# Evaluation of Subgrade Modulus and Bearing Capacity with Large Scale Field Tests on Geogrid-Reinforced Granular Fill over Clay Soil

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## ABSTRACT

This study aims at experimentally explaining the potential benefits of geogrid reinforced soil foundations using large scale field tests. A total of 8 large scale field tests were carried out to evaluate the effects of replacing natural clay soil with stronger granular fill layer and single-multiple layers of geogrid reinforcement placed into granular fill below circular footings. The large scale field tests were performed using two different sizes of the circular footing diameters which have 0.30 and 0.90m. The results of testing program are presented in terms of subgrade modulus and bearing capacity. Subgrade modulus and bearing capacity values were calculated for each test at settlements of 10, 20 and 30mm.

It has been seen that based on the test results, the use of granular fill and geogrid for reinforced soil foundations (RSF) have considerable effects on the subgrade modulus and bearing capacity.

***Keywords***: *Field test, geogrid, natural clay, granular fill, subgrade modulus, bearing capacity*

## 1. INTRODUCTION

The use of geosynthetics in civil engineering applications is increasing annually. One of the new application, the construction of a reinforced soil foundation (RSF) to support a shallow foundation, has considerable potential as a cost-effective alternative to conventional methods of support. In this technique, one or more layers of a geosynthetic reinforcement and controlled fill material are placed beneath the footing to create a composite material with improved performance characteristics. In the literature beneficial effects of geogrid reinforcement on the increased bearing capacity and reduction in settlement has now been recognized. Most of the experimental studies in this area have been performed on sand with geosynthetic reinforcements using large scale footing [1-5]. Adams and Collins [1] studied the effect of geosynthetic reinforcement on the ultimate bearing capacity of reinforced sands using square plates ranging in sizes from 300 to 910mm. Gabr and Hart [2] reported the results of nine plate load tests on geogrid reinforced sand in terms of elastic modulus. As can be expected, it was reported that the elastic modulus decreased with increasing depth of the top geogrid layer. DeMerchant et al. [3] conducted an experimental study on geogrid-reinforced lightweight aggregate beds to determine their subgrade modulus in laboratory

conditions. A total of 25 plate load tests were performed using a 305mm diameter rigid steel plate. The results of the tests are presented in terms of subgrade modulus rather than bearing capacity ratio as traditionally presented in the literature. Hirofumi et al. [4] reported that the plate loading test with different-sized loading plates is effective as a method for studying design constants in the design of spread footing on soft rock ground, gravelly soil and rock fill embankment. Chen [5] investigated the potential benefits of using the reinforcement to improve the bearing capacity and reduce the settlement of shallow footings with conducting small and large scale tests. Most of the aforementioned studies in the literature were conducted in laboratory conditions and large scale tests performed for RSF were comprehensively on the sandy soils. It is believed that there are very limited studies on the use of granular fill and geogrid for reinforced soil foundations (RSF). In this study, large scale field tests were carried out to determine the improvement of bearing capacity and subgrade modulus characteristics of circular shallow footings supported by a compacted granular fill with and without geogrid over natural clay soil. For this purpose, a series of field tests were performed using circular footings which have diameters of 30 and 90cm. Geogrid layers were placed into the granular fill bed overlying natural clay deposits at predetermined depths. For all tests with geogrid reinforcement, the thicknesses of the granular fill layer were kept constant as 0.67D, according to the footing diameter. The parameters, bearing capacity and subgrade modulus were defined to evaluate improvement performance of granular fill reinforced-natural clay deposit system. The test results showed that the bearing capacity and subgrade modulus values of reinforced natural clay deposit increase with an increase in geogrid layer and also, the thickness of the granular fills and reinforcement with geogrid have considerable effects on the bearing capacity and subgrade modulus characteristics of the circular footings, rested on natural clay deposits reinforced with granular fill layers.

