USE OF HIGH-STRENGTH GEOTEXTILES OVER PILES - RESULTS FROM A FULL-SCALE TEST

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ABSTRACT: Geosynthetic-reinforced embankments over piles are starting to become a commonly accepted method of construction over weak soils. For optimum system behaviour, construction of pile caps and concrete slab footing is often required, and this increases construction costs. To replace the concrete slab footing and to optimize the size of the pile caps, instrumented full-scale tests have been performed in a test pit at NUS Singapore. The Polyfelt Group and the University of Grenoble (IRIGM) were also involved in the research. A geosynthetic test structure of 0.5 – 1.5 m height was constructed on a group of piles. The sand surrounding the piles was then removed in order to observe the transfer of loads and deformations. The soil total pressure, the pile loads and the deformation profile of the geotextile were recorded using appropriate instrumentation. The results obtained show that for the geometry of the embankment tested, the vertical loads due to the embankment are transmitted to the piles primarily by membrane effect.

1 INTRODUCTION

Soil subsidence is a major problem in the construction of embankments and other structures on soft ground. Surface settlement is a problem resulting from this phenomenon. Reinforcement with vertical piles has been widely used to minimize this problem. But the piles on which the embankment is constructed must have large pile caps, or the piles must be close to one another, to ensure the effectiveness of load transfer via a soil arching mechanism.

In recent years, this concept has been refined by adding a reinforcing geotextile at the base of the embankment (Fig.1) in order to increase the pile spacing, improve the effectiveness of load transfer and speed up construction as well as to reduce the pile-cap size. Hence, a more cost effective and maintenance free embankment can be obtained.

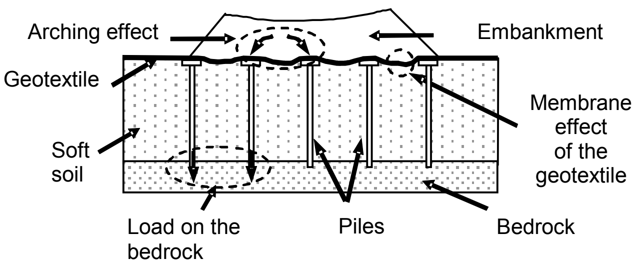

Figure 1 – Reinforced embankment by piles and geotextile.

Adding a geosynthetic allows the transfer of the total vertical load due to the weight of the embankment to the piles in order to minimise the stress on the soft soil. The vertical embankment load can be directly transferred to the piles by the arching effect or indirectly by way of the membrane effect.

The arching effect acting in the embankment allows a direct transfer of part of the vertical load to the pile caps. It depends on the geometry of the embankment and the foundation (shape and width of the pile caps, distance between piles, and the geometry of the pile placement) and on the geotechnical characteristics of the soil.

The membrane effect allows the transfer to the pile caps of that part of the load which is not applied by arching effect.

The design of this kind of structure is complex (arching effect, membrane effect, overall and local loads on the pile caps, subgrade reaction). The methods available today do not allow all these parameters to be accurately assessed for an efficient design of the structure.

To improve the knowledge of the behaviour of reinforced embankment with piles and geotextiles, a full-scale instrumented experiment was launched in Malaysia in July to September 2002, in collaboration with the Lirigm of Grenoble, the National University of Singapore and Bidim Geosynthetics (a member of the Polyfelt group).

2 FULL-SCALE EXPERIMENTS

2.1 *Type of experiment*

Five full-scale instrumented experiments simulated the behaviour of reinforced structures with piles and geotextiles (Tab.1). The main purpose of the experimentation was to illustrate the membrane effect and the arching effect in one particular case (no influence of the soft subgrade). However, in order to carry out the experiments, a subgrade soil was installed around the piles to support the embankment during construction.

For the given pile geometry (equal spacing, triangular distribution), different heights of soil embankment were tested (0.5 m to 1.5 m). Two types of soil were used to construct the embankments: a sandy gravel and a residual soil. The properties of the sandy gravel (less than 1% silt) are shown in Table 2.

In experiments 2 and 3, after the subgrade soil had been excavated measurements made, a new embankment

(Fig.2) was added on the top of the first embankment as a surcharge, and trafficking was continued. The surface settlement obtained did not restrict the passage of vehicles.

A "no-geotextile" experiment, shown as experiment 4, was performed and compared with the results of the geotextile-reinforced experiments.

Experiment 5 was carried out to test the influence of the tensile rigidity of the geotextile on the results.

