FULL-SCALE EXPERIMENTAL STUDY OF AN EMBANKMENT REINFORCED BY GEOSYNTHETICS AND RIGID PILES OVER SOFT SOIL

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Abstract: Soft soil improvement by geosynthetics and rigid piles is an interesting technique to provide an economic and effective solution, which reduces settlements, construction time and cost. The geosynthetics could be introduced in the embankment or granular earth platform. Shearing of the earth platform and the existence of a pile group could provide the load transfer mechanism from superstructure to deep bearing stratum.

The load transfer mechanisms as a global behaviour developed in geosynthetics, earth platform, along the pile and in the underlying soft soil between the piles remain incompletely understood. Some of the existing design methods are restricted to the load transfer mechanism within the earth platform, while some others consider the interaction with the underlying soft soil.

This paper presents a full-scale experiment which is conducted within the French national research project A.S.I.RI and developed to provide a new design method. The full-scale test is constructed above a zone of soft soil, which represents four instrumented embankment sections. Three sections are reinforced in the middle of the embankment by a 4 x 4 pile group with pile spacing of 2 m, as well as one of their two slope sides. One section is not reinforced at all. Among the three sections reinforced by piles, two are reinforced respectively by a layer of geotextile and two layers of geogrid.

Several instrumentations are installed for monitoring the evolution of the stress applied on the piles as well as the differential settlements between a pile and its surrounding soil, while an embankment loading surcharge above all sections reached a height of 5 m. This study shows the presence of soil arching effect in the earth platform, which distributes significantly the surcharge load to the piles and decreases the differential settlement. Furthermore, this paper could also confirm the influence of geosynthetics in this technique.

Keywords: piled embankment, soil reinforcement, full-scale test, instrumentation, geotextile, geogrid

INTRODUCTION

Soft soil improvement by geosynthetics and rigid piles is usual. However, some of the existing design methods do not take into account the complex behaviour developed in these reinforced structures (Briançon et al., 2004[a]). From that, French national research project A.S.I.RI was launched to improve the knowledge on this topic and to draft a document constituting the guidelines related to the set up and the design of embankments and pavements on ground reinforced by rigid piles.

In this frame, a full-scale experimentation of embankment reinforced by geosynthetics and rigid piles over soft soil was carried out. Four experimental sections with different reinforcement solutions were tested under an embankment. A comprehensive instrumentation was set up and provides a better understanding of the overall embankment-reinforcement-pile system. This study shows the significant distribution of the surcharge load to the piles and the decrease of the differential settlement for the section reinforced with geosynthetics.

EXPERIMENTAL SITE

Context

This full-scale experiment of embankment reinforced by geosynthetics and rigid piles over soft soil was piloted by the Geotechnical Chair of “le Conservatoire National des Arts et Métiers”. The Geotechnical Chair managed the working site and took part to the instrumentation and monitoring with the other French national research project members. This experiment occurred over a period of 6 months (two months for the construction and four months for the monitoring). The full-scale experimentation sections were erected above a zone of soft soils located near Paris and lend by “le Conseil Général de Seine & Marne”

Ground conditions

Eight static cone penetrations (PS) were carried out to determine the thickness of soft soil layer (Figure 1), two boreholes (SC) and soil tests were accomplished to characterize it. The ground water level, controlled by a piezometer, was at a depth of 2 m. The soft soil layer is found between 8 m and 10.5 m. The oedometer compressibility is designated as medium. The soft soil consists of clay and sandy clay with small plasticity index. A pre-existing clayey fill less than 2 m thick is laid on soft soil.

FULL-SCALE TEST SECTIONS

Description

Full-scale test sections are constructed on a 52 m by 23 m surface of ground level divided in four instrumented sections (1R, 2R, 3R and 4R). Three sections (2R, 3R and 4R) are reinforced by the rigid pile grids. One non-reinforced section (1R) is included for the reference. The height of the embankment to be supported by each section is 5 m. A typical cross-section showing soft soil, piles, load transfer platform and embankment used in the project is shown schematically in Figure 1. Every reinforced section has a surface of 8 m by 8 m square under the embankment, which is set out of 4 by 4 square rigid pile grids spaced at 2 m. A load transfer platform formed by compacted granular fill reinforced by geosynthetics is installed above sections 3R and 4R. For section 3R, reinforcement is constituted by one geotextile layer and for section 4R, by two geogrid sheets.

