Improvement in bearing capacity of soil by geogrid - an experimental approach

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Abstract: When designing structures that will impose a significant load over a large area, such as buildings, tanks, walls, slopes or embankments, geotechnical engineers must address the following situations, especially when dealing with weak foundation soils: bearing capacity failures, intolerable total and differential settlements, large lateral pressures and movement, and slope instability. The construction of reinforced soil foundations to support a shallow spread footing has considerable potential as a cost-effective alternative to conventional methods of foundation support. With this technique, more than one layer of geogrid reinforcement is placed within layers of engineering fill material under the footing to create a composite material with improved performance characteristics.

Here an attempt is made to present the details of an investigation of the performance of geogrid reinforcement in soil. For this purpose, model isolated footing load tests were conducted on soil with and without multi-layers of geogrid at different depths below the footing. The load settlement characteristic for each soil-geogrid configuration was observed. The influence of various selected parameters on the load settlement behavior were studied and critically appraised for their practical significance.

The paper discusses the mechanisms of this system using a large-scale model footing for a case studies in which geogrid-reinforced soil footing is used for a schools project in Saudi Arabia. That site has a very soft silty clay/clayey silt soil, and the large-scale plate loading test was tested according to the procedure of ASTM D1194.

Also, the paper presents the successful application in the use of geogrid-reinforcement. The field observations proved that the geogrid-reinforced system creates an enhancement to the very soft/soft soils and minimizes the differential settlement. The geogrid-reinforced system is more economic and attractive and demonstrates superior performance compared with most other ground improvement techniques and is optimal for rapid construction and/or strict total and differential settlements of the structure and/or a thick and newly placed fill.

Résumé: Lors de la conception des etablissements comme: Batiments,Chateaux.deau,murs soutiens , pentes , barrages , cela suppose que les charges importantes se repartient sur une grande superficie (surface) et specialement les ingenieurs geotecniciens quand ils traitent le sol de faible fondation, doivient traiter les cas suivantes: Cas dechec de support du sol par decapage, descente totale, difference d`abaissement differential, Pressions – laterals, Grands Mouvements, Instabilite des inclinaisons des pentes. L`applicatain de la technique de sol arme et consolide sous les foundations superficielless et peu profondes a de grandes potentialites considererables. C`est une alternative economique pour les methodes traditionnelles dans la consolidation des fondations , Par lutilisation de cette technique plusieurs couches de renforcement de grille Geogride sont mises a linterieur des couches de remblai construcrives sous les fondations pour former une couche de sol fonde qui a des caracteristiques d`execution ameliore. C`est une tentative pour presenter des details experimentals appliques par l`ulilisation de Geogride comme moyen d`armament et d`amelioration du sol , et pour ce but on a executer tsois (3) experience comme modele reel pour tester le chargement du sol: Le premier test a ete effectue sur un sol consolide par plusieurs couches de grilles de Geogride aux profondeurs differentes sous la base (foundations), Un autre test a ete execute sur un sol naturel sans amelioration, Le troisume test pour un sol ameliore par lutilisation de systeme de colnnes pierreuses, ces deux dermiers test sont effectues au voisinage du premier test.

On a observe et enregistre les resultas de la caracteristique d`abaissement du sol sous l`effet de la charge , et ceci pour le sol ameliore de Geogride et pour le sol naturel. L`influlence des divers parametres choisis et emouvants sur les valeurs d`abaissement sous l`effet de charges a ete etudie et a ete evaluee dune maniere critique pour leur signification pratique. Ce papier discute les mecanismes d`execution pratique pour cette exeperience , par lutilisation de grande base de chargement comme modele pour etudier le comportement du sol ameliore par lemploie de grille de Geogride.

La compraraiossn entre sol ameliore par Geogride , sol naturel sans amelioration et sol ameliore par l`utilisation de colomnes pierreuses sous les memes charges. Cette esperience de comparaison a ete faite dans une situation d`un projet d`ecole en cours de construction en Arabie Saoudite. Le sol de de ce site est un sol de limon argile/ argileux tres souple ( doux). Par la des procedures dexcperience et de test de chargement ont ete fait par l`emploie de grande base de chargment selon les caracteristiques Americaine ASTM 1194.

Aussi ca papeir presnte l`application reussites par l`usage de Geogride comme armature el renforcement du sol. Les resultats des experiences sur champ ont prouve aussi que le systeme de sol arme de grille de Geogride cree une ameliorations du sol doux / tres doux et diminue les valeurs de descente totale et de descente differentille.

Le systemc de sol arme de grille Geogride et un systeme tres economique et pratique et demontre quil est superieur compare a la plus part des autres techanique utilisees dans l`amelioration du sol. Aussi Cest une methode ideale pour la construction rapide et diminue la descente totale et l`abaissement differentiel des fondations du batiment a cause des charges subites..

Keywords: settlement, strength, in situ tests, layered materials, load tests.

