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Membrane action in geotextile laying on a void

P.M.F.VIANA, B.S.BUENO, University of São Paulo, São Carlos, Brazil

ABSTRACT: To contribute in the development of a proper design method to predict deflection, deformation and tensile stress on stretched geosynthetic a small scale test program were carried out at the laboratory to register stress and deformation of geosynthetic layer resting on a bottom of small test tank (1500 mm x 700 mm x 500 mm). The bottom of the test tank, which incorporated a yielding trapdoor (100 mm x 650 mm), and the compacted soil were fully instrumented with load cells and dial gauges. This apparatus allowed the recording of the load transference from yielding zones to higher rigidity zones as well as the geosynthetic deflections. In this way, the membrane action and the stress reduction on the trapdoor caused by the presence of the geosynthetic could be quantified. In addition, the deformed shape of the geosynthetic was measured and compared with analytical results.

1 INTRODUCTION

The use of geosynthetics as reinforcing elements in geotechnical works is growing everywhere in the world. Applications encompass retaining structures, steep slopes, shallow foundations, pavements and works on soft soils.

Geosynthetics can also be used to build embankments passing over localized or longitudinal voids that can arise in the soil mass as a consequence of several causes including differential soil movements, karstic collapse, soil dissolution, depressions and localized subsidence. In this application the geosynthetic can support part of the vertical stress that reach the top of the void, due to the self weight of the embankment or/and surcharges by the called membrane effect.

The theory of the stretched membrane is based on the fact that as it deforms under loading it mobilizes its longitudinal tensile resistance. If the boundary conditions do not change and membrane does not creep the system reaches a permanent equilibrium

When bridges a void with sufficient length to guarantee pull out capacity a geosynthetic can be considered a stretched membrane. Under vertical stresses due to self weight of embankment and external loads it deflects vertically, deforms and mobilizes tensile resistance as an anchored membrane. As it stiffness increases its loading capacity also increases. Therefore impractical applications the designer has to predict more accurately possible the vertical load reaching the geosynthetic in order to compute its tensile stress and to select a proper material to attend requirements of codes of practice.

Because of the high loading carrying capacity of geosynthetics extending over voids or embedded into soil mass but resting on compressible soil layers several analytical models and experimental researches have been developed so far and it is worth mentioning the contribution due to Bonaparte & Berg (1987), Giroud et al. (1990), Poorooshasb (1991), McKelvey III (1994), Giroud e Noiray (1981), Milligan et al. (1988), Espinoza (1994) and Raumann (1982). Figure 1 presents a example of application of geosynthetics to reinforce works on soft soils.

Despite the large research effort directed to the understanding of membrane effect many aspects of the interaction between soil and geosynthetics is not fully understood. Besides that tensile stress and geosynthetic deformation can not be computed with confidence yet. Among the aspects which deserve further investigation it can be mentioned its deformed shape under loading and the magnitude of the vertical load that is really applied to it since as it deforms part of the vertical load is redistributed to the lateral soils by arching. It is also important to verify the working hypothesis that the edges of the voids do not deform as the geosynthetic is stretched.

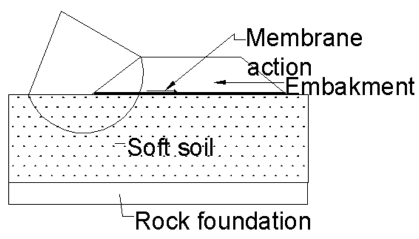

Figure 1. Membrane effect in works on soft soils.

Figure 2 sketches the interaction between soil, geosynthetic and void.

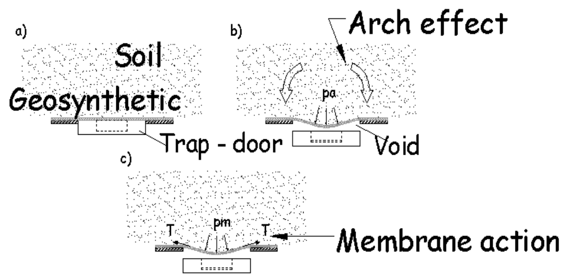

Figure 2. Membrane action in geosynthetic laying above a yielding trapdoor

1.1 *Objective*

This paper evaluates the membrane action of geotextiles laying on a void.