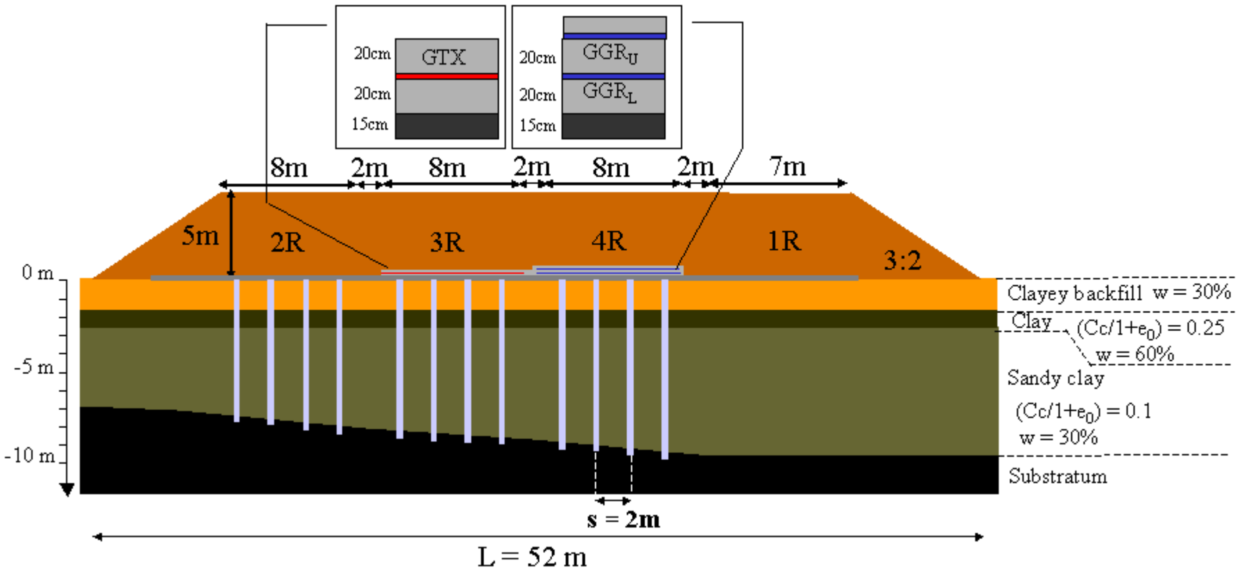

Figure 1. Typical site cross-section and geometrical characteristics

Construction

After removing the vegetal layer, a 0.15 m layer of gravel was set up before pile installation activities for the equipment traffic. Soil displacement piles were performed by Keller Foundation with a concrete C20/25. Each pile of 0.38 m in diameter is slightly founded in substratum (0.3 m) and the top of pile is cut back below the traffic layer.

The load platform of section 3R is constituted by (Figure 1):

- 0.15 m of traffic platform,
- 0.2 m of industrial gravel 0/31.5 (concrete and road pulling down) classified B_{41} in the French GTR classification (noted G_{F71}),
- bi-directional reinforced geotextile constituted by a non-woven and a PET reinforcement wires (TenCate Rock Pec 75/75),
- 0.2 m of industrial gravel G_{F71}.

The load platform of section 4R is constituted by (Figure 1):

- 0.15 m of traffic platform,
- 0.2 m of industrial gravel G_{F71},
- bi-directional geogrids (Tencate Miragrid 55/55),
- 0.2 m of industrial gravel G_{F71},
- bi-directional geogrids (Tencate Miragrid 55/55),
- 0.1 m of industrial gravel G_{F71}.

The geosynthetics mechanical properties are shown in Table 1. The backfill used in the embankment construction was marly and chalky compacted soil (layers of 0.30 m) under optimum water content (w_{npo} = 29 %) at a typical bulk weight of 18.5 kN/m^3.

Table 1. Geosynthetics mechanical properties

Properties (EN ISO 10319)		Unit	Bi-directional geotextile	Bi-directional geogrid
Tensile strength	MD (min)	kN/m	79 (75)	58 (55)
	CD (min)	(kN/m)	79 (75)	58 (55)
Elongation at nominal strength (MD / CD)		%	10 / 10	10.5 / 10
Tensile strength at :	2 %, MD & CD	kN/m	16	10
	3 %, MD & CD		22	13
	5 %, MD & CD		37	17

Instrumentation

More than 70 sensors are installed in the load transfer platform, in soft soils and inside rigid piles. This paper presents only the instrumentation of the sections reinforced with geosynthetics (3R and 4R). Earth pressure cells (CPT) measure the load transfer. Pressure transmitters for level measurement (T) measure the settlement of soil and rigid piles. Geosynthetic strain is monitored with optical fibres using the technique of Bragg grating. This optical device, called Geodetect, measures the local strains accurately without disturbance (Briançon et al., 2004[b]).

Instrumentation of section 3R consists in soil pressure cells and pressure transmitters for level measurement localised at the level of pile head (Figure 2a). Two Geodetect strips are located below the geotextile sheet, one between two adjacent piles and one between two diagonal adjacent piles. On the load transfer platform, the earth pressure cell CPT8 is under the earth pressure cell CPT7 and the CPT9 above the CPT5. Lastly, pressure transmitter for level measurement T21 is localised on the geotextile sheet under sensor T14.

Instrumentation of section 4R consists in soil pressure cells and pressure transmitters for level measurement localised at the level of pile head (Figure 2b). Two Geodetect strips are located below the lower and the upper geogrid sheets between two diagonal adjacent piles. On the load transfer platform, the earth pressure cell CPT13 is under the earth pressure cell CPT12 and CPT14 above CPT10. Finally, pressure transmitters for level measurement T33 and T34 are localised on the upper geogrid sheet under sensors T28 and T26 respectively.

