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Multiple layers of geogrids for strength enhancement in a soft Ugandan clayey soil

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ABSTRACT: Rapid urban development has resulted in increased land pressure, including areas with weak foundation soils such as soft clays. These soils often require improvement, using techniques like geogrid reinforcement, in order to increase their bearing capacity and reduce their settlement tendencies. Although geogrid reinforcement has been widely accepted, there is limited research to support its application in soft clays. This study investigated the performance of multiple layers of geogrid reinforcement in enhancement of the bearing capacity of a soft Ugandan clayey soil. Experiments were conducted to investigate the number (N) and the spacing (h) of consecutive geogrid layers that could yield the maximum bearing capacity improvement (BCI). Thus, h and N were the variables, while the width (b) and the depth of embedment (u) of the geogrids were kept constant. Loading tests were conducted under three conditions to determine the percentage strength improvement in terms of BCI: (i) without geogrid reinforcement, (ii) varied h with constant b, u and N, and (iii) varied N with constant b, h and u. The load-settlement characteristic generated from the tests yielded optimum h and N of 50 mm and 3 respectively. The BCI achieved was found to be up to 219%.

1 INTRODUCTION

Escalating land costs and scarcity of areas for urban development have resulted in increased land pressure in previously undeveloped areas. Such areas, however, often possess weak foundation materials (Rahman & Ashraf 2006) such as soft clays. The presence of soft clays on site necessitates geotechnical engineers to make special design considerations, especially for high load-bearing structures such as large walls, storage tanks, storeyed buildings, steep slopes or embankments. Often, a possible fast and long-term reliable way of addressing the design concerns of bearing capacity failures, intolerable total and differential settlements, large lateral pressures and movement, and slope instability is by reinforcing the soil, rather than opting for deep excavations (to reach stronger founding soil), which are usually costly. Geogrid reinforcement is one of the techniques that are currently employed in construction works (Yadu & Tripathi 2013, Sasaki et al. 2004, Kamel et al. 2006). It is applied in the construction of earth-retaining structures (Yang et al. 2009), foundations (Omar et al. 1993) and roads (Ghafoori & Sharbaf, 2016).

In soft clays, geogrids mobilise their strength through lateral restraint (Kiptoo et al. 2015, Kiptoo et al. 2016) by preventing lateral spreading and extrusion of the contained soft soil. Shear stresses generated in the soft soil are transmitted through the interconnected links of the geogrid apertures (Sarkar & Majumder 2012). As a result, a resistive force is generated in the geogrids. Consequently, the resulting geogrid-soil composite is less susceptible to excessive deformation and has increased shear resistance (Sharbaf et al. 2017).

Although, several studies (Shin et al. 2002, Jones 1995, Patra et al. 2005, El Sawwaf 2007) have been published on the effects of geogrid reinforcement on soils in different parts of the world, there is still limited research to support the application of geogrids in soft clayey soils in Uganda.

The study presented in this paper focussed on the use of multiple layers of geogrids to enhance the bearing capacity of soft Ugandan clayey soil in the Lubigi area. It should be noted that although Uganda has an extensive variation of soils, the results and discussions in this paper are specific to the soft clayey soil that was investigated during this study. A bench scale model was designed to measure simultaneous changes in applied load and vertical displacement. The number and spacing of the geogrid layers were varied to ascertain their influence on the bearing capacity of the clayey soil.

2 RESEARCH MATERIALS, SET-UP AND METHODOLOGY

The research materials, experiment set-up and methodology are described below.

2.1 *Testing materials*

A brownish grey soil with a plasticity index of 20.9 %, bulk density of 2.16 Mg/m^3, undrained cohesion (c_u) of 24.6 kN/m^2 and undrained angle of internal friction (ϕ_u) of 2° was obtained from the Lubigi swamp area. Samples were collected up to a depth of 4.8 m using a drilling rig.

TriAx TX160 geogrids supplied by Kaytech (South Africa) were used. The geogrids had an average tensile modulus and tensile strength at fracture of 268 kPa and 1193 kPa respectively. The detailed properties of the geogrids are provided in Musenero (2012). For this study, only the reinforcement function of the geogrids was considered.

