New Horizons in Earth Reinforcement – Otani, Miyata & Mukunoki (eds)
© 2008 Taylor & Francis Group, London, ISBN 978-0-415-45775-0

Two examples of recent innovation linked to optimization of soil reinforced structures

Ph. Delmas
Cnam

A. Nancey
Tencate Geosynthetics France

ABSTRACT: The paper presents 2 cases of innovative design. Both are linked to a previous research on reinforcing soil above soil subsidence area. The first one allowed reducing the vertical loads on large water pipes under a high embankment and the second allowed solving the problem of crossing a soil subsidence area by a motorway in a cut-off, by using a bimodulus reinforcing geosynthetic.

1 INTRODUCTION

The optimisation of the earth reinforcement structures is a permanent task of the civil engineer and the high innovation potential of the geosynthetics offers the engineers a great potential. Two structures built recently in France show the interest of such developments. Both of them are based on further developments of a previous research program "Rafael" (Delmas & al., 1999) on geosynthetic reinforcement in case of risks of soil subsidence.

2 REDUCTION OF VERTICAL LOAD ON A LARGE WATER PIPE BY USING GEOSYNTHETIC REINFORCEMENT

In Valenton, city close to Paris, the stresses applied by the high embankment (>10 m high) of a new motorway (A86) on large water pipes (2.76 m & 2.24 m diameter), which may be partly under water during certain periods of the year, could be reduced by using a specific reinforcement structures and allowed an important reduction of costs of the structure.

2.1 *Principle of the solution proposed*

The principle of the proposed solution consists in reducing the vertical stresses above the pipes by using a compressible material above the pipes and creating above this compressible area a reinforced mattress which transfers the vertical loads laterally on two reinforced structures.

Additionally a specific layer of reinforcement geosynthetic was placed above the pipes and anchored laterally counterbalancing the uplift forces due to the highest potential water table.

The principle of the proposed structure is presented in the figure 1, with the two designs which where realised depending on the number of pipes (1 or 2).

This design allowed using HDPE DN2000 and HDPE 2500 pipes (instead of metallic pipes) which reduces highly the cost of the structure.

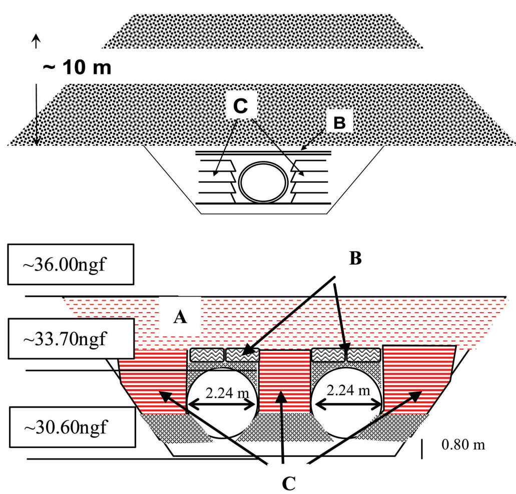

Figure 1. Principles of the structure – 1 pipe design & 2 pipes design: (A) reinforcing mattress transferring the vertical loads laterally, (B) compressive layer, (C) lateral reinforced structures supporting the vertical loads transferred from mattress (A).

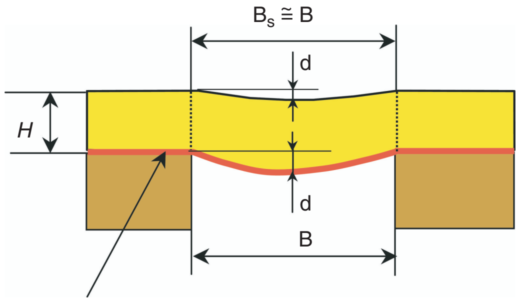

Figure 2. Membrane design principle.

2.2 *Design of the reinforcements*

The specification of the water pipes limits the vertical deformation to a maximum of 6% of the diameter.

A layer of old tires is placed just above the pipes to avoid the vertical load transfer. A reinforced mattress above the tires acts as membrane like in the case of soil subsidence (figure 2).

The reinforcements of the mattress have been designed using the method developed during the “Rafael” research program (Blivet et al., 2001). The width of the membrane effect is considered equal to the diameter of the pipes.

According to the results of this program, the influence of the dilatancy of the granular soil above the reinforcement layers has been taken into account to evaluate the load transfer on the geosynthetics.

Long term design strength has been taken into account as far as the load will last during the service life of the structure (100 years). This leads to a reinforcement by 4 layers of Rock PEC 200 (T_{max} = 230 kN/m) anchored laterally on a length of 3.3 m on the side of the side reinforced structures.

The side reinforced structures have been designed considering the added vertical surcharge due to the transfer of load by the reinforced mattress. Both external and internal long term design have been realised. This leads to reinforced structures of 1.5 m width using the same geosynthetic with a spacing of 0.4 m corresponding to an optimum thickness for the compaction of the soil used.

To control the potential uplift of the pipes linked to the changes of the water table, especially in the case of empty pipes, a reinforcement geosynthetic as been placed above the pipes and anchored laterally under the side reinforced structures.