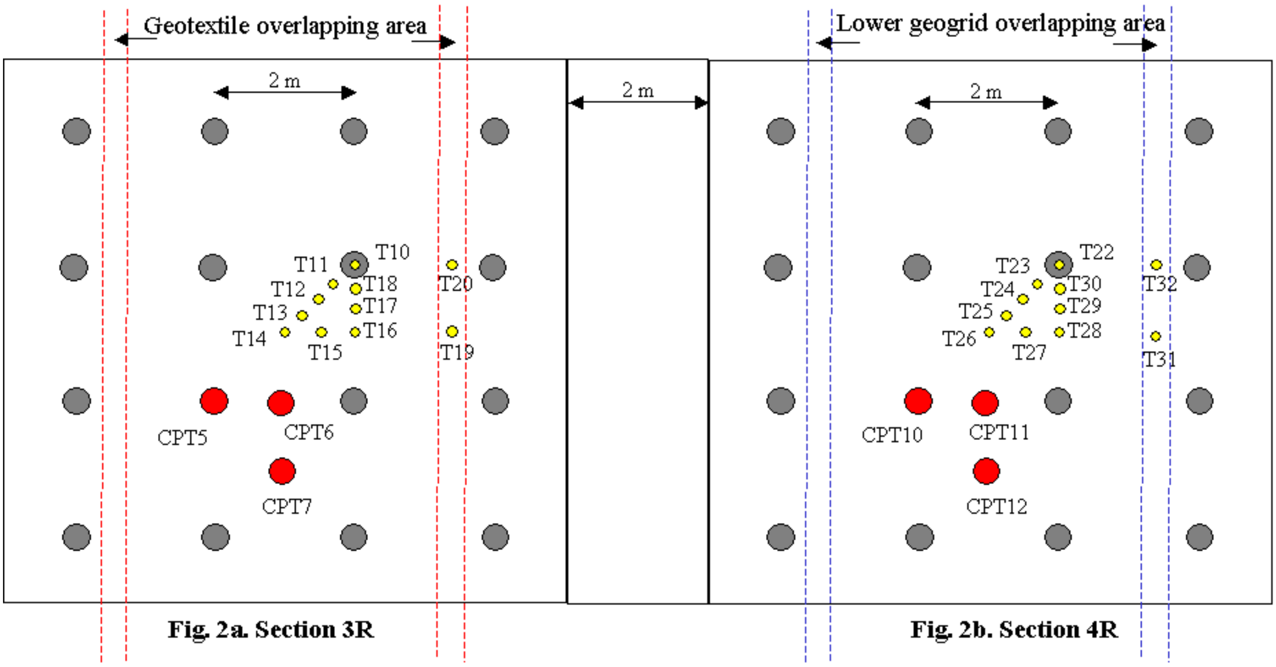

Figure 2. Instrumentation of sections 3R and 4R at the pile head level

MEASURES

Load transfer

The stress measured on the pile head shows that for both sections, the reinforcement system transfers the load toward the piles head (Figure 3). At the end of the embankment construction (19/09), the stress on pile in section 4R is equal to 96 % of the maximum value reached one month later. After that, we notice that the stress decreases to a value equal to 2500 kPa. In section 3R, the stress, at the end of embankment construction is equal to 85 % of the maximum value reached two months later. As for section 4R, a slight decrease is observed to attain 2940 kPa.

On the load transfer platform, the stress above the pile is different in section 3R (CPT9) and section 4R (CPT14) although the stress on the pile head level is the same at the end of embankment construction. This difference shows that mechanisms in load transfer platform are different depending on the geosynthetic reinforcement used. During the decrease of the section 4R pile stress (CPT10), the stress measured on the load transfer platform (CPT14) remains constant. So, the stress transfer due to the pile driving in soft soil is redistributed in the load transfer platform and at the pile head level but does not modify the stress on the load transfer platform vertically to the pile head.

Reinforced platforms lead to a better load transfer than the non-reinforced platform. To compare, for section without reinforced sheets, the stress transferred toward the pile head is only of 600 kPa.

The transfer toward rigid inclusions of section 4R is less than the one in section 3R. This difference could not be conferred to the geosynthetic sheet nature but rather due to the soft soil thickness (10m in section 4R versus 9m in section 3R) or to the pile anchorage length (slightly lower for the piles in section 4R).

The significant load transfer from soil to the piles has also been highlighted in recent instrumented pile-supported embankment (Liu et al., 2007).