2.2 *Bench scale model for loading tests*

The bench scale model was composed of a rectangular loading box (900 mm long, 170 mm wide and 400 mm high), which was designed to model a strip foundation with minimal boundary effects between the soil and the box. The box was heavily braced with equal angle steel sections (50 mm × 50 mm × 8 mm) to eliminate any possibility of structural failure as well as avoid any lateral deformation. One side of the loading box was made of a 6 mm transparent thick acrylic glass to facilitate visual observation of the soil deformation during testing. The rest of the sides of the loading box were made of timber of 5 mm thickness. A timber block (140 mm long, 100 mm wide and 40 mm thick) was used to transfer compression loads from the loading machine to the soil (Figure). The block was made out of dry "musizi" timber (Maesopsis eminii), which had a mean compressive strength of 27 N/mm^2 and shear strength of 8 N/mm^2, parallel to the grain; and the basic density was 407 kg/m^3 (Zziwa et al. 2010).

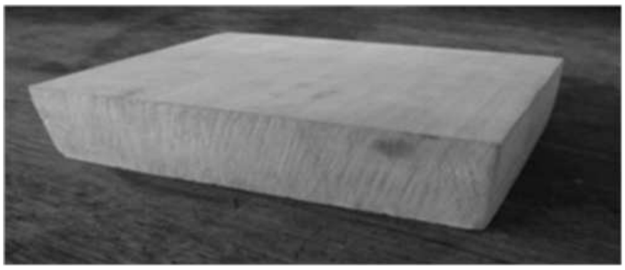

Figure 1. Timber block

Sand paper of grit designation P50 (ISO/FEPA) and average particle diameter 336 µm was placed at the bottom of the block to simulate the rough surface in a structural footing.

2.3 *Methodology*

a) Material preparation

Approximately 170 kg of soil was thoroughly mixed at a moisture content of 66%. This conservative value of moisture content was adopted since it corresponded to the average natural moisture content of soil in the Lubigi swamp area from where the test samples were collected. The moisture content of the soil was ascertained by oven drying a representative portion for 24 hours and sealing the rest of the soil in an airtight bag. If the moisture content was not found to be 66%, it was adjusted by either adding water to it or by allowing the required amount of soil to air dry in order to reduce its moisture content to the desired one.

The geogrid was cut into 150 mm wide and 140 mm long rectangular strips. The width of the geogrids (b) was equal to 1.5B where B was the width of the footing block. These geometric parameters were selected based on the findings of Hartley (2010).

b) Soil loading tests

Soil was placed in the loading box in four consecutive equal layers up to a height of 750 mm. Each layer was uniformly compacted using a 2.6 kg rammer with a drop of 310 mm up to 27 blows in order to achieve the soil density of 2.16 Mg/m^3 that was encountered on site. Depending on the test series, the relevant geogrid configuration was adopted as shown in Table 1.

The loading box was positioned centrally below a 28 kN-capacity compression machine and the timber block was placed in its centre. The prepared sample was then loaded (Fig. 2) at a constant rate of 1.25 mm/min until an ultimate bearing state was reached. This loading rate was chosen because the shear box tests, used to determine the soil's undrained shear parameters, were conducted at the same strain rate. The undrained conditions were considered the worst scenario to investigate under. The ultimate bearing state was defined as the instant when settlement continued at uniform load or where there was an abrupt change in the load-settlement relationship. Settlement of the footing was measured using a displacement gauge attached to the loading machine. The applied load was also recorded.

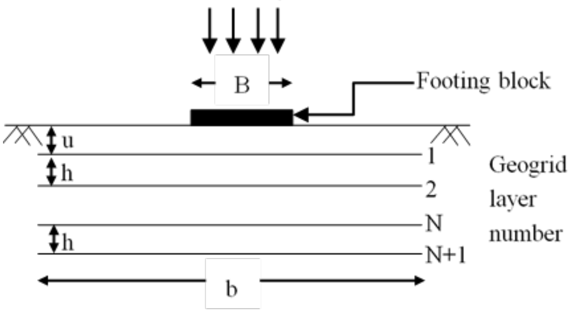

Figure 2. Parameters for the loading tests

Three series of loading tests were conducted. The characteristics of each test are presented in Table. B was the width of the footing block (Fig. 2) which was equivalent to 100 mm.