INTRODUCTION

Rising land costs and decreasing availability of areas for urban infill have established the situation that previously undeveloped areas are now being considered for the siting of new facilities. However, these undeveloped areas often possess weak underlying foundation materials – a situation that presents interesting design challenges for geotechnical engineers. To avoid the high cost of deep foundations, modification of the foundation soil or the addition of a structural fill is essential.

Binquet & Lee (1975a and b) investigated the mechanisms of using reinforced earth slabs to improve the bearing capacity of granular soils. They model tested strip footings on sand foundations reinforced with wide strips cut from household aluminium foil. An analytical method for estimating the increased bearing capacity based on the tests was also presented. Fragaszy & Lawton (1984) also used aluminium reinforcing strips and model strip foundations to study the effects of density of the sand and length of reinforcing strips on bearing capacity. Several authors also studied strip foundations but reinforced with different materials such as steel bars (Milovic 1977, Bassett & Last 1978, Verma & Char 1986), steel grids (Dawson & Lee 1988, Abdel-Baki et al. 1993), geotextiles (Das 1988) and geogrids (Milligan & Love 1984, 1985, Khing et al. 1993, Ismail & Raymond 1995). Other researchers adopted circular (Rea & Mitchell 1978, Haliburton & Lawmaster 1981, Carroll et al. 1987, Kazerani & Jamnejad 1987), square (Akinmusuru & Akinbolade 1981, Guido et al. 1985, 1986, 1987, Guido & Christou 1988, Adams & Collin 1997) or rectangular footings (Omar et al.1993, Yetimoglu et al. 1994).

All of these researchers concluded that reinforcement increased the bearing capacity and reduced the corresponding settlement of the foundations compared to the unreinforced soil. However, it was also realized that an initial horizontal and vertical movement of the reinforcement is needed to mobilize the reinforcing strength. Hence, the ultimate bearing capacity of the reinforced earth would be increased but the initial settlement at small loads still could not be avoided. This is important as the design of foundation systems are usually controlled by limiting the expected settlements, which are generally about three to five percent of the settlement corresponding to the ultimate bearing capacity. Within this range, the traditional reinforced methods cannot develop their strength sufficiently and, consequently, the observed improvement in performance has been limited. For example, Adams & Collin (1997) showed that using a single layer of reinforcement, the pressure producing a settlement of 0.50% of the footing diameter, B, is between 92% and 119% of that for the unreinforced case.

The interaction between the geogrid and soil is very complex. Jewell et al. (1985) identified three main mechanisms of interaction between soils and geogrid: (1) soil shearing on plane surfaces of the grids, (2) soil bearing on lateral surfaces of the grids, and (3) soil shearing over soils through the apertures of the grids. The first two are the skin friction and passive pressure resistance of the contact area between soils and geogrid. The third is the interfacial shear on the surface of a rupture zone created during shearing.

MATERIAL PROPERTIES

Geotechnical specifications

The experiment was conducted at a school project's site. The school project was located at the eastern region of Saudi Arabia close to the Arabian Gulf and the soil investigation found the soil is very soft/soft, light grey/grey sandy silty clay, with shells, with a thickness of 20 m. The soil had low permeability (K = 1.92 x 10^{-4} ~ 3.27 x 10^{-4} cm/sec) and the ground water level was observed at a depth of 1.5 m.

Geogrid

A geogrid is defined as a geosynthetic material consisting of connected parallel sets of tensile ribs with apertures of sufficient size to allow strike-through of surrounding soil, stone, or other geotechnical material (Koerner 1998). Existing commercial geogrid products include extruded geogrid (Geogrid – Tenax LBO 330 SAMP) (which was used in the experiments), woven geogrids, welded geogrids, and geogrid composites. Extruded geogrid are formed using a polymer sheet that is punched and drawn in either one or two directions for improvement of engineering properties. Extruded geogrids have shown good performance when compared to other types for soil reinforcement applications (Cancelli et al. 1996, Miura et al. 1990, Webster 1993). Most geogrids are made from polymers, but some products have been manufactured from natural fibres, glass, and metal strips. This paper, however, will focus exclusively on polymer-based geogrid.

EXPERIMENTAL SET UP

Two bearing capacity tests using large-scale plate load tests were conducted on unreinforced 'natural' soil and on compacted soil reinforced with geogrid. Load verses settlement curves were produced for each test. The variation in bearing capacity over increase in settlement is represented by bearing capacity verses settlement curves.

The loading tests where conducted on two stages. In the first stage the load was increased incrementally until reaching the load of failure; after that unloading was conducted until zero load according to ASTM - D1194. In the second stage a quick loading was performed until reaching the load of failure followed by quick unloading reaching to zero load according to DIN - 18134 1993. The field tests were performed at the site of the school project with isolated square footings of a size 1 m x 1 m and 0.4 m deep (Figure 1). Testing was carried out with a Universal Testing

Machine. For accurate measurement of the load, it was applied through a jack pressure of capacity 200T (=2000 KN) with least count 10T (=100 N). Settlement was recorded using four dial gauges of least count 0.01 mm.