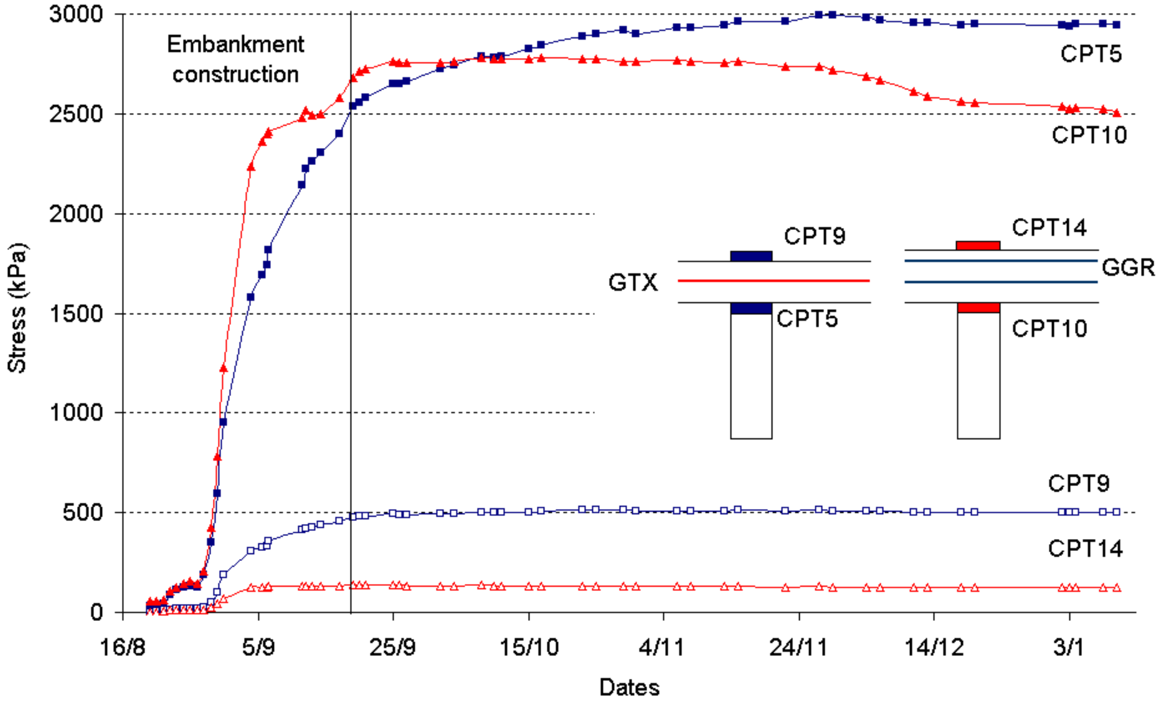

Figure 3. Load transfer measurement (stress on pile)

Settlement

In section 3R, the settlement of piles is equal to 31 mm. Soil settlement is slightly lower on the grid side than on the diagonal of the grid (Figure 4). The settlement is greater near the pile than in the middle of grid. Probably, the stress due to the arching effect and transferred via geosynthetic reinforcement is greater near the pile. The settlement of soil reaches 70 mm 4 months after the end of embankment construction (19/09) and it is stabilized.

The differential settlement between soil and pile is generated during the embankment construction. After that, pile drives in and soil and pile settles homogeneously (Figure 5).

