E3S Web of Conferences **644**, 03007 (2025) https://doi.org/10.1051/e3sconf/202564403007
EUROGEO 8

Lessons learned from the ASIRI+ project on the use of geosynthetics in load transfer platform

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Abstract. Geosynthetics are used for the reinforcement of the granular layer acting as a load transfer platform in the case of embankments on piles or rigid inclusions. This article highlights the results obtained on the use of geosynthetics during the French national project ASIRI+ (2019 - 2025), an extension of the ASIRI project (2005-2012), aiming to provide recommendations for the design of a soil reinforced by rigid inclusions with practical suggestions for the installation. Full scale experiments, field monitoring, physical models at the centrifuge, as well as numerical models have been used to get a better understanding of the geosynthetic behaviour, confirming the interest of this reinforcement solution.

1 Introduction

The use of geosynthetic to enhance the load transfer in pile-supported embankment was initiated already 30 years ago. But the development of the technic and the need to get better design models, have been pursued over the time. In France, and in the continuity of the previous project ASIRI from 2012 [1], the national project ASIRI+ was launched in 2019 to improve the knowledge of the mechanisms, especially where the old design models have shown their limitations, such as the case of thin embankment with or without effect of the traffic. Full scale experiments and other physical models were developed to study particularly the effect of geosynthetics on the efficiency of the load transfer to the rigid inclusions and the settlement. The behaviour of the geosynthetic anchorage and the overlapping were also studied. Numerical models have been developed and calibrated, allowing parametric study and comparison with analytical methods. This publication proposes an overview of the research performed on geosynthetics in the ASIRI + project.

2 Experiments

Several experiments have been conducted at different scales to study the behaviour of geosynthetics used as basal reinforcement of thin embankment over piles: tests pit at INSA Lyon and in CEREMA Rouen, as well as centrifuge tests in UGE Nantes. The objectives were to evaluate the role of geosynthetic on the load transfer and try to determine their number, their properties, their types and their best locations to optimize the load transfer platforms.

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2.1 Test at CEREMA Rouen

As described by Briançon et al. [2], full-scale tests were carried out at CEREMA Rouen on different embankment configurations based on rigid inclusions to evaluate the efficiency of geosynthetic reinforcement on granular load transfer platforms.

The device is shown in Figure 1: 16 rigid inclusions of 30 cm in diameter were placed in a watertight pit of 8 m x 8 m x 1 m following a square mesh with a spacing of 2 m. A 50 cm layer of granular material (0/31.5) formed the load transfer platform (LTP). A 1.5 m height embankment overloaded the reinforced soil.

Fig. 1. Test pit at CEREMA Rouen

The first challenge in this experimental study was to simulate correctly the behaviour of the soft soil and to have the same behaviour for each test. For that, three layers of materials were used. The first layer was composed with honeycomb cardboard planks called Biocofra. These planks are rigid when dry but can be completely dissolved in water. The dissolution of this layer was used to apply a large settlement at the end of the embankment construction. To simulate the settlement of the soft soil during the construction of the embankment and during its overloading, a layer of tire aggregates called Deltagom was used. This material has a high compressibility and adding a layer of loose sand, it has been possible to obtain the same representative compressibility for all the tests. A complete instrumentation on the central mesh of the inclusion network was set up to measure the load transfer and settlement as well as the deformation of the geosynthetic layers. The granular LTP is non reinforced in pad 1.Two superimposed and crossed layers of a reinforcement geotextile were placed in the LTP at 10 cm above the inclusion heads for pad 2 and at the base of the layer for pad 5. For pads 3 and 4, two layers of crossed monoaxial geogrids 20 cm apart were placed in the granular layer.