The work comprised (i) a small scale testing program at laboratory to register vertical stresses in the soil mass and deformation of geotextile, (ii) the development of an analytical method to calculate deformation and tensile stress of the geotextile and (iii) numerical simulations of the tests carried out at laboratory in order to get a better insight of the experimental results.

2 MATERIALS AND METHODS

The experimental program was carried out using a small tank (1500 mm x 700 mm x 500 mm), Figure 3. The tank was a rigid steel structure with smooth side walls that could simulate a plane state of deformation. At the center of the tank bottom plate a transversal narrow opening allowed to fit a longitudinal yielding trapdoor. Downward movements of the trapdoor could simulate void formation or soil settlements and therefore the whole mechanism of load transference to the geosynthetic could be investigated. If the trapdoor was removed and a geosynthetic sheet was placed on the bottom of the test tank bridging the void one could simulate the building of an embankment over a void. In this case direct access to the geosynthetic sheet was possible allowing to register its deformed shape. Figure 4 shows details of the trapdoor.

Three earth pressure cells were fixed to the bottom of the test tank and to the center of the trapdoor to register vertical stress during the tests. Cell C00 was fixed at the center of the trapdoor, cell C01 was placed at a distance of 100mm from the edge of the trapdoor and cell C02 at 200mm from the same reference.

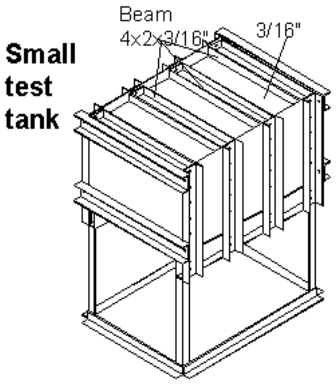

Figure 3. The small test tank

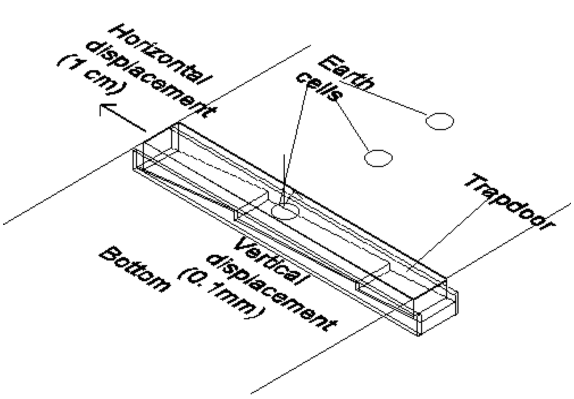

Figure 4. The trapdoor

The cross sectional deflections of the geosynthetics was measured by two dial gages fixed at the below the test tank with accuracy of 0.01mm.

A uniform surcharge was applied on the soil surface via an air bag.

Two soils were used in this experimental program, a pure sand (Soil A) and a fine sandy soil, with 15% clay (soil B). Table 1 shows the main geotechnical characteristics of these two materials.

Table 1 Properties of the soils used in the experimental program

Soil parameter	Unit	Soil A	Soil B
γ_{dmin}	kN/m^3	14.8	16.60
γ_{dmax}	kN/m^3	17.7	18.38
c	kPa	-	20
ϕ	^{0}	36	32
ν	-	0.35	0.39
K_0	-	0.54	0.64
E	kPa	38,000	5,000

Soil A was deposited in the test tank by raining technique (Kolbuzusky 1948) and soil B by tamping (compaction degree ≥ 85% of Proctor standard test and moisture content of 10,7%).