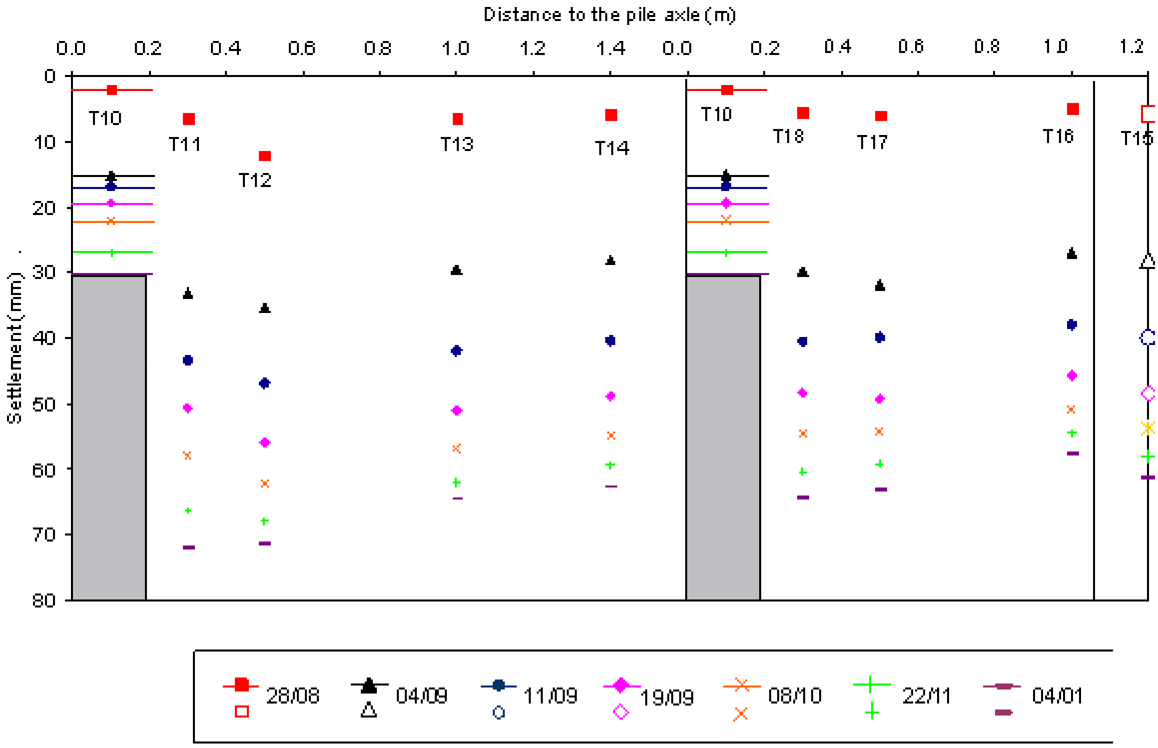

Figure 4. Settlement in section 3R

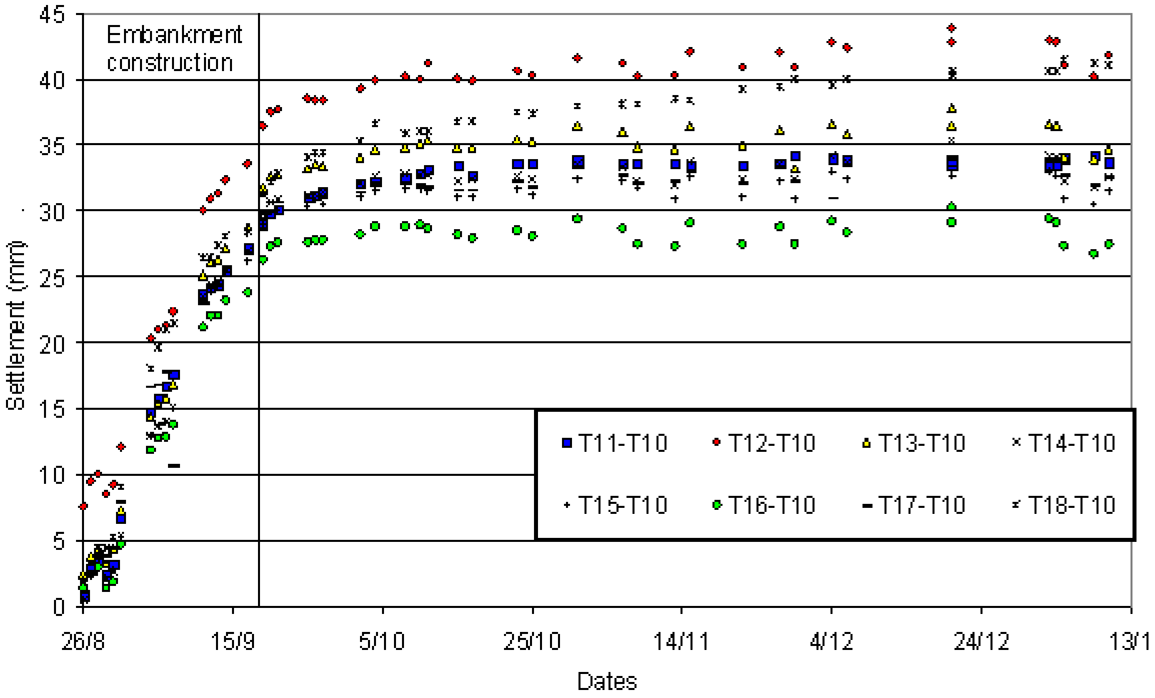

Figure 5. Differential settlement in section 3R

In section 4R, the settlement of piles is equal to 28 mm. Soil settlement is slightly lower on the diagonal of the grid than on the grid side (Figure 6). Soil settles homogenously. The settlement of soil reaches 60 mm 4 months after the end of embankment construction (19/09) and it is stabilized.

The differential settlement between soil and pile is generated during the embankment construction. After that, pile drives in and differential settlement is slight (Figure 7).

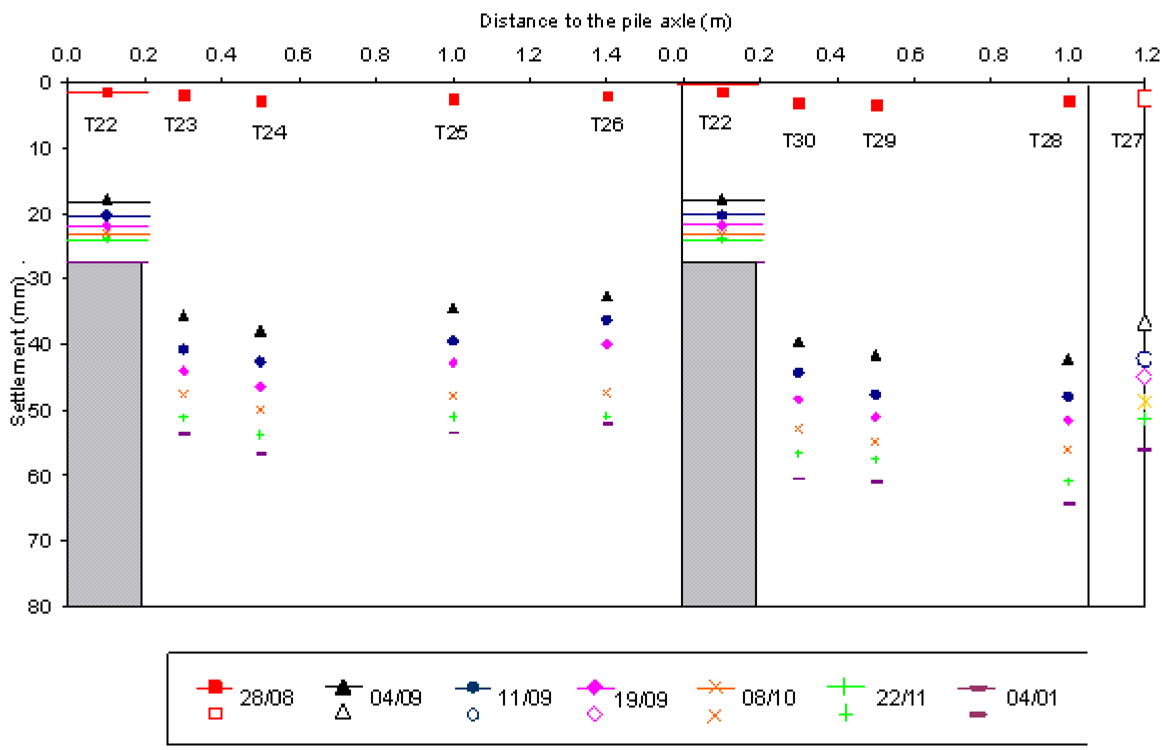

Figure 6. Settlement in section 4R

Even if load transfer seems to be different in section 3R and 4R, settlement of piles and differential settlement are nearly identical for both sections. We can notice that the shape of soil settlement is not circular as often supposed but is almost flat.