## 2. FIELD TESTS

Before conducting the tests, a comprehensive soil investigation was performed to determine the soil properties. The site investigation covers an area of about $350m^2$ which the sizes of 30m and 11.6m for length and width, respectively and situated in the west part of Adana, Turkey (Figures 1-2).
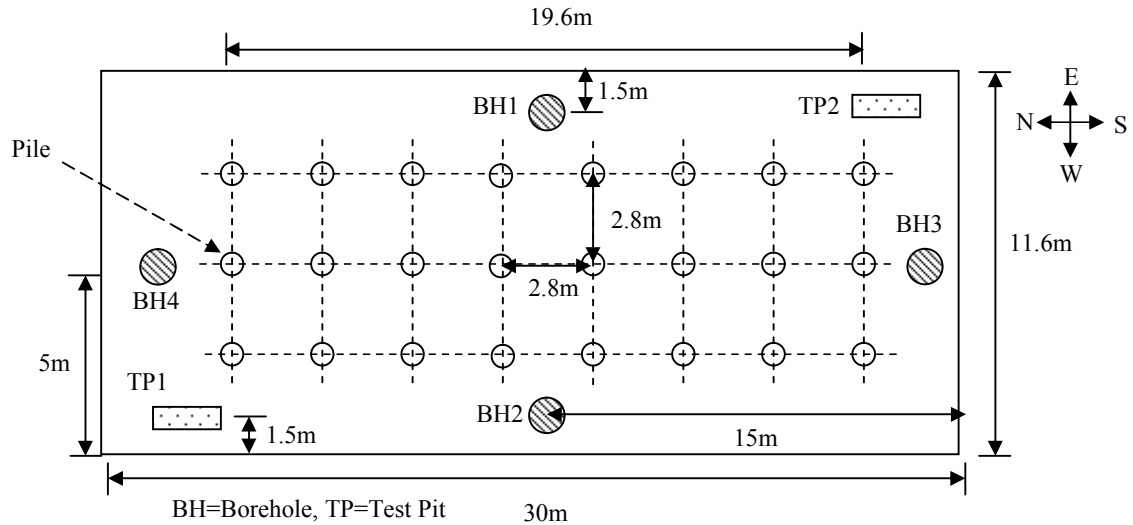


Figure 1 The plan view of test site

Figure 2 Plan view showing piles, borings and test pits

First layer of 0.80m depth observed as topsoil and the second layer between the depths of 0.80m and 2.60m observed as silty clay from the test pits. Then, boreholes were drilled with depths changing from 13.0m to 20.0m. Water table level was determined as 2.40m from borehole drillings. Standard Penetration Test (SPT) was carried out during drilling each borehole the values refer that the soil tested classified as medium stiff clay (Figure 3). Conventional laboratory tests were performed in Geotechnical Laboratory of Civil Engineering Department at Cukurova University, Adana, Turkey. Detailed information of the testing procedure can be found in Laman et al. [6] and Ornek [7].
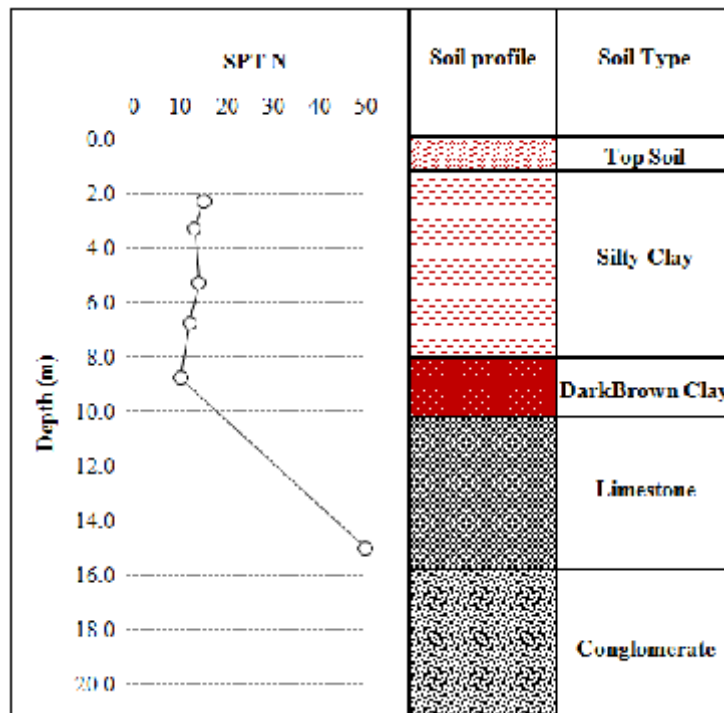


Figure 3 Average SPT(N) values measured from borehole drillings

## 2.1. Model Foundations

The model foundations with the diameters of 0.30m and 0.90m used in the tests were made of mild steel. The thickness for the model foundations was 0.03m. The foundations were loaded with a hydraulic jack against a reaction steel frame. Two different hydraulic jacks were used. Big one which has 60tons of capacity was used for 0.90m diameter foundation and small one which has 30tons of capacity was used for 0.30m diameter foundation. Before the field tests, calibrations were performed for 30tons and 90tons capacity hydraulic jacks.