Table 1. Testing conditions for the loading tests

Test Series	Test Number	Geogrid spacing, h	Number of geogrid layers, N	Constants
I	1	N/A	N/A	N/A
	2	N/A	N/A	
II	3	0.2B	2	u = 0.25B; b = 1.5B
	4	0.2B	2	
	5	0.3B	2	
	6	0.4B	2	
	7	0.5B	2	
	8	0.6B	2	
III	9	N/A	1	u = 0.25B; b = 1.5B; h = 0.5B
	10	0.5B	3	
	11	0.5B	4	

Test Series I: The purpose of this test series was to determine the bearing capacity of unreinforced soil. This was referred to as the control test and it was used to compare the loading capacity of reinforced against unreinforced soil.

Test Series II: This test series was conducted to determine the optimum spacing (h) between geogrid layers. Tests were carried out with two layers of reinforcement and h ranging between 0.2 B and 0.6 B (at 0.1 B increments). This variation of h was chosen to cover the range of findings for the optimal spacing provided in previous work (El Sawwaf 2007).

Test Series III: The purpose of the final test series was to determine the optimum number of geogrid layers (N). This was achieved by varying N from 0 to 4 while setting h at the optimum spacing obtained in test series II. Due to the boundary limitations caused by the depth of the loading box, N was limited to 4. Based on the number of geogrid layers used in previous studies (Raheem & Abdulkarem 2016, Abbas 2018, Verma et al. 2000), N = 4 was deemed adequate for this study.

For Test Series II and III, the distance from the base of the footing block to the first reinforcement layer (u) was set at 0.25 B. This was chosen in order to minimise the influence of dimensional constraints (boundary effects) of the bench scale model on the experimental results by ensuring that the last geogrid layer was not "too close" to the bottom of the loading box. However, it is not fully established what offset of the last geogrid layer and the bottom of the loading box is considered as "very close." Further studies around this argument should be undertaken.

3 RESULTS AND DISCUSSION

During the tests, the applied load (in newtons) and vertical displacement (in mm) were measured. These were used to assess the effect of h and N on strength enhancement of the clayey soil. Furthermore, the results of reinforced soil and unreinforced soil were compared.

3.1 *Test Series I – Control Tests*

Two control tests were undertaken in order to check repeatability of the tests.

Figure shows the load-settlement variations for the two tests carried out on unreinforced soil.

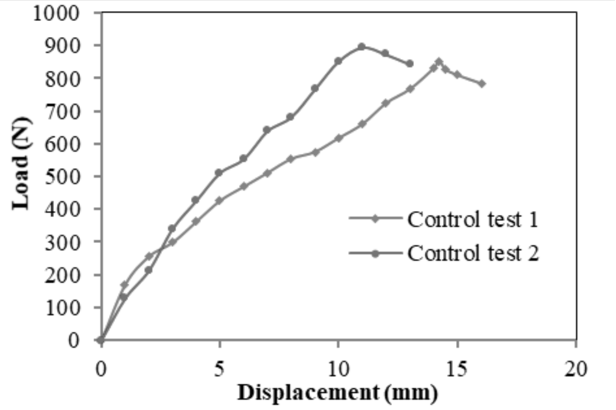

Figure 3. Load-Displacement relationship for unreinforced soil

In both cases, after undergoing initial settlement, the vertical displacement increased steadily with the applied load towards the peak after which the soil samples failed. The soil samples were deemed to have failed when the applied load required to cause further displacement was less than the preceding load. The peak loads recorded for control tests 1 and 2 were approximately 852 N and 895 N respectively. These two peak loads had a negligible standard deviation of 0.001 implying that the experimental setup offered good repeatability.