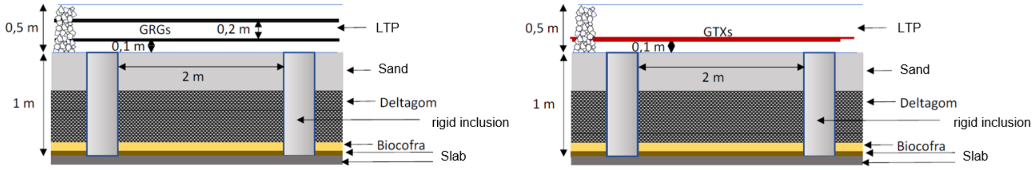


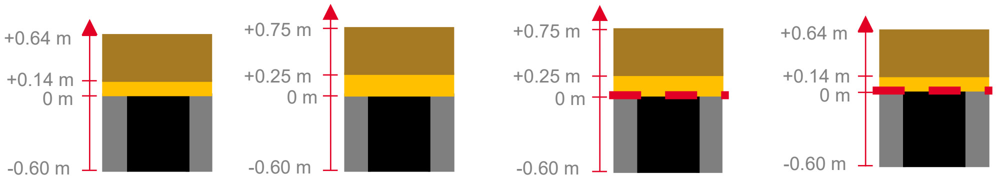
Fig. 2. Cross section with geogrid (left) and with geotextile (right)

These trials have highlighted several mechanisms:

- The geosynthetic reinforcement provides better efficiency when positioned near the heads of the inclusions,
- The horizontal settlement profiles are very flat with a significant differential settlement near the inclusion, allowing us to assume what the shape of the stress profile is and how the geosynthetic is mobilized,
- A large part of the settlement is consumed during the installation of the embankment and during the few days that follow,
- Except for pad 5, geosynthetics do not allow a reduction in settlement compared to the unreinforced platform which is already very effective; in fact, their tensioning requires a differential settlement greater than that required to obtain a shear load transfer in the load transfer platform,
- Geosynthetic play their full role for large displacements when the platform does not allow a sufficient part to be transmitted to the inclusions or when overloads are applied to the top of the embankment,
- The association of geosynthetic with inclusions makes it possible to form the equivalent of a support zone ("hard point"), on the top of the LTP, with a section greater than that of the inclusion, near their heads. This effect promotes the unloading of the soil.

2.2 Test at GEOMAS laboratory

Five other tests (Figure 3) were realised at GEOMAS laboratory-INSA Lyon using a ½ scale model with the deltagom material reproducing the soft soil. The goal was to validate the efficiency of the load transfer to the rigid inclusions (IR) and to check the influence of the thickness of the reinforced or unreinforced platform.



Test A: LTP 14 cm unreinforced	Test B: LTP 25 cm unreinforced	Tests C & D: LTP 25 cm reinforced	Test E: LTP 14 cm reinforced

Fig. 3. Tests configuration at GEOMAS

From these tests, it can be concluded:

- Without reinforcement, a thicker platform allows a better transfer of the stress to the rigid inclusions.
- For the thick platform, the geotextile doesn't reduce the settlement of the compressible soil nor provides a better load transfer. When the thickness is too large, the geosynthetic doesn't work, loads go directly into shear stresses.
- For the thin reinforced platform, the reduction of settlement is significant. The same settlement is obtained with the 14 cm thin reinforced platform or the 25 cm thick unreinforced platform.
- The smaller the thickness of the platform, the more the geosynthetic works.

2.3 Centrifuge tests at the University Gustave Eiffel in Nantes

Small-scale instrumented models using a mobile plate device in the geotechnical centrifuge (Figure 4) at the University Gustave Eiffel have been carried out. The objectives of these tests were to check the influence of the overlap between two layers and the effect of the traffic on the load transfer efficiency and the differential settlement.

Fig. 4. Centrifuge at University Gustave Eiffel and mobile plate device

2.3.1 Study of the overlaps

In practice, two options are possible to reinforce the LTP over piles. Either two layers crossed of a uniaxial product are installed in transverse and longitudinal direction. This ensures the continuity of the reinforcement on most of the area to cover. However, the overlap between two successive rolls shall secure the transfer of tensile. Current rules ask a minimum overlap length of 1 to 3 times the spacing between piles. Or one layer of a biaxial product (same strength in both directions) is placed. In this case, the tensile needs to be transferred also between two adjacent layers. The rule above becomes unrealistic when the spacing is too large. As an example, with piles having a spacing of 2 m, at least 2 m overlap would be required that corresponds almost to a half of a geotextile roll width !

Thus, the centrifuge tests have been used to check different overlaps in order to propose a more optimised solution. The overlap of 2 strips of a biaxial geosynthetic (GSY), located at the base of the granular load transfer platform, has been studied by Thorel [3,4].

Several tests have been performed, with different overlap width or positions as shown on Figure 5 and compared to the results obtained with a continuous reinforcement.