## 2.2. Test Material

### 2.2.1 Clay Soil

Laboratory tests were conducted on representative soil samples for gradation, specific gravity, maximum and minimum densities and strength parameters. These properties are summarised in Table 1. As seen the values of mean water content and mean unit weight of soil is measured at 23% and 20.7kN/m$^3$, respectively. Table 1 shows that the soil layers classified as lightly overconsolidated from odometer tests.

Table 1. Soil profile in test area

| Depth (m) | Soil Type | $\omega_{mean}$ (%) | $\gamma_s$ (kN/m$^3$) | $I_P$ (%) | $c_u$ (kPa) | $P_0$ (kPa) |
|---|---|---|---|---|---|---|
| 0.8-2.2 | CH | 20-21 | 25.7-26.0 | 30-39 | 60-70 | 63-91 |
| 2.2-3.5 | CL | 22-24 | 26.0-26.9 | 12-33 | 20-40 | 44-67 |
| 3.5-5.0 | CL | 22-24 | 25.7-26.6 | 17-19 | 20-40 | 80-120 |

$\omega_{mean}$= mean value of water content (%); $\gamma_s$ = soil unit weight (kN/m$^3$); $I_P$= plasticity index (%); $c_u$=undrained cohesion (kPa); $P_0$= preconsolidation pressure (kPa)

### 2.2.2. Granular Fill

The granular fill material used in the model test was obtained from the Kabasakal region situated northwest of Adana, Turkey. Some conventional tests were conducted on this material. Granular soil was prepared at optimum moisture content of 7% and maximum dry unit weight of 21.7kN/m$^3$ obtained from the standard proctor test. The values of internal friction angle and the cohesion of clay soil were obtained as 43° and 15kN/m$^2$, respectively from direct shear tests. Specific gravity of the granular soil was obtained 2.64. From the sieve analysis, granular soil was classified as well graded gravel-silty gravel, GW-GM according to the unified soil classification system.

### 2.2.3. Geogrid

A white coloured, Secugrid Q type geogrid with maximum tensile strength of 60kN/m was used as reinforcing material in the model tests. The physical and mechanical properties of the geogrids as listed by the manufacturer are given in Table 2.

Table 2. Engineering properties of geogrid

| Parameter | Value |
|---|---|
| Structure | biaxial |
| Aperture shape | squared |
| Aperture size | 30mm x 30mm |
| Raw material | polypropylene |
| Elongation at nominal strength | 8 % |
| Tensile strength at 2% elongation | 22 / 22 (md/cmd) |
| Tensile strength at 5% elongation | 48 / 48 (md/cmd) |

### 2.3. Test Setup and Procedures

The experimental set-up has been used extensively for the bearing capacity of shallow foundations on reinforced clay soils. The schematic view of the test is shown in Figure 5, where, D is the foundation diameter and N is the number of geogrids.
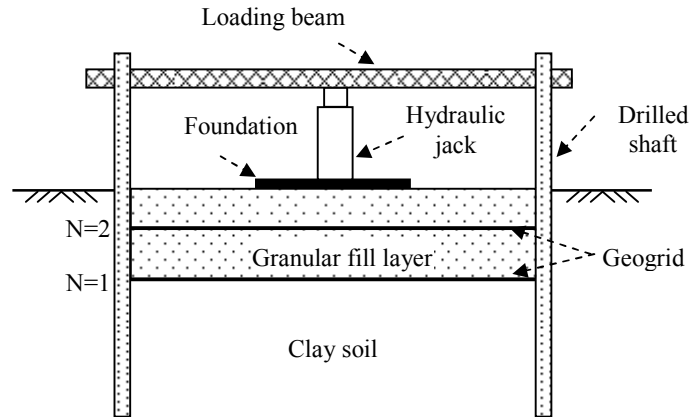


Figure 5 Schematic view of the test (unscaled)

In the tests, steel loading beam (I240) with a length of 3.5m was assembled on drilled shafts. The loads were applied against this reaction steel frame. Then model foundation, transducer, hydraulic jack and two LVDTs were placed. Hydraulic jack and LVDTs were connected to a data logger unit and data logger unit was connected to a computer. Load-settlement curve was drawn with loading simultaneously during tests. Loading was performed until the vertical deformation, i.e. settlement recorded until 10% of foundation diameter. In all tests with geogrid reinforcement, the thicknesses of the granular fill layer were kept constant as 0.67D, according to the footing diameter. To maintain the convenient density throughout the test area, a similar compactive effort was applied on each layer of granular fill. Geogrids were laid inside granular fill in predetermined depths. A total of 8 tests were performed in the experimental studies and the details of the tests are given in Table 3.