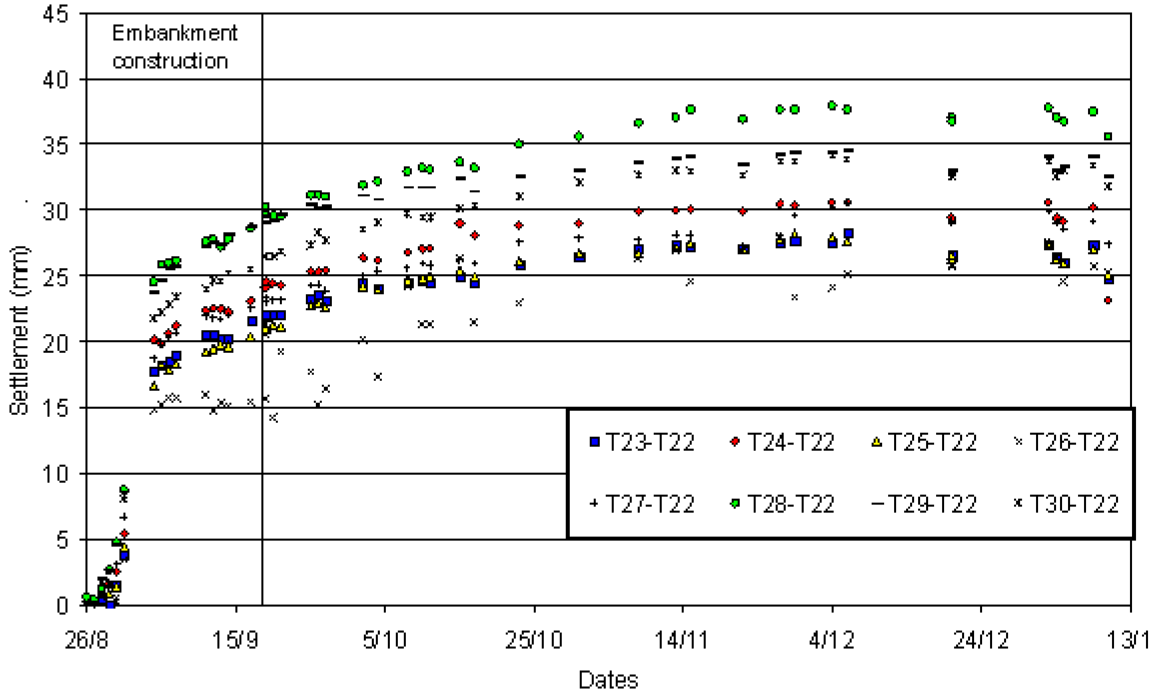

Figure 7. Differential settlement in section 4R

In section 3R, under overlapping areas (T19 & T20), the settlement is comparable to the one measured under the geotextile sheets. In section 4R, the settlement under overlapping areas (T31 & T32) is 30 mm lower than that measured under the lower geogrid.

For both sections, settlement measured on the platform (T21 and T33) in the middle of grid is 10 mm lower than that measured under the platform (T14 and T28).

Geosynthetic sheets strain

In section 3R, two Geodetect strips measure the strain below the geotextile between two diagonal adjacent piles (Figure 8a) and between two adjacent piles (Figure 8b). For each Geodetect strip, Bragg grating sensors are localised on the pile and on the soil. The strain measured in the reinforced direction is higher than that measured in diagonal. For both directions, measures show that after load transfer platform set up, the strain is insignificant: geotextile is not pulled. After the end of embankment construction, we observe that the strain is not uniformed; it reaches 0.6 to 0.8 % on the pile and 0.1 to 0.4 % on the soil. This observation is in concordance with the flat shape of the soil (Figure 4).

In section 4R, two Geodetect strips are localised below the lower (Figure 9a) and the upper (Figure 9b) geogrid sheets between two diagonal adjacent piles. For each Geodetect strip, two Bragg grating sensors are localised on the pile and three on the soil. During compaction of the load transfer platform, a uniform strain of 0.1 % is measured for both geogrids, higher than that measured under the diagonal geotextile (Figure 8a). After the end of embankment construction, the strain is not uniformed and reaches 0.7 % on the pile and less than 0.2 % on the soil. Almeida et al. (2007) also show from a full-scale experiment of embankment supported of piles with bi-axial geogrids that the strain values measured between piles are smaller than those measured near the face of the pile heads.

In section 4R, during compaction the geogrid is stretched and soil particles are forced into the apertures, it’s for this reason that the settlement under overlapping areas (T31 & T32) is 30mm lower than the one measured under the lower geogrids: compaction opened the overlapping.

