Performance of a granular column underlying a geotextile reinforced sand layer

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ABSTRACT: The granular column technique is a popular approach of ground improvement which is used in construction to enhance the engineering properties of problematic soils. In more recent studies, placement of a geosynthetic within a sand bedding layer which was created on top of the column, has demonstrated better improvements. For this research, a geotextile was proposed for reinforcing the sand layer which rested on a singular sand column of diameter 100 mm so as to improve the load carrying capacity of the weak soil. The column was installed within a local soft silt bed in a laboratory testing tank, and the sample was loaded compressively up to a maximum settlement of 50 mm. Two parameters were varied, namely: geotextile diameter and sand layer thickness. The load-settlement characteristics were recorded and thereafter analysed. Results showed that the lateral geotextile inclusions generally raised the load carrying capacities of the improved ground whereby a diameter covering the entire cross-section was found to produce the highest strength in the treated ground. From the test results, the stress concentration ratios were found to vary between 2.1 and 9.7. It was also noted that the load carrying capacities increased with thicker sand layers.

1 INTRODUCTION

From a study conducted by the Agricultural Geo-Referenced Information System (AGIS 2011), it was deduced that 50% of the South African soil coverage constitute of soils with poor properties. In fact, Diop et al. (2011) reported that expansive soils solely occupy 35 % of that soil coverage. The high percentage of problematic soils, coupled with the need for land to accommodate for further construction, has urged engineers and property developers to reconsider sites which were previously regarded as unfeasible development land.

To address the challenges pertaining to the soil conditions, ground improvement techniques are often employed, amongst which the granular column method appear to be minimally used locally despite their high popularity overseas. For these reasons, previous studies were conducted on soft soils in South Africa whereby it was confirmed that granular columns could effectively improve the geotechnical properties of the local weak soils (Sobhee-Beetul 2012, Aza-Gnandj 2014).

Past studies on granular columns have demonstrated that crushed aggregates and sand are the most common materials utilised to form the columns (Ambily & Gandhi 2007, Sivakumar et al. 2007, Sobhee-Beetul 2012). Under certain ground conditions, these columns may not be adequate to fully support the vertical pressures being exerted post-construction. Hence, this laboratory-based research proposed the combined use of the granular column with a geotextile to produce higher load carrying capacities while also reducing the degree of settlement in a weak soil.

2 LABORATORY INVESTIGATION

2.1 *General information*

The unit cell concept was adopted such that a bespoke steel cylindrical tank of diameter 300 mm was fabricated to carry the bed of silt; the purpose was to replicate field conditions under a more controlled environment to obtain the performance of the improved ground under the different test conditions. The silt was obtained from the Durbanville quarry of Corobrik (a brick manufacturer in South Africa).

Columns of diameters 100 mm and lengths of 400 mm were installed in base silts prepared at liquid limit (LL). The high moisture content was preferred for the silt bed since granular columns are commonly used in grounds of high moisture contents due to their draining abilities. Sand was used to form the columns since it was a readily available material in the locality. Besides, it was clean and easy to work with.

The geotextile was sourced from a local manufacturer of geosynthetics. The mass per unit area of the geotextile was maintained as 200 g/m^2 for all the tests. The following sections further describe the characteristics of the materials as well as the test procedure adopted.

2.2 *Testing programme*

For this study, a total of 11 tests (2 as control tests and 9 for the different testing conditions) were conducted to be able to achieve the required comparisons. An additional 3 experiments were also performed for repeatability purposes to confirm that the laboratory procedure followed was repeatable. Two variables were used in this study namely: the diameter of the geotextile (150, 200 and 300 mm) and the thickness of the sand bed overlying the geotextile (25, 75 and 125 mm). The geotextile diameters were based on the diameter of the column (100 mm) whereby they were always larger than 100 mm. The thicknesses of the sand layer were determined through trial experiments such that they were large enough but not overflowing from the tank during testing. Table 1 describes the characteristics of each test. The pure silt bed is denoted by S, the presence of a 100 mm diameter sand column is shown by C, G indicates the geotextile and T is the thickness of the sand layer on top of the geotextile. The diameters of the geotextiles and the thicknesses of the sand layers for the respective tests are also given.