Table 1 – Details of the experiments performed

Series	Number of GTX sheets	Fill height (m)	Additional fill height (m)	Rein-forcement type	Fill Type
1	2	0.5	-	PEC 75	Sand
2	2	1.0	0.5	PEC 75	Sand
3	2	0.5	1.0	PEC 75	Residual soil
4	-	1.0	-	No geotextile	Sand
5	1	1.0	--	TS60	Sand

Table 2 – Soil properties of the sandy fill material

Properties	Value	Properties	Value
Specific gravity	2.65	Maximum dry unit weight (kN/m^3)	19.4
Internal angle of friction (°)	37	Minimum dry unit weight (kN/m^3)	14.9
Cohesion (kN/m²)	19	In-situ bulk unit weight (kN/m^3)	19.0
Optimum moisture content (%)	11.4	In-situ moisture content (%)	6 - 10

Figure 2 – Final embankment of experiment 2 before traffic tests

2.2 *The geotextiles*

The two geotextiles used are respectively: a nonwoven geotextile reinforced by high-modulus polyester yarns in one direction (Rock PEC75), and a nonwoven continuous filament polypropylene geotextile (TS 60). In experiments 1, 2 and 3, two layers of geotextile were placed over the piles caps in two orthogonal directions. The sheets are clamped in a mobile steel frame (Fig.3) fixed around the test pit.

The principal mechanical properties of the two types of the geotextiles are shown in table 3. The values given correspond to the average values measured in the laboratory. The reinforcement machine direction (MD) refers to the yarns running in length direction. The cross-machine direction (CD) is the direction perpendicular to MD.

Table 3 – Technical properties of the geotextile sheets

Property	Rock PEC 75	TS 60
Tensile strength at break (MD/CD)	75 / 14 kN/m	19/19 kN/m
Elongation at break (MD/CD)	13 / 60 %	100 / 40 %
Thickness (mm)	2.3	2.2
Mass (g/m²)	340	250

Figure 3 – Layers of geotextile crossed and fixed on a steel frame

Figure 4 – Geotextile with strain gauges being installed in the pit

2.3 *The test pit and piles*

The experiments were carried out in a test pit (Fig.5) 3 m wide, 4.75 m long and 2 m high. Three of the four walls of the test pit are made with concrete; Wall 4 is a 0.015 m thick steel plate reinforced by triangular frames. Two doors were created on this plate in order to remove the subgrade soil and to allow the measurement of vertical displacements of the geosynthetic sheet.

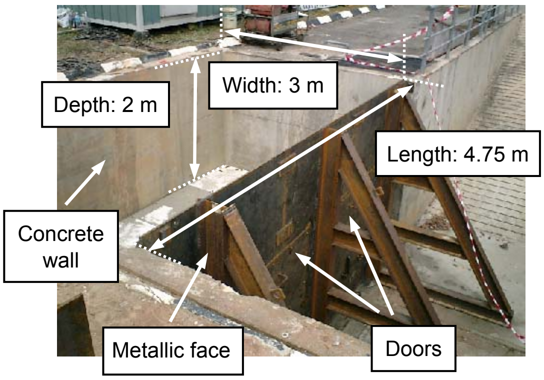

Figure 5 – View of the test pit

Eight steel piles, 1 m high (Fig.6) made of I-beams were fixed in a triangular grid at 1.2 m spacing. The steel pile caps are circular with a diameter of 0.205 m. The piles are surrounded by the subgrade soil (sandy fill material used for the building of the embankments of experiments 1, 2, 4 and 5).

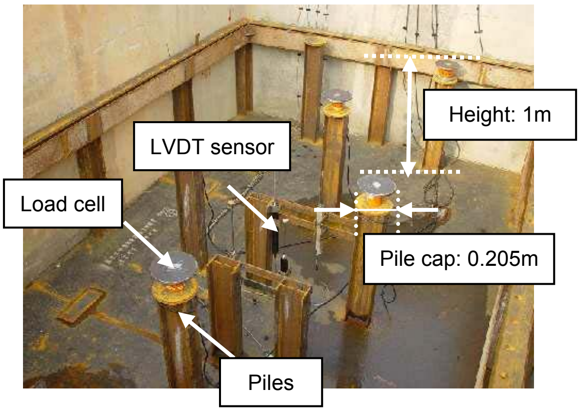

Figure 6 – View of the piles before installation of the sand

2.4 *Instrumentation*

Instrumentations were installed to measure, during the test, the vertical displacements and the deformations of the geotextile, the vertical surface displacements of the embankment, and the vertical loads supported by the piles.

