, by using pressure sensors from the produced TML data logger. The testing apparatus is shown in Figure 3 and the experiments were conducted by taking the following aspects into consideration. The pressure sensors were fixed onto the base inside of the testing box by using glue in order to disable any movement of the sensors throughout the experiment [22]. Sandy soil was placed into the box as layers and by performing compaction in order for the sand to have a specific gravity of γ_k = 15.03 kN/m^3. After the compaction process was performed for the specified sand layer, the geogrid reinforcement was put into that layer. Afterwards, the other layers were placed as well [16]. Subsequent to the compaction of the sand, the foundation plate was carefully placed in order to have a proper positioning with respect to the pressure sensors. It was paid attention for the applied load to have an impact in the vertical direction towards the centre of the foundation plate and to be uniform [16].



a : Section View



b : Top View

Figure 3. Lay-out of the experiment

3. RESULTS AND DISCUSSION

In this study, bearing capacities were determined which occurred as a result of shallow foundations located inside and outside of a shear plane by means of a reinforced and unreinforced slope model. On the other hand, for the same slope model, comparisons were made by obtaining bearing capacities of shallow foundations which were under loading conditions as a result of being located outside of shear planes.

3.1. Experiments for Shallow Foundation Located in the Shear Plane of the Slope

When the shallow foundation is in the shear plane of the slope, there is no bearing capacity for the unreinforced and single line geogrid reinforcement cases because of the quick movement of soils.

3.2. Experiments for Shallow Foundation Located outside of the Shear Plane of the Slope

The vertical displacement graphics of bearing capacities for the unreinforced case and for the case where a single line geogrid reinforcement was used can be seen in Figure 4 and Table 4. The values of stresses which occurred as a result of the foundation at a depth of Z=2.0D for both of the reinforced and unreinforced conditions can be observed in Figure 5 and Table 5. The bearing capacity was defined as the tangent intersection between the initial, stiff, straighter portion of the loading-pressure-settlement curve and the following steeper, straight portion of the curve [25]. All the test results were interpreted using this approach (Figure 4).

In the case where a layer of geogrid reinforcement was used, improvements of up to 38% were observed in the values of the bearing capacities compared to the unreinforced case. In addition, at a specified depth, significant amounts of decreases were seen in the additional stress values at the center of the foundation (52%) for the case where a reinforcement layer was used. As well as a significant increase occurred in the values of the bearing capacities with the usage of a reinforcement layer, significant decreases occurred in the additional stress values at the specified depth. The reason of the significant increase in the value of the bearing capacity is thought to be sourced from the occurrence of a strong adherence between the reinforcement and the soil mass. The aforementioned adherence between the reinforcement and soil inside and outside of a shear plane was in question for the case where a reinforcement layer was used in the shear plane of the slope. This strong adherence is believed to be sourced from the adherence of the soil environment which was outside of the shear plane of the slope. On the other hand, the aforementioned significant reductions in the additional stress values which were generated by the foundation at a specific depth took place since the stresses were taken by the soil in the unreinforced case whereas they were mostly compensated by the reinforcement in the reinforced case.