Table 1. Characteristics of each test

Test code	Descriptions	
	Diameter of geotextile (mm)	Thickness of sand (mm)
S	-	-
S-C	-	-
S-C-G1-T1	150	25
S-C-G1-T2	150	75
S-C-G1-T3	150	125
S-C-G2-T1	200	25
S-C-G2-T2	200	75
S-C-G2-T3	200	125
S-C-G3-T1	300	25
S-C-G3-T2	300	75
S-C-G3-T3	300	125

2.3 *Properties of materials used*

Three different materials were used for these tests, namely: Durbanville silt, Cape Flats sand and Fibertex geotextile. The properties of the silt and sand are summarized in Table 2. Based on this information, the silt was classified as a low plasticity silt (79.4 % of the particles smaller than 0.075 mm) while the sand was found to be poorly graded (98.9 % of the particles smaller than 1.18 mm).

With regard to the geotextile, the manufacturer reported the following properties: unit weight of 200 g/m^2, thickness of 1 mm, tensile strength (MD/CMD) of 15/15 kN/m, static puncture strength of 2600 N, elongation at break of 40 to 65 %, pore size of 90 µm, and a permeability of 0.05 m/s.

Table 2. Properties of the silt and the sand

Property	Descriptions	
	Silt	Sand
Specific gravity (Mg/m^3)	2.71	2.70
Liquid limit - LL (%)	37	-
Plastic limit - PL (%)	30.6	-
Optimum moisture content (%)	17.7	12.5
Maximum dry density (Mg/m^3)	1.7	1.8
Angle of friction (°)	0 (LL)	36 (dry)
Cohesion (kN/m^2)	6.42 (LL)	5 (dry)
Coefficient of uniformity	-	2.83
Coefficient of curvature	-	0.98

2.4 *Sample preparation and test procedure*

To prepare a silt bed in the steel tank, dry silt was mixed at liquid limit by means of a mechanical mixer. The wet mix obtained was stored in an airtight container for 24 hours to allow for even distribution of water in the clay. Subsequently, it was poured in 8 layers in the tank whereby each layer was pressed down by hand so as to expel any large pockets of trapped air. This procedure was repeated for each layer until a bed of 400 mm deep was formed as shown in Figure 1a. For an experiment with only the silt, this bed was loaded to obtain the results for the first control test.

For tests where a granular column was present, a greased metal cylindrical open tube (100 mm diameter) was manually pushed through the centre of the tank until the base was touched. The soil within the cylinder was then augered and its inner surface was wiped to remove any smudge. A predetermined mass of sand was poured through the cylinder which was afterwards retracted by 35 mm. The sand layer was then compacted to form a layer of 50 mm using a 2.3 kg hammer, dropped 12 times through a height of 180 mm. The process was repeated 8 times until a column of length 400 mm was obtained and was levelled with the silt surface. Figure 1b shows a prepared sample with granular column.

Additional improvement of the ground required the placement of a layer of geotextile and sand on top of the silt bed consisting of the granular column. A 5 mm thick layer of sand was first placed on the entire top surface of the silt bed with column. The geotextile, cut to the required diameter (G1, G2 or G3) for the respective test, was then centrally positioned on the sand layer (Fig. 1c), after which more sand was poured on it to cover the geotextile while forming a sand blanket of the desired thickness (T1, T2 or T3).

Once prepared, the sample was subjected to a compressive load, through a centrally positioned 25 mm thick steel disc of diameter twice the column diameter. Each test was operated at a speed of 1.2 mm/min until a settlement of 50 mm was reached (based on a maximum allowable settlement for normal structures according to Eurocode 7). The fast speed was selected to allow for undrained conditions during testing. Figure 1d illustrates a typical test set-up where geotextile was used with the sand layer placed on top of the silt bed improved with the granular column. Load-settlement readings were electronically recorded and used for analysis. The results are presented in Section 3.