The embankment construction leads to an insignificant strain of geogrids on soil compared to that measured under geotextile. For both geosynthetic types, maximum of strain is localized around pile. In section 4R, load transfer mechanisms begin during the platform compaction. In section 3R, these mechanisms occur during the embankment construction. A single geosynthetic layer behaves like a tensioned membrane, whereas a multilayer system acts like a stiffened platform because of the interlock of reinforcement and the surrounding soil.

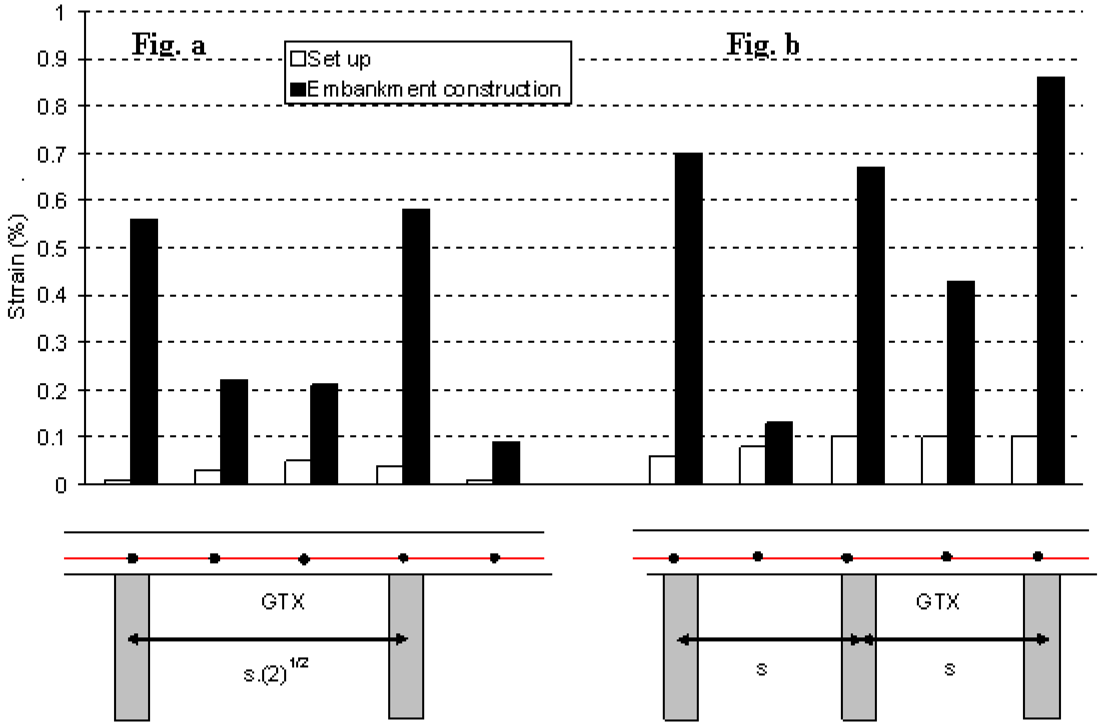

Figure 8. Geotextile strain

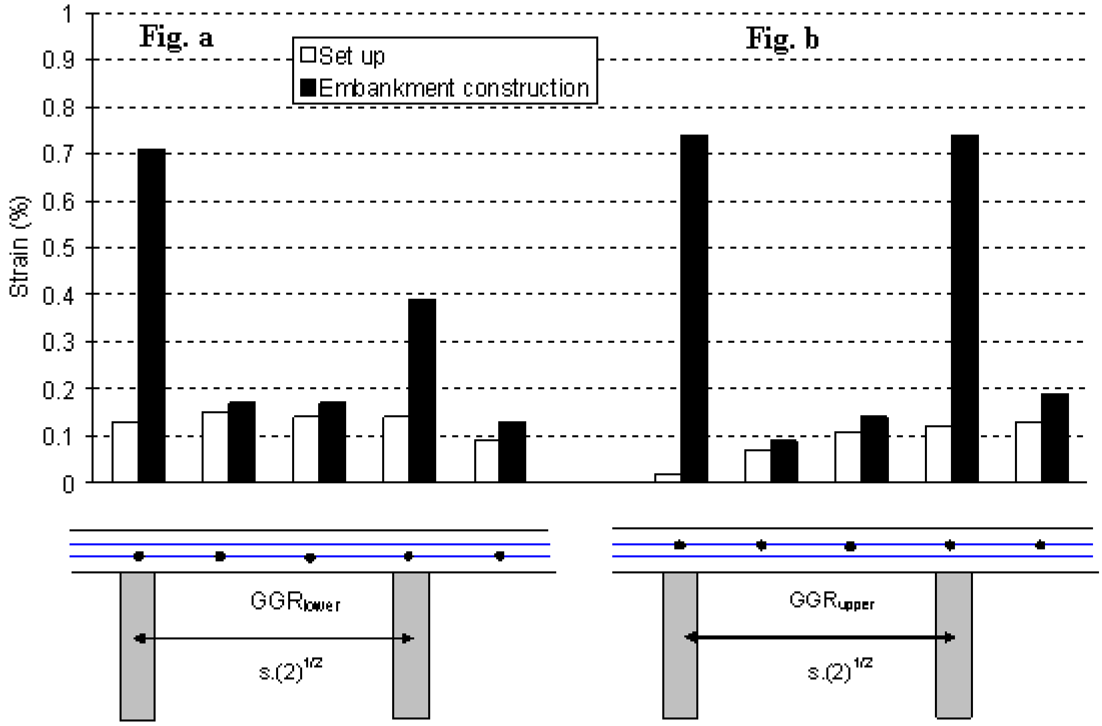

Figure 9. Geogrids strain

ANALYSIS

The efficiency (or efficacy), which is the ratio of the total load in a pile grid carried by a pile head, is compared for three stages (immediately after the end of the embankment construction, 2 months later and 4 months later) for the three sections (Table 2). Reinforced platforms lead to a better efficiency than the non-reinforced platform. The efficiency increases with time to reach a maximum value and decreases significantly only in section 4R when the pile drives in. The efficiency is significantly strong in sections with geosynthetics.

Table 2. Comparison of the results

Section	2R			3R			4R		
Stage	end of embankment	2 months later	4 months later	end of embankment	2 months later	4 months later	end of embankment	2 months later	4 months later
Efficiency	15.5 %	16 %	17 %	74 %	86 %	86 %	78 %	80 %	73 %
Pile settlement	4 mm	7 mm	10 mm	19 mm	27 mm	31 mm	22 mm	25 mm	28 mm
Differential settlement	82 mm	92 mm	103 mm	30 mm	34 mm	31 mm	18 mm	25 mm	24 mm

Although the compressibility of soft soil in the experimental area was not very strong (non-reinforced embankment settles only 0.26 m), reinforcement by piles and geosynthetics has decreased the settlement (Table 2). Differential settlement occurs during the embankment construction. For both sections with load transfer platform, differential settlement remains constant after the end of embankment construction in spite of piles settlement due to the strong stress applied on their head and their small anchorage. When the pile drives in, soil and pile settle homogenously.

Results of stress applied on pile head and strain developed in geosynthetic sheets show that the behaviour of platform reinforced by a single geotextile is different from that of a platform reinforced by two geogrids. In section 4R, the interlock of geogrids and the surrounding soil takes place during the platform compaction; during the embankment construction, the load transfer occurs more quickly than that in section 3R. The stress measured on the load transfer platform above the pile is equal to the embankment load (= 100 kPa). In section 3R, geotextile behaves like a tensioned membrane during the embankment construction. The platform compaction does not act on this mechanism. The stress measured on the load transfer platform above the pile is equal to that measured directly on pile in section 2R (without load transfer platform). In this case, it seems that arching effect occurs at the base of embankment. Even if load transfer seems to be different in section 3R and 4R, settlement of piles and differential settlement are nearly identical for both sections.