Table 3. Details of the field test program

| Test Series | Test Conditions | Number of Tests |
|---|---|---|
| I | Unreinforced | 2 |
| II | H/D=0.67 | 2 |
| III | N=1; u/D=0.67; H/D=0.67 | 2 |
|  | N=2; u/D=h/D=0.50; H/D=0.67 | 2 |

### 3. INTERPRETATION OF TEST RESULTS

Bowles [13] indicated that the modulus of subgrade reaction is a conceptual relationship between soil pressure and deflection that is widely used in the structural analysis of footing members. In field tests, the applied pressure versus the resulting settlement data was plotted for each of the model footings used. From these plots, the subgrade modulus was determined as;

$$k = \frac{q}{\delta} \tag{1}$$

where k is subgrade modulus all model footings, q is the bearing capacity, and $\delta$ is the settlement. Subgrade modulus and bearing capacity values were calculated for each test for settlements of 10 ($\delta_{10}$), 20 ($\delta_{20}$) and 30mm ($\delta_{30}$).

### 3.1. Series I: Natural Clay (Unreinforced)

Series I consisted of testing 30 and 90cm circular footings on the surface of natural clay. The Series I tests were to be the control (unimproved) tests with which to compare the RSF tests in Series 2 and 3.

### 3.2. Series II: The Effect of Granular Fill

Figure 6 shows the test results for two footing diameters on the compacted granular fill layer of limited thickness (H=0.67D) over the natural clay. It is shown that the granular fill layer helps increase the load bearing capacity of the footing and decreases the settlement allowable load since the granular fill layer is stiffer and stronger than the natural clay.
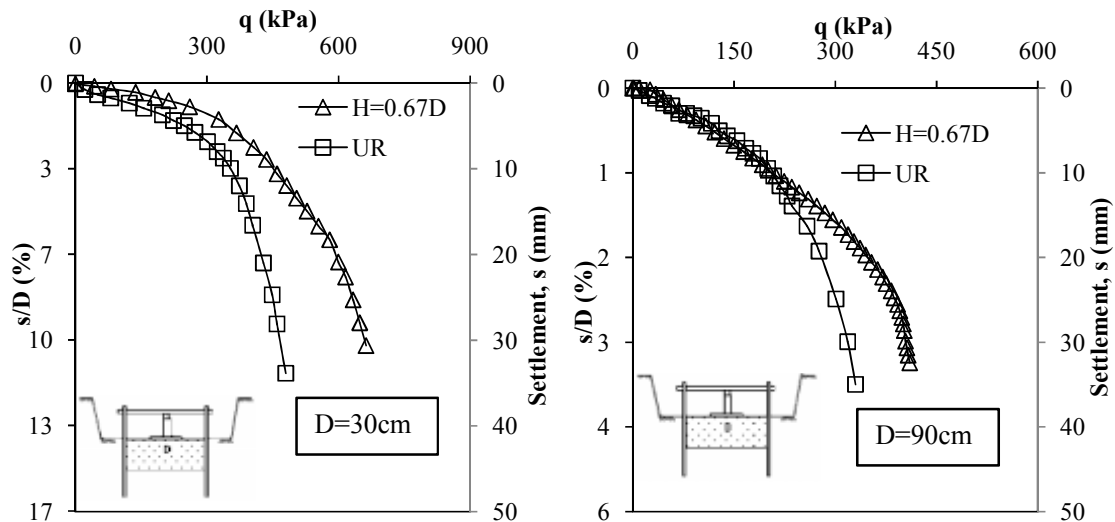