Three non-woven geotextiles with 25, 50, and 130 g/m^2 and axial module (EA) equals to 4.5, 25 e 100 (kN/m) were used. Figure 5 shows their tensile test results according to ASTM D 4595.

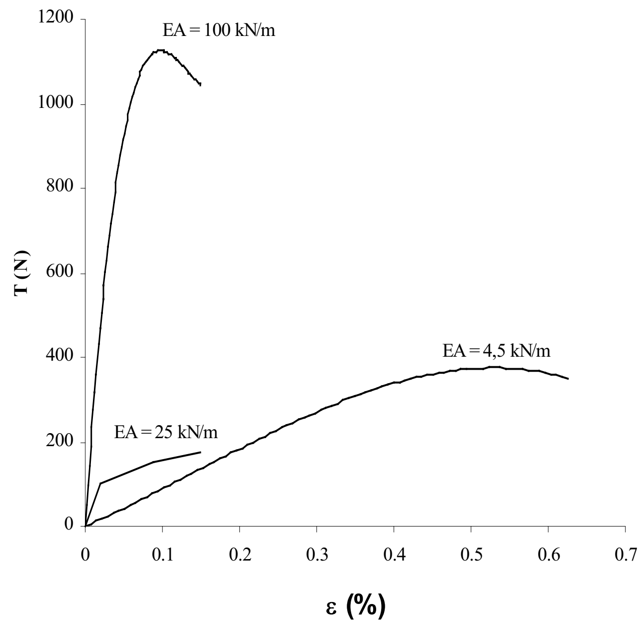

Figure 5 Tensile test results of tested geotextile carried out according to ASTM D 4595

3 THE TEST PROGRAM

In this experimental program ten tests were performed, Table 2. Two of them, called reference tests, were carried out without the geosynthetics. In these two tests, the vertical stress at the bottom of the tank was measured as the trapdoor moved downwards and these results were used as reference for the other tests.

In the other tests the variables investigated were the type of the soil, the geotextile axial module (EA) and the length of the geosynthetic resting on the bottom of the test tank and bridging the void. In this tests the trapdoor was removed and it was possible to register the geometric form of the geotextile under loading.

4 RESULTS

Figure 6 shows typical results of vertical stress measured in the reference tests and obtained by numerical simulations with Plaxis V.7.12. In the left hand side the Figure shows stress results measured by the three earth cells for a at rest condition. In the right hand side it is shown stress modifications caused by movements of the trapdoor.

Table 2 Nomenclature used to identify the tests

Test number	Soil type	EA (kN/m)	Reinfoircing length (mm)
10	A	-	300
11	A	25	300
12	A	4.5	300
13	A	100	300
11r	A	25	150
20	B	-	300
21	B	25	300
22	B	4.5	300
23	B	100	300
21r	B	25	150

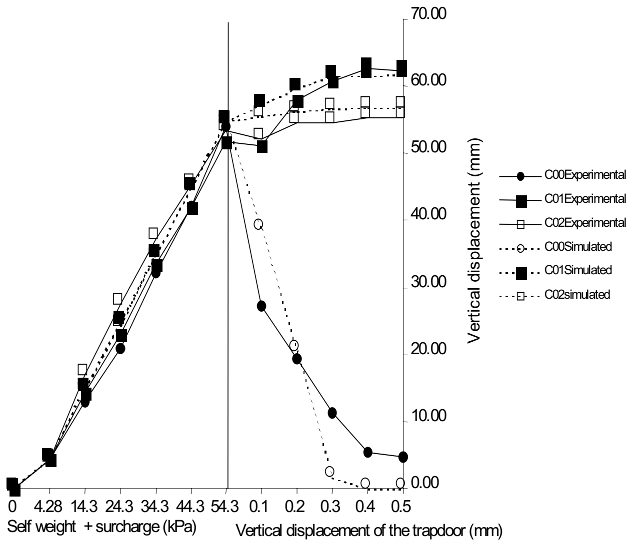

Figure 6. Results of vertical stress measured in test 10 and obtained with numerical simulation using Plaxis.