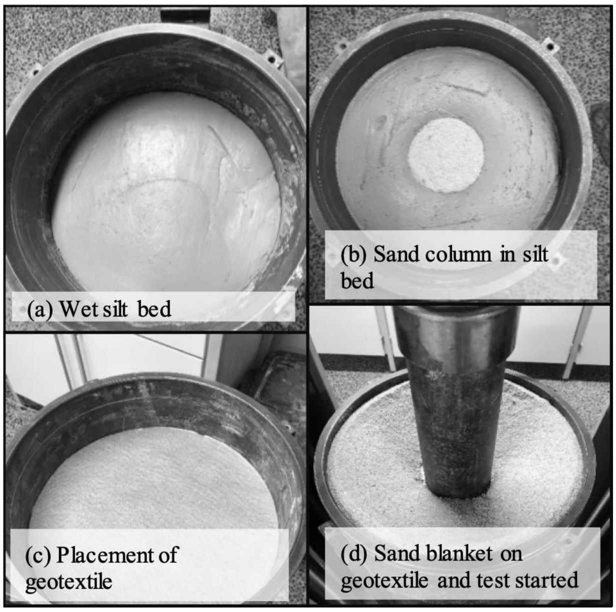

Figure 1. Test sample preparation and experimental set-up

3 RESULTS

3.1 *Results overview*

This section presents the outcome of the study in terms of the following for each test: (1) stress-settlement behaviour, (2) percentage improvement in vertical applied stress achieved in a treated silt bed when compared to an unimproved wet silt, and (3) stress concentration ratio for each test.

3.2 *Stress-settlement behaviour of the treated ground*

Figure 2 shows typical stress-settlement characteristics in treated silts at a moisture content of 37 % (liquid limit). Figure 2a illustrates these relationships for tests conducted with a geotextile of diameter 150 mm and sand thicknesses of 25, 75 and 125 mm. The observations made with geotextile diameters of 200 and 300 mm (varying thickness of sand in each case) are given in Figures 2b & 2c, respectively.

The general trend observed in the shape of the graphs indicate a gradual increase in settlement as the vertical applied stress was raised. In fact, the shapes are rather similar except when a sand thickness of 125 mm was used, irrespective of the geotextile diameter used. A sharp increase in stress was initially experienced, followed by a sudden drop, after which the trend remained similar to those in the other tests. This observation could possibly be due to the larger pressure build-up between the sand particles (when the sand layer is thicker), which suddenly drops as the particles slide past one another.

Generally, since all curves follow relatively similar shapes, this is an indication of the trend for the stress-settlement characteristics when the wet silt was improved using a combination of the granular column technology and a geotextile within a sand layer. Regardless of these similarities, each test displayed different load carrying capacities when a settlement of 50 mm was attained. Despite the differences in the loading response of the improved silt, the combination of the granular column with the geotextile reinforced sand blanket has repeatedly resulted in an additional improvement in strength of the wet clay, with the most remarkable increase occurring when the largest geotextile was used.