The sensors used are:

- 4 LVDT sensors positioned on the centre of the test pit (Fig.6) to measure the vertical displacement at any point on the geotextile,
- 30 to 40 strain gauges (Fig.4) positioned in two directions on the two geotextile sheets to measure the deformations in the longitudinal and the transverse directions,
- 5 load cells (Fig.6) placed between the geotextile and the pile caps to measure the vertical load applied to the piles.

Manual measurements were done at each stage of the experiment to confirm the sensor readings: vertical displacements of the geotextile and vertical settlements of the surface embankment were measured.

3 EXPERIMENTAL RESULTS

The main results presented here refer to different stages of the experiments.

- Measurements made after removal of the subgrade soil,
- Measurements made after construction of the upper embankment,
- Measurements made during trafficking tests.

3.1 *Deflection of the geotextile*

The vertical displacements of the geotextile sheet are measured with the LVDT sensors and at each stage of the experimentation with manual measurements. The mean results obtained on cross-section D as defined in figure 9, are presented on the following figure. The membrane effect acting around the piles is shown in figure 8.

Figure 7b shows that the action of the weight of the first embankment (H = 1 m) is, due to the membrane effect, greater than the action of the weight of the upper 0.5 m high embankment (maximum vertical displacements of 0.195 m for H = 1 m and 0.215 m for H = 1.5 m respectively).

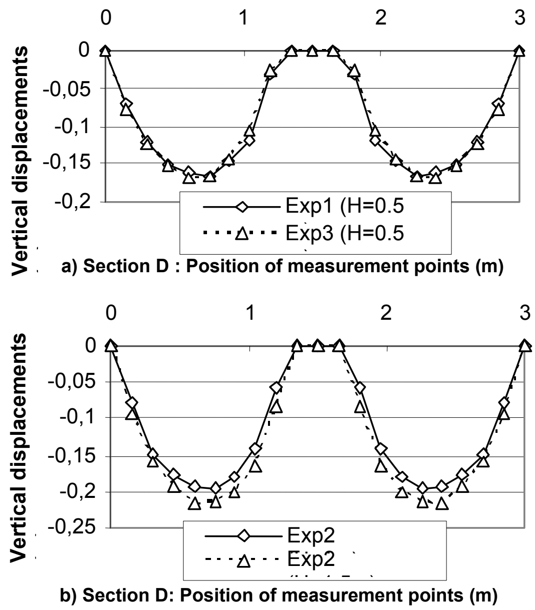

Figure 7 – Vertical displacements of the geotextile

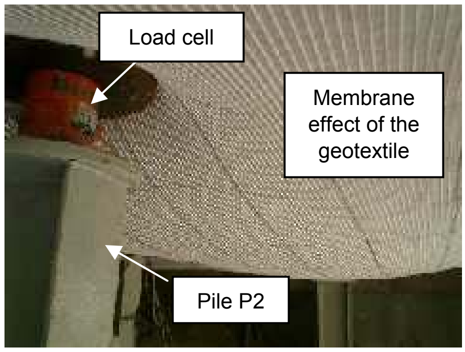

Figure 8 – Membrane effect observed over the piles (Exp2).

3.2 *Vertical settlements of the surface embankment*

After the removal of the subgrade soil and after stabilisation, we observed on the surface cracks in and settlements of parts of the embankment (Fig.9). The vertical settlements of the embankment surface measured on section D are presented and compared in figure 10 to the vertical displacements of the geotextile.

The results presented in figure 10a and 10c (H=0.5 m) show that the settlements of the soil surface are very similar for the two types of soil to the vertical displacements of the geotextile sheets. In this case, due to the small thickness of the embankment (H=0.5 m), no arching effect can be developed on the embankment.

Results obtained in the other experiments lead to the same conclusion. Indeed, experiments 4 and 5 induce breaks and no admissible vertical displacements of the embankments. For experiment 3, large surface settlements are obtained. The differences between the surface settlement and the vertical displacements of the geosynthetic sheet are due only to the decompaction of the 1 m high soil embankment.