Figure 1. Full scale loading test

Loading test setup on natural soil

- The dimension of the excavation was 2.5 m x 8 m and 1 m depth
- The loading continued until failure load (settlement was 25 mm)
- Maximum stress was 0.6 Kg/cm, and the settlement was 27.75 mm

Loading test setup on compacted soil reinforced with geogrid

- The dimension of the excavation was 6 m x 6 m and 3 m depth
- No compaction was performed on the natural layer of soil
- A cover of woven Geotextile was used on the top of the natural soil
- First layer of Geogrid was used directly on the top of the Geotextile
- The total depth of the construction fill was 2.0 m
- The construction fill on the top of 1^{st} layer of Geogrid was 200 mm
- The construction fill on the top of the next four layers was 400 mm each
- The total number of Geogrid layers was 5
- The loading isolated footing was on the final layer of construction fill
- Maximum stress was 4.2 Kg/cm, and the settlement was 28.85 mm

INTERPRETATION OF RESULTS AND DISCUSSION

Various useful graphs have been prepared based on the observations of the experiment. Following interpretations have been drawn:

- The graph of load verses settlement of unreinforced ‘natural’ soil indicated failure of the soil for a settlement of 27.75 mm at a stress equal 0.6 Kg/cm^2 (Figure 2).
- Improvement in bearing capacity of reinforced soil over that of unreinforced soil was observed for all five reinforcing layers
- The load settlement curves for the reinforced soil test continued to rise beyond the failure point of unreinforced ‘natural’ soil at a settlement of 27.75 mm. This indicated the contribution of reinforcement in resisting bearing pressure
- Reinforced soil is better than natural soil by 7 times and better than stone column by 1.75 times (Table 1).

Table 1. Comparison between natural soil, reinforced soil and soil enhanced by stone column

Soil situation	q_u Kg/cm2	q_{all} Kg/cm2	Total settlement (mm) at maximum load	Safety factor	Note
Natural soil	0.6	0.2	27.75	3	Immediate settlement
Soil reinforced by Geogrid	4.2	0.8	28.85	3	
Soil enhanced by Stone column	2.4	0.8	21.56	2	Data from parallel test

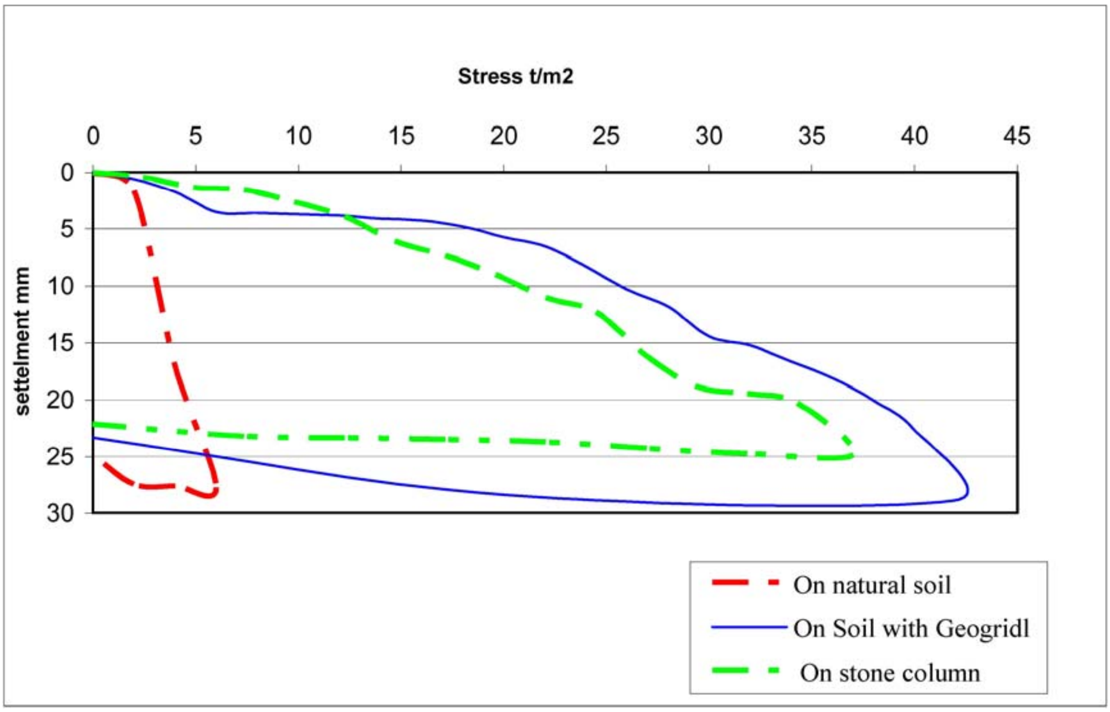

Figure 2. Relation between stress and settlement

CONCLUSIONS

- Considerable improvement in bearing capacity was observed in the reinforced soil compared with the unreinforced soil.
- Cost has been reduced to be 1.5% of the total cost.
- Construction time for the geogrid was less than construction time for stone columns.
- Geogrid is expected to be more stable with time than stone columns.
- Technical work for stone columns needs proficiency but Geogrid method does not.
- Quality control and quality assurance are easier to satisfy than for stone columns.

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