Figure 6 The Effect of granular fill in Series I and II

### 3.3. Series III: The Effect of Geogrid Reinforcement

The tests in this series were conducted to determine the effect of geogrid reinforcement within the granular fill layer on bearing capacity and subgrade modulus. The thickness of granular fill layer, H was kept constant as 0.67D. Series III was divided into two sets. The first set of Series III tests consisted of a single geogrid layer. In these tests a single geogrid layer was placed at the granular fill-clay interface as reported by Love et al. [11] and Khing et al. [12]. The second set of Series III tests consisted of double geogrid layers. In these tests, the first geogrid was placed at the granular fill-clay interface while second one was placed at depth 0.17D in granular fill. Thus it was aimed to examine the effect of 1 versus 2 reinforcement geogrid layer. Figure 7 shows the load-settlement curves for all the tests performed in Series I, II, and III, respectively. As seen in Figure 8, a single layer of reinforcement at the interface of natural clay and the compacted granular fill does not bring further improvement on BCR values. However, BCRs clearly increase with two layers of geogrid reinforcement.
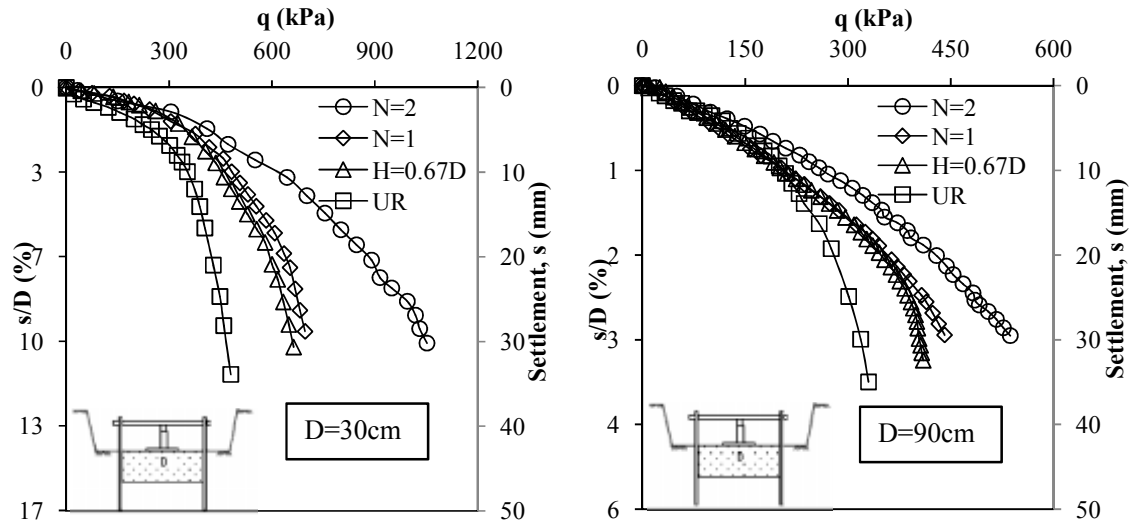
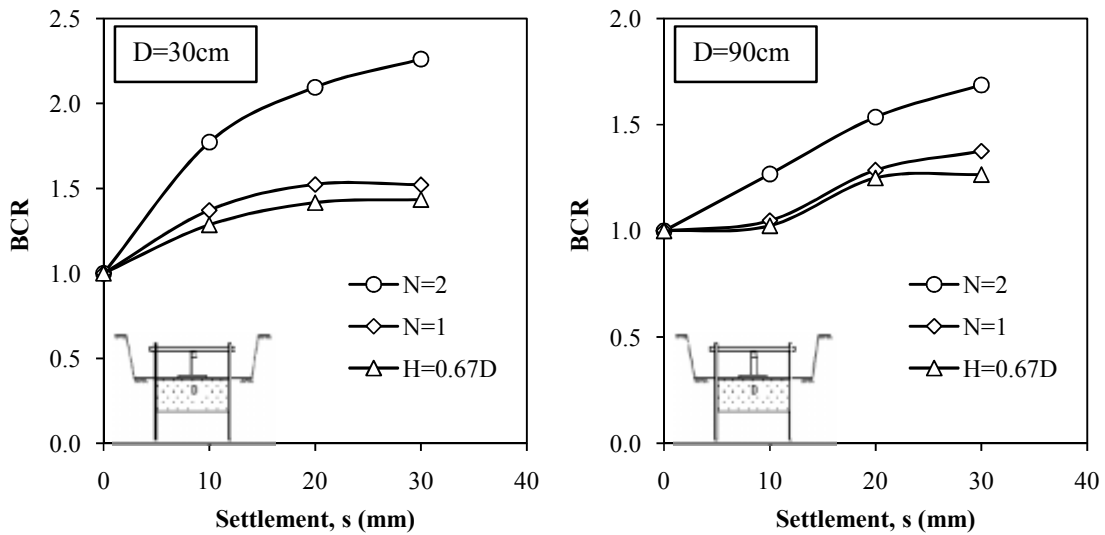Figure 7 The Effect of reinforcement in Series II and III