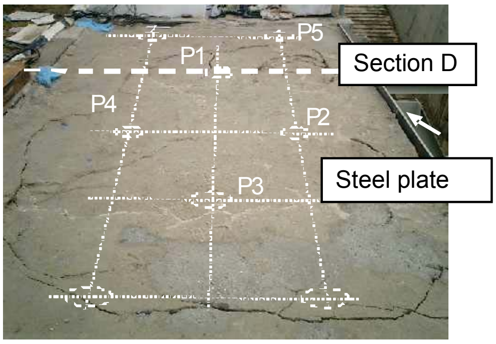

Figure 9 – Surface settlement (Exp2).

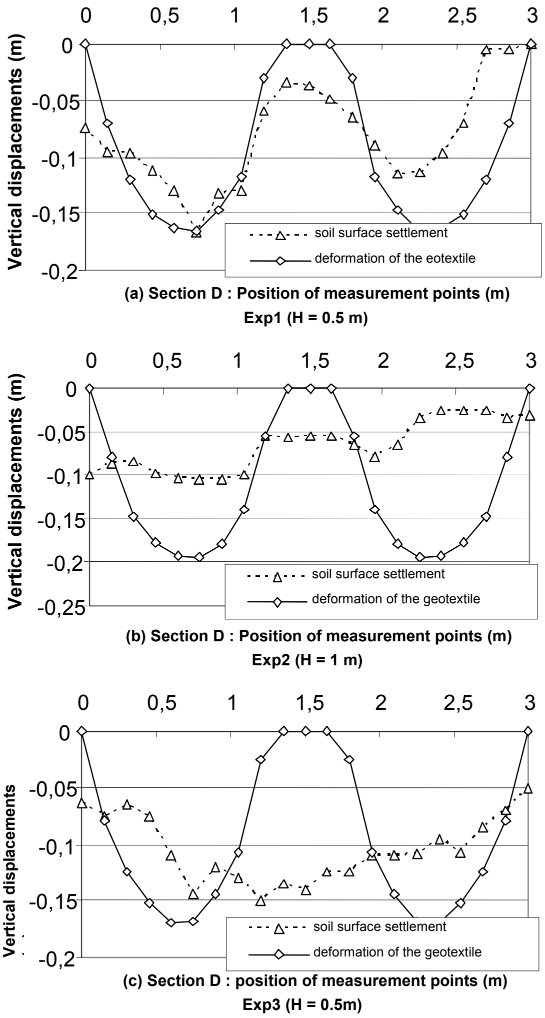

Figure 10 – Comparison between the soil surface settlement and the vertical displacements of the geotextile sheet

3.3 *Vertical loads applied to the piles*

The vertical loads were measured on the pile caps by the load cells during the experiment. It can be seen (Tab.4) that the weight supported by all the piles is around 40 % of the total vertical load due to the embankment. The remaining 60 % of the total vertical load is supported by the metallic frame fixed around the test pit.

Table 4 – Vertical loads applied to the piles

	P1 (kN)	P2 (kN)	P3 (kN)	P4 (kN)	P5 (kN)	Percent of load applied to the piles
Exp1 (H= 0.5 m)	10.9	9.6	11.2	8.9	4.2	42.3
Exp2 (H=1 m)	23.1	22.7	23.4	19.4	7.8	44.2
Exp2 (H=1.5 m)	30.1	32.4	35.1	30.7	10.0	41.4

3.4 *Trafficking tests (Exp2)*

After construction of the upper 0.5 m high embankment, trafficking tests were carried out using two kinds of vehicle. The first is a 1.5-tonne 4x4 car and the second a 5-tonne backhoe (Fig.11). Due to the initial shape of the geotextile sheet resulting from the weight of the embankment (membrane effect), no significant increase in the vertical displacements of the geotextile was obtained during the trafficking tests. No increase in surface settlement can be noted.

Figure 11 – Trafficking tests for experiment 2 (H = 1.5 m)

4 CONCLUSION

The experiments carried out show that:

- reinforcement by piles and geosynthetics is an interesting alternative solution to the reinforcement of embankment built on soft soil.
- for the geometries tested and materials employed, only the mechanisms of membrane effect could be highlighted.

Complementary experiments need to be carried out for different heights, pile spacing, or for different pile cap widths to allow the reinforcement process (type of geosynthetic, diameter of the piles, position of the piles, etc.) to be optimised and design rules to be developed.

5 REFERENCE

Villard, P., and Giraud, H. (1998). "Three-Dimensional Modelling of the Behaviour of Geotextile Sheets as Membranes", Textile Research Journal, Vol. 68, No. 11, November 1998, pp. 797-806.

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