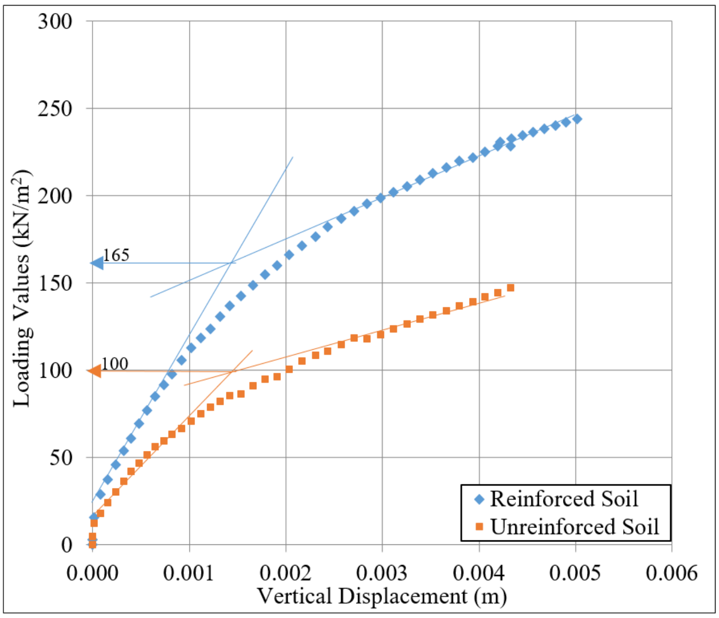


Figure 4. Comparison of reinforced-unreinforced cases

Table 4. Bearing capacity of reinforced-unreinforced cases

Cases	**Bearing Capacity (kN/m^2)**
Reinforced Soil	165
Unreinforced Soil	100

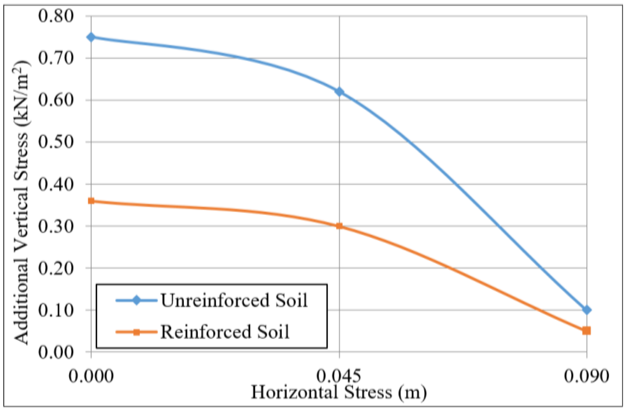


Figure 5. Comparison of additional vertical stress values

Table 5. Additional vertical stress values of reinforced-unreinforced cases

Horizontal Distance (m)		**0.000 m**	**0.045 m**	**0.090 m**
Additional Vertical Stress (kN/m^2)	Reinforced Soil	0.360 kN/m^2	0.300 kN/m^2	0.050 kN/m^2
	Unreinforced Soil	0.750 kN/m^2	0.620 kN/m^2	0.100 kN/m^2

Bearing capacity values for the eccentric loading condition of the shallow foundation in the reinforced case can be seen in Figure 6 and Table 6, respectively. In Figure 7 and Table 7, additional vertical stress values can be seen under eccentric loading conditions for the reinforced case at specified depths (Z=2.0D). The bearing capacity values were decreased as far as 85% when the distance of the vertical load to the centre of the foundation increased (increasing eccentricity). As a result, a significant decrease occurred in the values of the bearing capacities with the increasing eccentricity. It was observed that it is important to direct the vertical load which was applied on the shallow foundation towards the centre of the foundation.

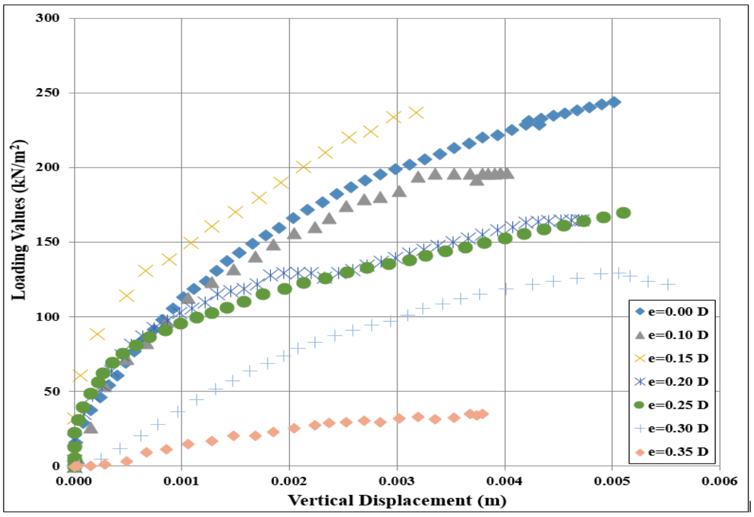


Figure 6. Comparison of bearing capacity values for different eccentricities

Table 6. Bearing capacity values for different eccentricities

Eccentricity (e)	**Bearing Capacity (kN/m^2)**
e=0.00 D	165
e=0.10 D	161
e=0.15 D	134
e=0.20 D	122
e=0.25 D	92
e=0.30 D	81
e=0.35 D	25

As the distance of the vertical load was increased (increasing eccentricity), the additional vertical stresses were decreased up to approximately 33% at the center of the foundations at the specified depth. On the other hand, the additional vertical stresses which were measured at an increasing horizontal distance from the center of the foundation were increased slightly (10%) as a result of the increasing eccentricity.