As can be seen very small downward movements of the trapdoor induce arching effect which reduce vertical stress on cell C00 to values of 10% of self weight plus uniform surcharge. To reach an asymptotic value required movement was 0.5mm which correspond to 0.5% of trapdoor width.

Figure 7 presents a typical result concerning the deformed shape of the geotextile under loading. As can be seen it can be approximated very well by a parabola, with equation of the form:

$$y = ax^2+b, \qquad (1)$$

Figure 8 presents for all the eight tests the vertical displacement of the geosynthetic at the center of the void as the embankment was compacted and also during surcharge application. As can be seen most of the displacements occur during construction. Besides that it can be said that the largest displacements happen when the first two or three embankment layers are built.

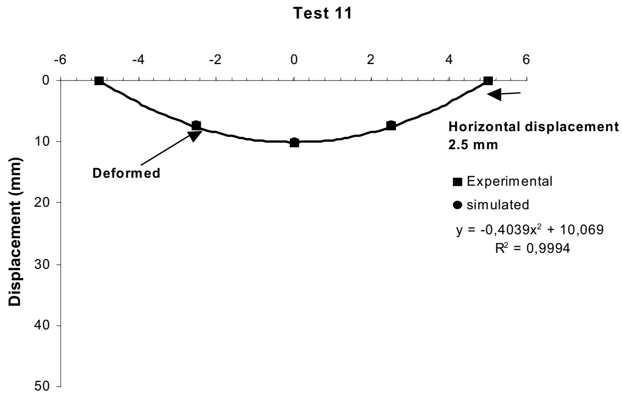

Figure 7. Typical result of the vertical displacements of experimental tests accomplished in the tests box.

Based on these results one is tempted to suggest that when dealing with geosynthetics bridging voids, two loading situations may be considered:

a) *small heights of cover*: the vertical stress reaching the geosynthetic is due to the self weight of soil layers plus compaction loads. Since most geosynthetic deformations happen during the construction of the first layers there is little chance of arching to occur because it may be destroyed by compaction. Therefore at the end of construction the vertical stress can be assumed as being the geostatic stress but to compute geosynthetic deformation compaction load must be also considered;
b) *high heights of cover*: above a critical height of cover the effect of compaction on deformations of the geosynthetic tend to disappear. Further deformation is caused by dead and external loading and this can induce arching effect.

For condition b) the total deformation of the geosynthetic is the sum of deformation which occurs due to a), which is the major component and happens while height is below a critical value (H_c), plus deformation due to embankment loads due to layers above H_c. To calculate the stress on the geosynthetic Marston for heights above H_c theory for pipe in trench can be used as proposed by Giroud et al. (1991).

The major difficulty arise in definition of this critical height of cover which also depends on the compaction equipment. For preliminary calculation it can be estimated as H_{crit} = 1.5B, being B the width of the void.