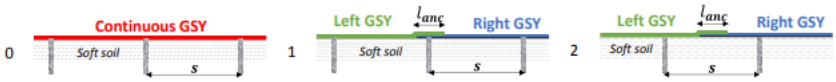


Fig. 5. Different geometric configurations: (0) Continuous GSY; (1) GSY overlap centred on an IR line; (2) GSY overlap between 2 IR lines

Scale model experiments have shown that increasing the lap width improves the efficiency of the load transfer and decreases the differential settlement on the surface of the load transfer platform. For low GSY overlaps, poor characteristics (low efficiency and high differential settlement) are observed. On the other hand, with the increase in overlap, we tend to behave in a similar way to that of the continuous geosynthetic test. For a cover greater than s/2, we observe here a behaviour very close to that of continuous GSY for settlements less than 1 diameter of IR.

For higher compressible soil compaction, the differential compaction gradually diverges, while the efficiency is little changed. This tends to show that the "critical" overlap width is more sensitive to a differential settlement criterion than to an efficiency criterion.

2.3.2 Effect of the traffic

At the "Geotechnical Centrifuges" laboratory of the Gustave Eiffel University, Dubreucq [5] also studied the effect of a rolling load on a thin granular platform based on a soft soil reinforced by a mesh of rigid inclusions with a coverage rate equal to 10%. Figure 6 shows the 1/10th scale model in 2D geometry made of a sandy platform, with a soft analogous soil made of expanded polystyrene and possibly reinforced by a geogrid sheet.

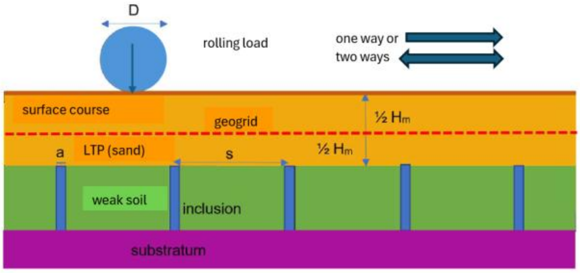


Fig. 6. Physical model 2D

A dozen configurations were tested by varying the thickness of the platform, the width of the foundation, the presence or absence of geosynthetic layers, one-way or two-ways driving on the platform, reinforced or not by geogrid, was carried out to simulate a linear traffic. Twenty-three rolling loads were tested. Arching effects and induced compaction in the subgrade were observed. The load efficiency of the reinforcement was quantified for these loadings.

Results have shown that when the roll crossed the IRs, the vertical pressures on the soft ground changed significantly: the distribution of vertical pressures is asymmetrical on either side of the IR, with a higher effect in the presence of the geogrid. During the two ways traffic the geogrid at the middle of the LTP appears to reduce the diffusion of horizontal load distribution and accentuate its vertical diffusion towards the base of the LTP. It reduced by half the settlement at the top of the LTP. The pressure on the soft ground on the 1st pass of the roller is 25% higher with a geogrid (GGR) at the middle of LTP, compared to the same geogrid at the base of the PTC. Full results will be available in further publication.

This study shall be completed by using a 3D geometry of the 1.2 cm diameter inclusions in model size, even more representative of the real reinforcements, but also more complex.

3 Field monitoring

Due to timing issues during ASIRI+ project, it was hardly possible to monitor jobs where geosynthetics were used to reinforce the load transfer platform. Nevertheless, two jobs offered the opportunity to install a geogrid in a small section, and a monitoring to evaluate the effect of the reinforcement.

3.1 Project Chambéry (France) A41 interchange.

The project concerns the extension of a motorway embankment of the Chambéry interchange of the A41. The widening project consists of constructing a 6.5 m high wall reinforced with geosynthetics with gabion facing on a soil reinforced with rigid inclusions. The reinforcement solution was designed without geogrid in the load transfer platform. To check the role of a geogrid on the general behaviour of the pile-supported embankment (under the embankment and under the slope), two sections were instrumented (Figure 7): the first with the proposed soil reinforcement, the second by adding a geogrid to the granular platform.