The ultimate bearing capacity of the unreinforced soil was determined as 156 kPa by using Terzaghi's bearing capacity equation (Eq. 1).

$$q = cN_c + \gamma D_f N_q + \frac{1}{2}\gamma B N_\gamma \qquad (1)$$

Where c = cohesion of soil
γ = unit weight of soil
D_f = depth of footing into the soil
N_c, N_q, N_γ = bearing capacity factors that are functions of the soil friction angle (ϕ). N_c, N_q, N_γ were determined as 6.3, 1.2 and 0.2 respectively.

3.2 *Test Series II – The effect of spacing of geogrids (h)*

For this test series, 2 layers of geogrids were used. The spacing of geogrids (h) was varied from 0.2 B to 0.6 B. Figure 4 presents the load and displacement variation for different values of h.

It can be seen that all the tests under this test series followed the same trend. In addition, the peak applied load ranged from approximately 2087 to 3067 N with the lower and upper bound values being associated with the geogrid spacing of 0.2 B and 0.5 B respectively. It was noted that almost all the peak loads of this test series corresponded to a settlement of approximately 14 mm. It is likely that the foundation failed at this point. As such, any further increment in the applied load did not cause significant change in displacement.

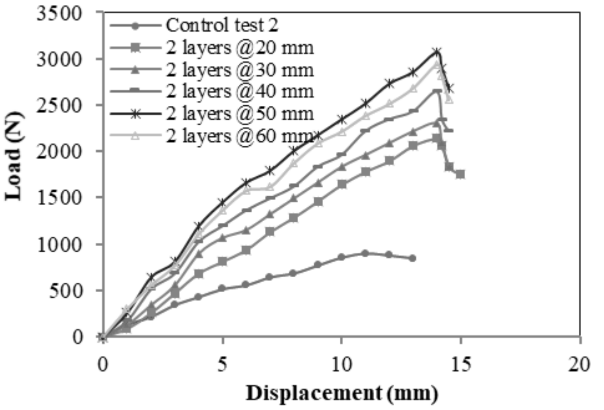

Figure 4. Load-Displacement variation for Test Series II

3.3 *Test Series III – The effect of number of geogrid layers (N)*

In this test series, h and depth of embedment of the first layer of geogrid below the base of the footing (u) were kept constant. N was varied from 0 to 4, with the objective of determining the optimal number of geogrid layers. The peak bearable load increased with increasing N. The increase in peak of bearable applied load was more significant from N = 0 to N = 3. However, for N values higher than 3, a negligible increase in the maximum bearable load was recorded.

Figure 5 shows the effect of N on maximum bearable load applied on the model footing.

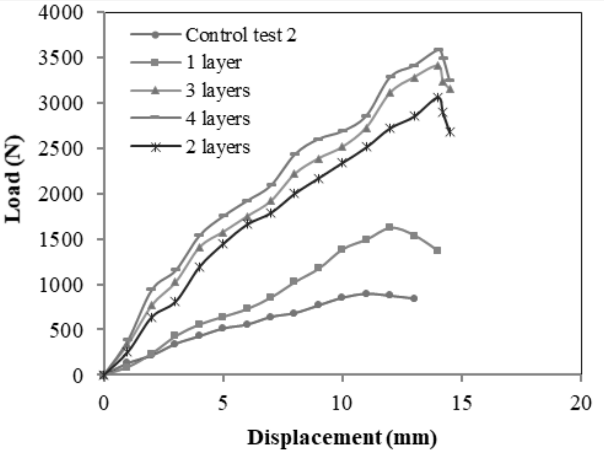

Figure 5. Load-Displacement relationships for Test Series III

3.4 *Bearing Capacity Improvement*

The bearing capacity improvement (BCI) for the different soil-geogrid configurations was calculated at the value of displacement (settlement) corresponding to the highest applied load obtained with unreinforced soil. The value of settlement adopted was 11 mm, which was the displacement at the highest applied load in the second control test. Therefore, BCI was computed as the ratio of the applied load on the reinforced soil at displacement of 11 mm to the maximum applied load on unreinforced soil (Musenero 2012, Patra et al. 2005). This obtained BCI was a measure of how much the strength of the soil had improved for the different reinforcement configurations at the instant when the settlement was 11 mm.