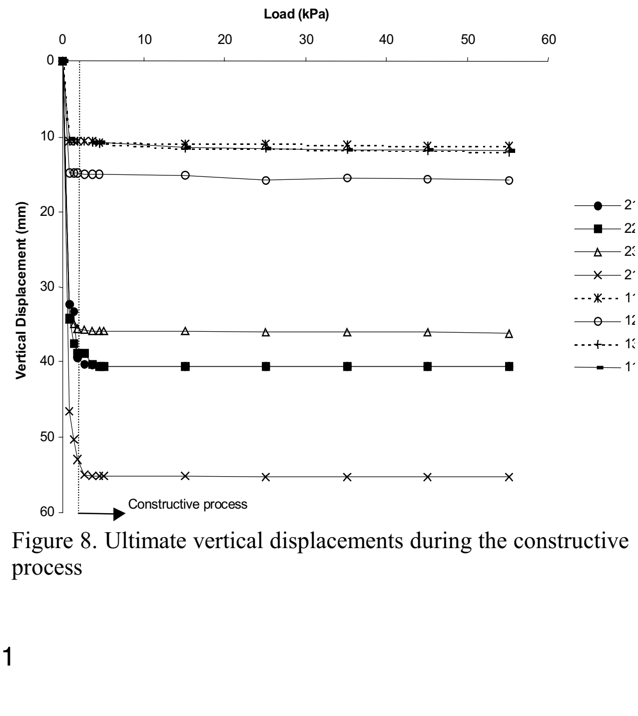

Figure 8. Ultimate vertical displacements during the constructive process

4.1 *An analytical method to compute the tensile resistance of geotextile*

Having the deformation of the geotextile along the width of the void, it was possible to calculate the tensile stress in the geotextile using a theoretical development for loads in stretched tendons. Since the deformed shape of the geotextile could well be approximated to a parabola, Figure 6, one can compute the deformation of the geotextile by:

$$\beta = \frac{2}{3}(\frac{y_b}{b})^2 \quad (2)$$

$$y_b = \sqrt[3]{\frac{3pb^4}{4EA}} \quad (3)$$

And from this result to calculate the tensile resistance as:

$$T = EA\,\beta: \quad (4)$$

In these expressions p = vertical stress on the geotextile (kPa); b = L/2 – half width of the void (m); EA = axial rigidity of the geosynthetic (kN/m); y_b = vertical displacement of the point b.

Results of tensile resistance of the geotextile predicted by this analytical method are summarized in Table 4 which also present data from numerical simulation with Plaxis 7.12.

Table 4 Vertical displacement (1) experimental, (2) simulated with Plaxis 7.12, (3) predicted usyng the analytical method, and tensile stress (1) calculated using measured vertical displacement and (2) calculated using predicted vertical displacement.

	Tensile stress (kN/m)		Vertical displacement (mm)		
Tests	1	2	1	2	3
11	0.06	0.05	2.80	2.70	3.11
12	0.09	0.09	8.42	8.42	8.40
13	0.28	0.03	3.25	3.20	1.11
11r	0.07	0.05	3.15	3.10	2.70
21	12.9	13.9	44.06	43.96	45.63
22	2.33	7.8	44.15	44.00	80.83
23	32.6	22.0	34.98	35.00	28.75
21r	44.4	13.8	81.61	82.00	45.63

Considering that the deformed shape of the geosynthetic could be approximated very closely to a parabola one can compute the displacement, deformation and therefore the tensile stress using the analytical method. Therefore since the vertical displacement shown in column 1 of Table 4 are the correct values they can be used to check the working hypothesis concerning the proposed way to consider vertical stresses on the geosynthetic.

As can be seen values of displacements of column 1 and 3 apart from tests 13, 22 and 21r can be considered very close together. The analytical method requires that the edges to not deform when the geosynthetic stretches. However in tests 13 and 21r it was registered edge displacement of 6mm in both tests. This is certainly the main reason for the large discrepancies observed between experimental end predicted results.

5 CONCLUSIONS

Based on the results presented the following conclusions can be made:

a) Geosynthetics bridging longitudinal void deform in a parabolic form;

b) Most of the deformation of geosynthetics bridging void occurs during construction period and particularly during building of the very first compaction layers;

c) A simple theoretical method developed to compute tensile loads in stretched tendons can be used to predicted the deflection, deformation and the tensile stresses of the geosynthetic resting on longitudinal void;

d) The main difficulty in using the model to compute the tensile strain rests on the definition of the vertical load on the geosynthetic. A suggestion was made to overcome this difficulty and consists in considering two construction steps. In the first step compaction loads are relatively high, destroy any arching and must be considered in the calculation of geosynthetic deformation. Above a critical height compaction load are of small importance and arching can develop. Vertical loads can be calculated using Marston theory for underground pipes.

6 ACKNOWLEDGEMENTS

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