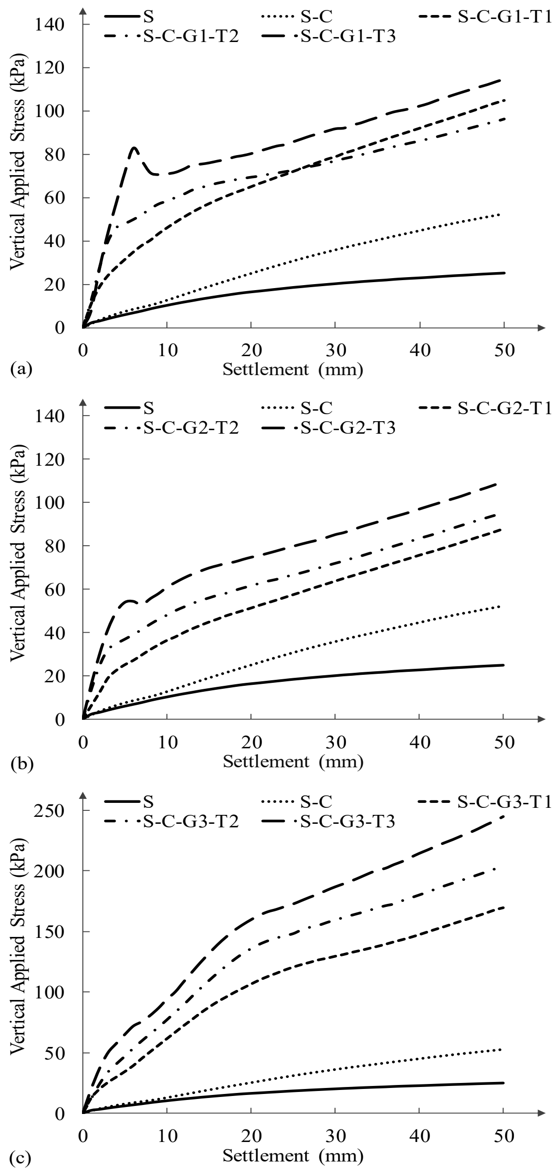

Figure 2. Stress-settlement characteristics for tests with geotextile diameters of a) 150 mm, b) 200 mm and c) 300 mm

3.3 *Improvement in vertical applied stress*

Figure 3 summarises the percentage improvement achieved in the vertical applied stress for each test when compared to that for a pure silt bed.

From the figure, it is evident that the inclusion of the geotextile reinforced sand layer above the column generally resulted in much higher increase in the vertical applied stress. As the geotextiles were made larger, the load carrying capacity was also more pronounced. Additionally, as the thickness of the sand layer was augmented, the gain in strength generally heightened, irrespective of the diameter of the geotextile. These observations can be explained in terms of the better shear strength properties of the geotextile and the sand compared to the silt. The placement of the sand blanket also allowed for distribution of the load within it prior to being transmitted to the improved silt bed. Since sand is much stiffer and, therefore, has a larger bearing capacity than silt, thicker sand layers allow for even more significant load carrying capacities. An exception is, however, noted in the test with a geotextile diameter of 200 mm and sand thickness of 75 mm (S-C-G1-T2). In this case, the percentage improvement dropped when the diameter of the geotextile was raised from 150 mm. This could have been an anomaly since this behaviour was only noted herein.

Overall, the optimum improvement of 875 % was recorded in the test where the largest geotextile and the thickest sand layer were utilised (S-C-G3-T3). This was 8 times higher than that achieved with a silt bed improved with only the granular column.

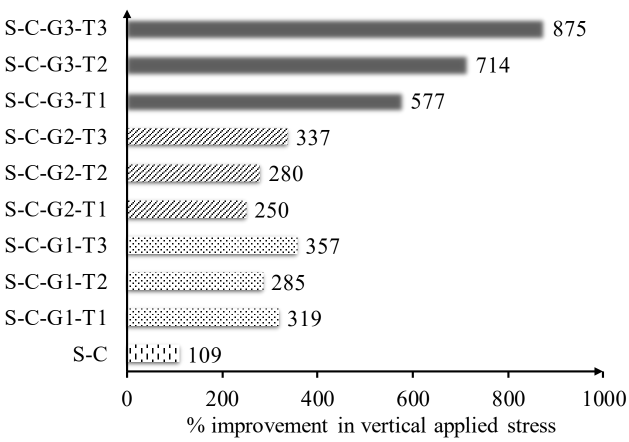

Figure 3. Percentage improvement in the vertical applied stress for each test

3.4 *Stress concentration ratio*

The stress concentration ratio *n* is an important factor which is considered in the design of granular columns, especially when computing the bearing capacity of grounds improved with this technology. It is essentially the ratio of the vertical stress on the column to that of the soil. The determination of this stress has varied from one author to another although the concept remains similar. When a granular column improved soil is vertically loaded, the applied stress is redistributed due to the higher stiffness of the column material; consequently, a higher stress concentration is experienced by the column if the column and the surrounding soil is assumed to undergo equal deflection (Barskdale & Bachus 1983, Griffith 1991, Bergado et al. 1996).