The extent of the reinforcement zone below the footing base (d) and geogrid spacing (h) were normalized relative to B and used in the experiments. d can be related to N through u and h as shown in Equation 2.

$$d = u + \mathrm{h}(N - 1) \qquad (2)$$

The normalised extent of reinforced zone was, therefore, the ratio of extent of reinforced zone to the width of the footing, d/B. Similarly, the normalized spacing (h/B) was the ratio of spacing between consecutive geogrid layers to the width of the footing. BCI was plotted against h/B (Fig. 6).

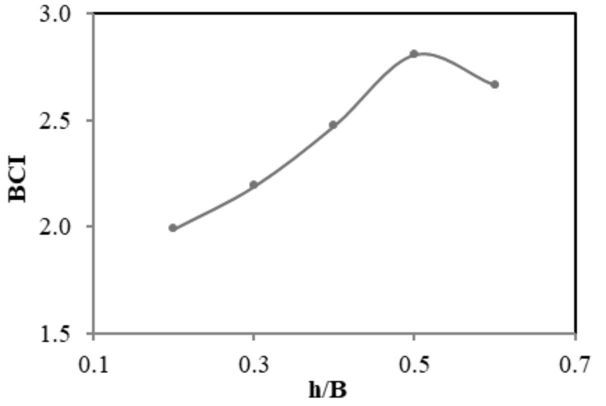

Figure 6. A graph of BCI against h/B for Test Series II

The BCI increased steadily from spacing of 0.2 B to 0.5 B after which it decreased. This is similar to the findings of Amala & Madhumathi (2016). This BCI - h/B relationship can be explained by the theory of geogrid reinforcement. The interaction between the soil and geogrids resulted in a composite material within a confined zone. This geogrid-soil composite had enhanced performance characteristics, which were dependent on the extent and depth of the confined zone. In this investigation, the ultimate bearing capacity peaked when the fully confined zone reached an optimal depth. The optimal fully confined zone depth was achieved when the geogrids were placed such that a continuous confined zone with the maximum possible depth of 75 mm was produced (Nabanoba 2011). Therefore, the spacing of 0.5 B created the optimal depth of the confined zone. This zone stretched from the soil surface to the base of the second geogrid layer (Musenero 2012). The spacing of 0.2 B to 0.4 B created a continuous confined zone. However, the confined zone had yet to reach its maximum depth, which it could only achieve at h = 0.5 B (50 mm). This hypothesis is confirmed by the gradual increase in BCI until it reached the peak value, which corresponded to the maximum depth of the continuous confined zone. Conversely, geogrid spacing of 0.6 B caused the confined zone to become discontinuous, resulting in a decrease in the BCI.

In a similar way, the BCI was assessed for different values of N. A general improvement in ultimate bearing capacity was observed with increasing N (Fig. 7). BCI significantly increased with d/B up to BCI ≈ 3.05 corresponding to d/B = 1.25 (N = 3). This is consistent with the findings of Patra *et al.* (2005) and Kolay *et al.* (2013). Beyond d/B = 1.25, any additional layers of geogrids resulted in a limited change in BCI (BCI of 3.19 for d/B = 1.75). From literature (Shin *et al.,* 2002), the zone of influence of a strip footing is 125 mm from the soil surface – which stretches up to N = 3 spaced at 50 mm in this setting. This implies that when h = 50 mm, the geogrid layers below the 3rd geogrid fall outside the zone of influence. Consequently, they barely contribute to improvement in the ultimate bearing capacity of the soil since they are positioned too deep to absorb any of the stress that is transmitted to the soil. Based on this, it was concluded that the optimum N was 3 placed within a depth of 1.25B.