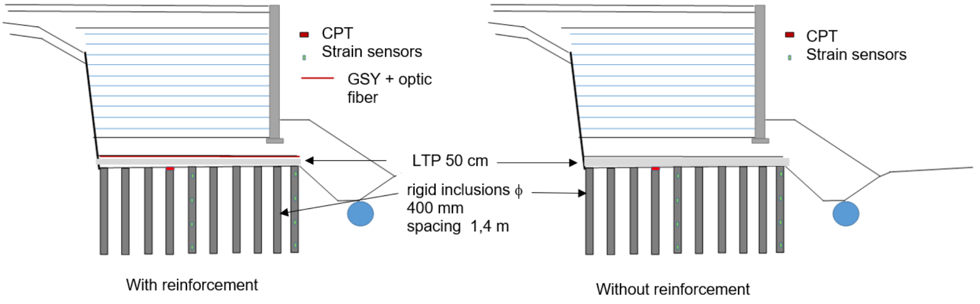


Fig. 7. Cross section with monitoring of both sections.

Initially, it was planned to install two geogrid beds within the granular material of the load transfer platform (LTP). Due to miscommunication with the contractor, the installation of the 50 cm of the LTP was achieved before the installation of the geogrid. As a result, only one layer of geogrid was installed on the LTP, which is not an optimal installation. These measurements were carried out a few weeks after the end of the construction of the embankment and were stable over time. Despite the geogrid position, 47% efficiency gain on the load transfer with the geogrid was seen. It was noticed that the geogrid deforms uniformly at the level of the inclusions and on the ground between the two inclusions with transition zones 50 cm wide.

3.2 A63 motorway near Bayonne (France)

The widening project consists of building an embankment (in red - Figure 8) to allow the passage to 2x3 lanes of traffic in the municipality of Ondres (F). This embankment is built on a soil reinforced by 9 rows of rigid inclusions.

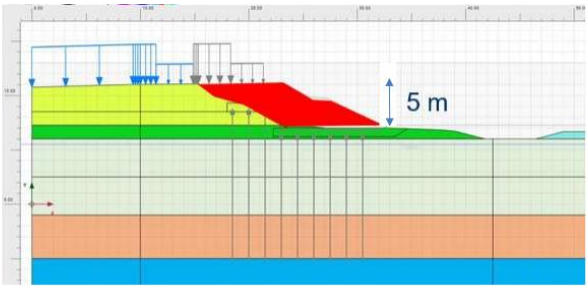


Fig. 8. Cross section with the embankment on piles.

It was proposed to the project owner to add a geosynthetic under an area of the embankment and to instrument by inclinometer an inclusion at the foot of the bank in the area with geosynthetic and an inclusion at the foot of the bank under the embankment without geosynthetics. A displacement measurement device has been added to analyse the influence of the presence of geosynthetics on horizontal displacements.

The embankment was elevated in several phases since the three additional rows had to be built halfway up the embankment. The final height was reached in June 2019. Figure 9 shows the evolution of the stresses during the rise of the embankment and up to January 2020, one year after the installation of the instrumentation.

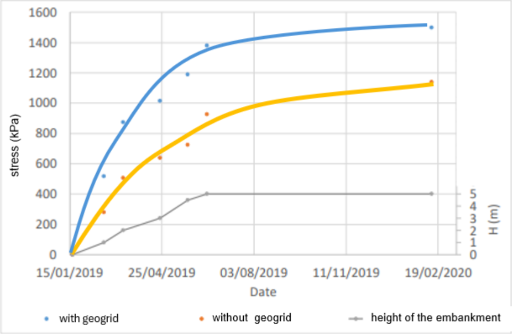


Fig. 9. Stresses on piles during embankment elevation.

There is a better load transfer on the inclusion with geogrid. It is also noted that the difference between the two sections occurs during the rise of the embankment. At the end of the embankment rise, the stress on the inclusion of block 1 is 50% greater than that measured on the inclusion of block 2. This difference decreases to 30% after one year. This observation indicates that the geogrid accelerates the load transfer and brings it to a higher value at the inclusion head. This different kinematics implies that the differential soil/inclusion settlement must be higher after the embankment has been placed in the section without the geogrid. The geogrid therefore accelerates the load transfer and achieves higher efficiency.

Inclinometric measurements at the foot of the slope show horizontal displacements at the top of the inclusion of 4 mm for section 1 with geogrid and 6 mm for section 2 without geogrid. The verticality of the inclusion of section 1 seems to be preserved with a deformation that begins at a depth of 6 m. For the inclusion of section 2, this same verticality is observed at the beginning of the loading of the embankment, then a slight inclination of the inclusion is observed from April onwards corresponding to a height of the embankment of 2 m. Horizontal displacements are stabilized at the final height of the embankment. A very slight improvement brought by the installation of the geogrid was observed in terms of the forces transmitted on the inclusions at the foot of the embankment.