Figure 8 Comparison of BCR with and without reinforcement

Figure 9 shows the subgrade modulus variations to footing diameter obtained at $\delta_{10}$ and $\delta_{30}$ settlements from the reinforced soil footings for tests Series I, II and III, respectively. When the H=0.67D compared with N=1 or 2 cases, it is seen clearly in Figure 9 that geogrid reinforcement effects significantly the subgrade modulus of RSF. The values of subgrade modulus, k, varies according to the size of footing used in field tests. Thus, k has no unique value and depends on the size of loaded area. As seen that k value decreases with increasing with size of footing. As a result, the values of subgrade modulus (k) recommended in literature should be used carefully (e.g. Bowles, [13]).
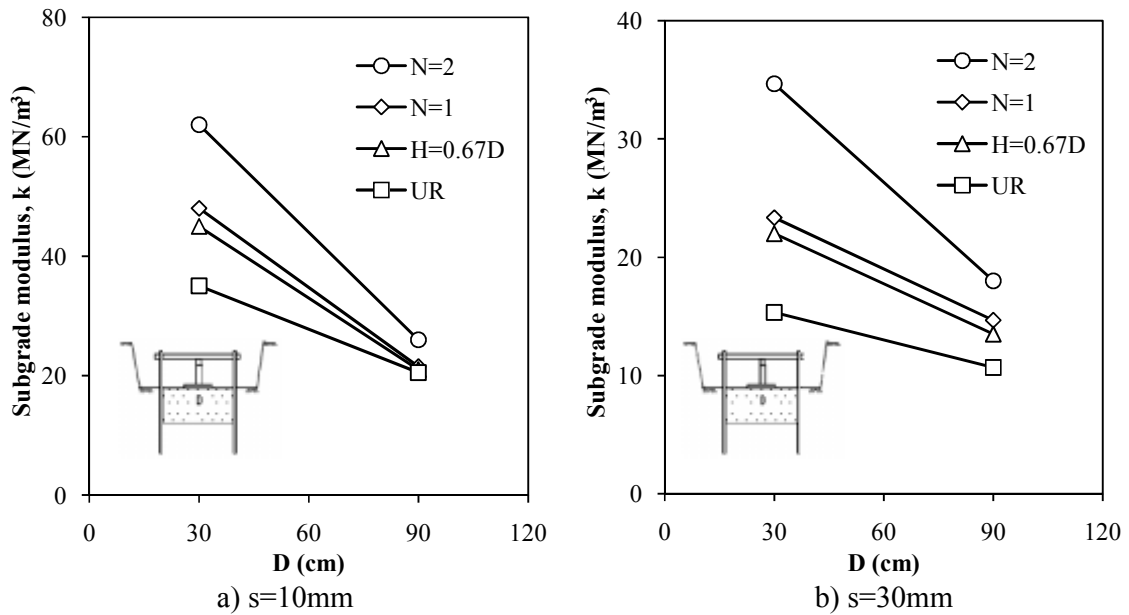
a) s=10mm                    b) s=30mm

Figure 9 Comparison of subgrade modulus with and without reinforcement

## 4. CONCLUSIONS

A series of large scale static tests was undertaken to investigate the load-settlement behavior of circular footings over a compressible clay soil and to compare this behavior with that of comparable reinforced granular fill (without geogrid) and reinforcement with a single or two layer of geogrid in the granular fill. Based on the results from this investigation, the following main conclusions can be drawn:

- In natural clay deposits with and without reinforcement, the bearing capacity increases with an increase in footing settlement, while subgrade modulus values decrease.
- The effect of reinforcement on the subgrade modulus is more beneficial at small displacement ($\delta_{10}$=10mm).
- When natural clay deposits are replaced with stiffer granular fill (H=0.67D), the bearing capacity of reinforced soil footing (RSF) increases about 40%.
- The improvement of bearing capacity and subgrade modulus of RSF with geogrid reinforcement (N=2) is higher than RSF with using the stronger granular fill. So, it can be explained that the footing loads are transferred to greater depths through the geogrid layers and the interlocking between the geogrid and the granular fill reduce lateral and vertical displacements below the footing.
- The subgrade modulus values of RSF decrease with an increase in footing size with using of reinforcement with geogrid or the stronger granular fill.

Using model footings with different geometries to search shape effect and geogrid inclusion with different configurations to search the effect of substantial particle breakage on the subgrade modulus values in more detail needs to be investigated by performing plate load tests in the field.

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