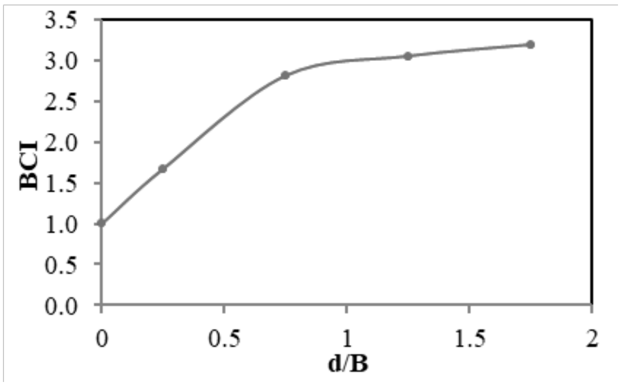

Figure 7. A graph of BCI against d/B for Test Series III

Finally, it can be deduced from Figure 7 that due to the inclusion of geogrids, the BCI was 1.67, 2.81, 3.05 and 3.19 for N = 1, 2, 3 and 4 respectively. This implies that the BCI ranged from approximately 67 % to 219 % corresponding to N = 1 and N = 4 respectively. No direct comparison could be made with the results from previous studies as both the soil type and specimen configurations were different from the ones used in this study.

3.5 *Settlement Reduction*

The percentage settlement reduction (SR) due to the inclusion of geogrids was determined using Equation 3.

$$SR = \frac{s_0 - s_r}{s_0} \times 100 \qquad (3)$$

Where s_0 is the settlement of unreinforced soil at a given applied load and s_r is the settlement of reinforced soil at the same load (Kiptoo et al. 2015). A footing pressure of 895 kN (corresponding to the maximum settlement of unreinforced soil) was used.

From Figure 5, SR was determined as 32 %, 73 %, 77 % and 84 % for N = 1, 2, 3 and 4 respectively.

4 CONCLUSION

The effect of multiple layers of geogrids on the enhancement of strength of a soft Ugandan clayey soil was investigated. The number of geogrids was varied from 0 to 4. The effect of geogrid spacing was investigated using 2 layers of geogrids at variable spacing ranging from 20 to 60 mm. Based on the results obtained from this experimental study, the following conclusions were drawn:

a. The bearing capacity of the soil improved with number of geogrid layers embedded in the soil specimen. Also, the bearing capacity improved with spacing of the geogrids up to an optimal value after which it decreased.
b. The number of geogrid layers (N) that yielded the greatest BCI was 4. Although N = 4 gave the highest BCI, the percentage reinforcement benefit between N = 3 and N = 4 was negligible. This was because the zone of influence of the footing was up to N = 3 for geogrids spaced at 50 mm. Therefore, the optimal number of geogrid layers was 3.
c. For the configuration set up used (B = 100 mm, u = 0.25 B, N = 2, and b = 1.5 B), the optimal spacing between two geogrid layers (h) was 50 mm.
d. The inclusion of multiple layers of geogrids has a higher reinforcement benefit compared to a single layer. For N = 2, 3 and 4, the increase in bearing capacity was in the range of 181 % and 219 % whereas that for a single geogrid layer was only 67 %.
e. Geogrids resulted in a reduction in foundation settlement of 32 %, 73 %, 77 % and 84 % for N = 1, 2, 3 and 4 respectively.

5 RECOMMENDATIONS

The following recommendations were made:

- Foundations are often designed for limiting settlement conditions. Therefore, it may be useful for future studies to define the settlement failure criteria to facilitate more accurate quantification of the effect that multiple layers of geogrid reinforcement have on settlement.
- An investigation, similar to this one, should be conducted with other types of typical Ugandan soils. From the results, geogrid design standards can be formulated relevant to the local soil properties.
- As with all small-scale model tests relating to bearing capacity studies, scale effect influenced the quality of results in this experiment. It is recommended that future studies include large-

scale field models to validate the laboratory-based results.
- It is worth investigating the offset of the last geogrid layer and the bottom of the loading box that is considered as “very close” as to yield significant boundary effect.

6 ACKNOWLEDGEMENT

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