In this study, the load was not directly applied to the column, but rather to the sand layer which was placed on top of it. However, the stress concentration ratios were still determined with the aim that they can be utilised in future research works in order to establish a more accurate method of determining the bearing capacity of a ground which has been treated with a combination of both granular columns and a geotextile reinforced sand layer. Figure 4 displays the *n* values calculated for each test. Curves have also been plotted to establish a potential relationship between *n* and the thickness of the sand layer. Each curve illustrates this relationship for the respective geotextile diameter utilised (G1, G2 or G3).

From Figure 4, it is evident that the addition of the geotextile reinforced sand layer further increased the value of *n* from 2.1, regardless of the diameter of the geotextile and the thickness of the sand layer. Generally, the stress concentration ratio increased as the thickness of the sand layer was augmented for all 3 geotextile diameters. The trends of the curves followed for geotextile diameters of 150 and 200 mm were rather similar. This is likely due to the small difference between the two diameters. However, the observation was more pronounced when the geotextile diameter doubled from 150 to 300 mm. Under these conditions, the stress concentration ratio in the 300 mm diameter geotextile was approximately twice that in the 150 mm one for all three sand layer thicknesses.

Based on the trends obtained in Figure 4, the shape of the curve indicates that much higher load carrying capacities are attained when the geotextile laterally spreads over the entire cross-sectional area of the unit cell. This is explained by the larger extent of reinforcement achieved in the sand upon inclusion of the largest geotextile.

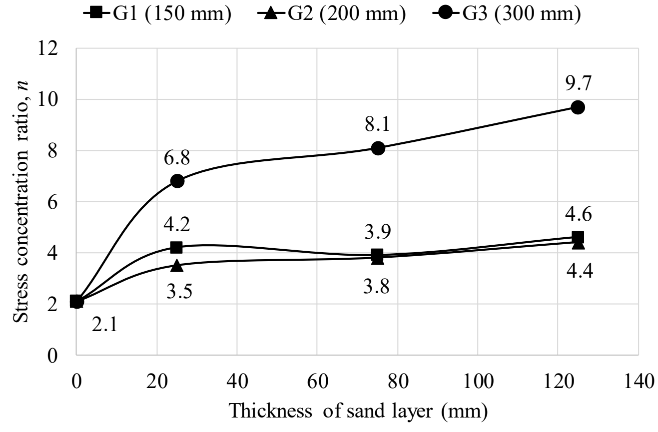

Figure 4. Stress concentration ratio determined for each test

4 CONCLUSIONS

This study demonstrated that the addition of a geotextile reinforced sand layer on top of a ground, treated with granular columns, further improved the load carrying capacity of the ground. With regards to the geotextile diameter variation, it was observed that the diameters of 150 and 200 mm produced results with relatively low variation. However, when the diameter was doubled from 150 mm, more remarkable changes were noted whereby the percentage improvement in load carrying capacity was approximately 8 times that of a silt bed which was improved with only a granular column. In terms of the sand layer thickness, it was apparent that the thicker the sand layer used, the stronger was the treated silt. This was clearly reflected in the stress concentration values which varied between 2.1 and 9.7 in this research. Overall, the optimum results, with 875 % of improvement in the load carrying capacity, was recorded in the test where the largest geotextile and the thickest sand layer were utilised.

From the results obtained, it is recommended that further research be undertaken to investigate the scale effects associated with the laboratory model. Furthermore, factors such as the mass per unit area of the geotextile and the column material may also be studied. Based on the results, numerical analysis must be performed followed by some field tests to validate the laboratory findings.

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