The deformations of the two inclusions are different. The inclusion in the GGR-reinforced section is more in demand at the head due to the action of the geogrid. The appearance of the deformation of the inclusion in the section without GGR is comparable to the range of displacements observed at the foot of the embankment on unreinforced compressible soil.

4 Numerical modelling and comparison with analytical methods

In the 3D discrete element (DEM) method, elementary particles are used to simulate the microstructure of granular materials, and a coupled discrete element - finite element (DEM) method is used to describe the behaviour of the geosynthetic and its interaction with the granular material. DEM method was used by Villard [6], Figure 10, for a parametric study that shows particularly that:

- The efficiency of the membrane effect is maximum when positioned at the base of the granular layer.
- The geosynthetic strips located between the piles contribute mainly to the reinforcement by membrane effect (85% of the total contribution of the reinforcement).

- The load that can be mobilized by the membrane effect (difference between the load acting on the water table and the load transmitted to the compressible soil) has a polynomial form of the third degree.
- Soil/geotextile interface friction has very low impact on the results.

Alzate [7] compared the results obtained by the concentric arches method (CA model) from Van Eekelen [8] and the 3D discrete element method (DEM).

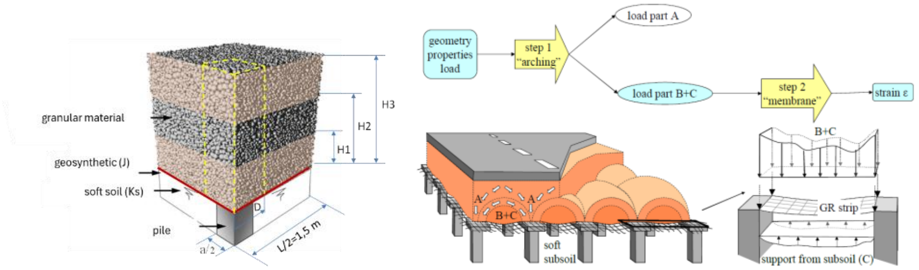


Fig. 10. Comparison of models: **(**left**)** DEM - (right) CA model from Van Eekelen-

The CA model described in Figure 10, is a commonly used geosynthetic reinforcement design method developed by S. Van Eekelen [8] and presented in the Dutch CUR 226 (2016). This method is based on a two-step calculation. The first step defines the part of the load transmitted by the shear stresses within the granular platform (A, B and C) and the second step describes the behaviour (tensile force and maximum deformation) of the geosynthetic under the residual load (B+C). With A the load part directly transfers to the piles, B the part applied on the geosynthetic and C the part supported by the subgrade.

Comparison was made on several configurations: square piles of 0.6 m on each side, 3.0 m x 3.0 m spacing, three mattress heights: H = 0.75 m, H = 1.5 m and H = 3 m, biaxial geosynthetic with stiffness J = 3000 kN/m.

The CA model showed a good consistency of the efficiency results with the DEM method in the case of dense soil, especially for an embankment with a height of 0.75m and is on the safety side for the other two embankment heights (1.5 and 3m).

5 Conclusions

Specific studies were launched during ASIRI+ project to improve the knowledge on the geosynthetics behaviour in load transfer platform:

Tests spit at INSA and CEREMA, as well as the numerical model, show that the geosynthetic reinforcement provides better efficiency when positioned near the heads of the inclusions. Geosynthetic play their full role for large displacements when the platform does not allow a sufficient part to be transmitted to the inclusions (thin platform) or when overloads are applied to the top of the embankment.

Centrifuge tests highlight the influence of the overlap on the load transfer and the effect of the traffic.

DEM numerical model was able to reproduce the behaviour of the reinforced platform allowing to perform a parametric study. The CA analytical model showed a good reliability compared to the results with the DEM method in the case of dense soil.

ASIRI+ project will result on a new guideline on the design and the installation of the load transfer platform on rigid inclusions and a specific design standard for the use of geosynthetic in this application will be developed.

This work was carried out as part of the national ASIRI+ project. The authors would like to thank all the members of this project for their support.

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