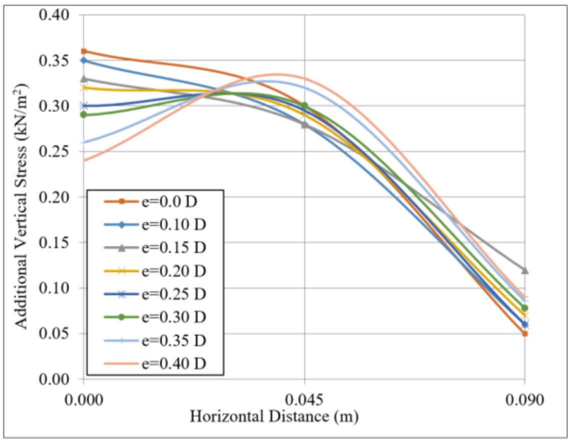


Figure 7. Comparison of additional vertical stress values for different eccentricities

Table 7. Additional vertical stress values for different eccentricities

	Eccentiricty (e)	**Horizontal Distance (m)**		
		0.000 m	**0.045 m**	**0.090 m**
Additional Vertical Stress (kPa)	e=0.00 D	0.360 kN/m^2	0.300 kN/m^2	0.050 kN/m^2
	e=0.10 D	0.350 kN/m^2	0.280 kN/m^2	0.060 kN/m^2
	e=0.15 D	0.330 kN/m^2	0.280 kN/m^2	0.120 kN/m^2
	e=0.20 D	0.320 kN/m^2	0.290 kN/m^2	0.070 kN/m^2
	e=0.25 D	0.300 kN/m^2	0.295 kN/m^2	0.060 kN/m^2
	e=0.30 D	0.290 kN/m^2	0.300 kN/m^2	0.078 kN/m^2
	e=0.35 D	0.260 kN/m^2	0.320 kN/m^2	0.086 kN/m^2
	e=0.40 D	0.240 kN/m^2	0.330 kN/m^2	0.090 kN/m^2

4. CONCLUSIONS

When a shallow foundation was located inside the shear plane of a slope, there was no bearing capacity for the unreinforced and reinforced cases where a single line geogrid reinforcement was used. On the other hand, for the case where the shallow foundation was located outside of the shear plane of slope, bearing capacity values was observed to arise for the unreinforced and reinforced with a single line geogrid reinforcement cases.

When a layer of geogrid reinforcement was used, improvements were observed in the values of the bearing capacities compared to the unreinforced case.

Significant amounts of decreases were seen in the additional stress values at a specified depth at the center of the foundation when a reinforcement layer was used.

The reason of the significant increase in the value of bearing capacity was thought to be sourced from the occurrence of a strong adherence between the reinforcement and the soil mass when a reinforcement layer was used. These significant decreases in the additional stress values which were generated by the foundation at a specific depth was believed to take place since the stresses were taken by the soil in the unreinforced case whereas they were mostly compensated by the reinforcement in the reinforced case.

The bearing capacity values were decreased when the distance of the vertical load which was applied on the shallow foundation from the centre of the foundation was increased (increasing eccentricity). As a result, a significant decrease occurred in the values of the bearing capacities with the increasing eccentricity.

It was observed that it is important to direct the vertical load which was applied on the shallow foundation towards the centre of the foundation as much as possible.

As the distance of the vertical load was increased (increasing eccentricity), the additional vertical stresses were decreased at the center of the foundations at a specified depth. On the other hand, the additional vertical stresses which were measured at an increasing horizontal distance from the center of the foundation were increased slightly as a result of the increasing eccentricity.

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