CONCLUSIONS

In the frame of French national research project A.S.I.RI, a full-scale experiment of embankment reinforced by geosynthetics and rigid piles over soft soil was carried out. Measures of stress, geosynthetics strain or soil and pile settlement validate the accuracy of the instrumentation. The monitoring of four experimental sections with different reinforcement solutions highlights the behaviour of reinforcement elements during various stages of embankment construction.

Load platform with geosynthetic improves the efficiency and decreases the settlement. Results of stress applied on pile head and strain developed in geosynthetic sheets show that the behaviour of platform reinforced by a single geotextile is different from that of a platform reinforced by two geogrids. Particularly, load transfer platform compaction acts on soil and geogrid interaction but not on the geotextile strength. Overlapping areas in platform reinforced with geogrid could be large enough to avoid separation during compaction.

Various analytical methods have been proposed to model the load transfer in piled embankment. The main existing design approaches assume that a cavity or no support resistance exists below the geosynthetic reinforcement layer. Results of our experiment such as the flat shape of soil or the non-uniform strain developed in geosynthetic sheets show that when there is a layer of soil at the pile head level strong enough to provide some embankment support, behaviour of load transfer platform is different from that assumed in existing design approaches.

The remaining work consists in comparing experimental results to existing design methods and in proposing a new design approach taking the mechanisms highlighted in the experiment into account.

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REFERENCES

Almeida, M.S.S., Ehrlich, M., Spotti, A. P. & Marques, M. E. S. 2007. Embankment supported of piles with bi-axial geogrids. Proceedings of the Institution of Civil Engineers Geotechnical Engineering, 160, October 2007 Issue GE4, 185-192.

Briançon, L., Kastner, R., Simon, B. & Dias, D. 2004[a]. Etat des connaissances - Amélioration des sols par inclusions rigides. Proceedings International Symposium on Ground Improvement (ASEP-GI 2004), Paris, France, 15-43.

Briançon, L., Nancey, A., Caquel, F. & Villard, P. 2004[b]. New technology for strain measurements in soil and the survey of reinforced earth constructions. Proceedings EUROGEO 3, Munich, Germany, 471-476.

Liu, H.L., Ng, C.W.W. & Fei, K. 2007. Performance of a Geogrid-Reinforced and Pile-Supported Highway Embankment over Soft Clay: Case Study. Journal of Geotechnical and Geoenvironmental Engineering, 133 (12), 1483-1493.