2.3 *Construction of the structure*

The photo 1 shows the construction of the reinforcing system with the compressive layer. Several years after construction, the behaviour of the pipes is satisfactory, confirming the interest of the solution chosen.

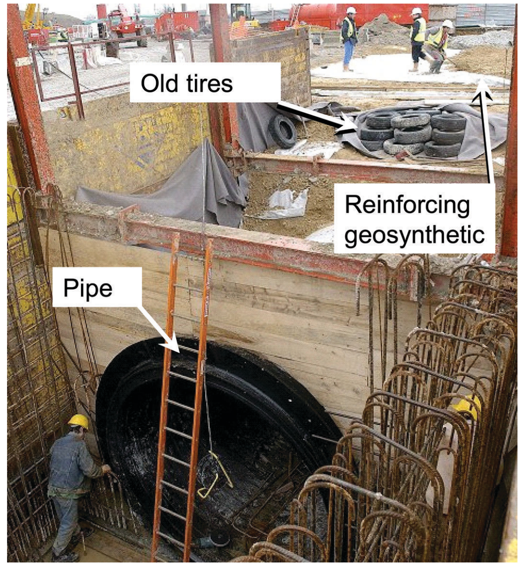

Photo 1. View of the different construction phases.

3 USING A SPECIFIC BIMODULUS GEOSYNTHETIC FOR CROSSING A SOIL SUBSIDENCE AREA UNDER A TREATED SOIL STRUCTURE

The southwest Meaux bypass is partly situated in an area of old gypsum quarries. The detailed investigations as well as the preventive treatments of these quarries by fillings and grouting let remained a high risk of collapse.

The figure 3 shows the geological profile of the project. The east part of the project is concerned by gyps quarries excavated from the surface but also from the slope. The galleries and the rooms are situated between 25 m and 30 m under the surface; this means between 15 m and 30 m under the level of the finished project.

The “old” quarries (XIX century) situated under the slope are not regular and the evaluation of average destruction level is around 75%. The height is estimated to 1.8 m.

The photo n°2 confirms that risks are real. It shows a subsidence discovered during the realisation of the road close to an injection borehole. During the injections the cavity has not been discovered.

3.1 *Design of the solution*

In similar situation the geotechnical state of the art in France plans to realise injections with a square pattern of 5 m × 5 m.

For the “old” quarries, the solution proposed consists in reinforcing the base of the structure by a

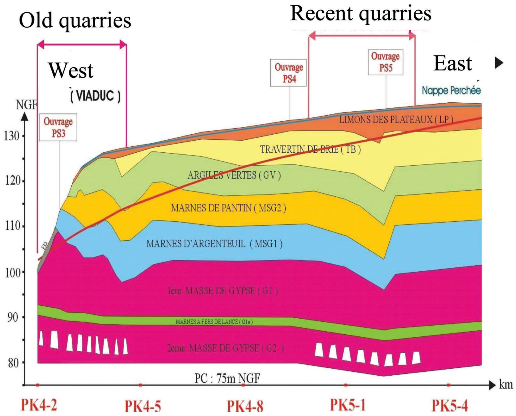

Figure 3. Geological profile of the project. The line corresponds to the final level of the road.

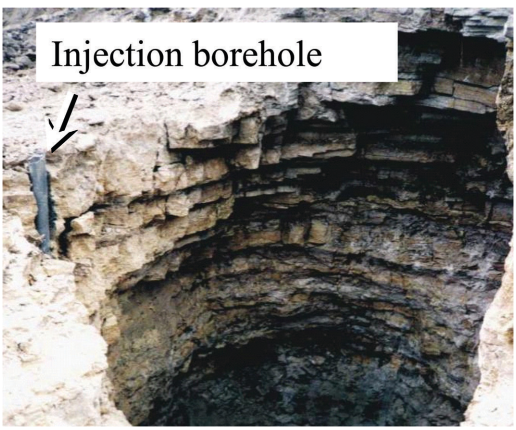

Photo 2. Cavity discovered during the construction close to an injection borehole.

geosynthetic which allow enlarging the pattern of injections to 10 × 10 m under the road and 15 × 15 m under the slopes. For the "geometrical" part, the spacing between the boreholes depends on the density of the columns in the quarries.

The road structure consists in 1.10 m with (1) 47,5 cm pavement $\gamma = 22\,kN/m^3$, (2) 35 cm base layer treated with 2% of lime and 6% cement ($c = 50\,kPa$ et $\varphi = 35°$, $\gamma = 20\,kN/m^3$), (3) 27,5 cm silt layer treated with 2% of lime ($c = 30\,kPa$, $\varphi = 30°$ et $\gamma = 20\,kN/m^3$).

The design of the geosynthetic required to take into account:

(1) cavity of a diameter of 2 m,
(2) a maximum vertical displacement at the surface d_s under the structure own weight of 10 cm
(3) the following reduction factors (in accordance with the French regulations)
   - $F_{inst} = 1,1$ (installation damage),
   - $F_{env} = 1,05$ (coefficient linked to the environmental behavior, chemical degradation),
   - $F_{géo} = 1,2$ (safety factor on the geosynthetic),
   - $F_{flu} = 1,54$ (creep factor linked to the reinforcement cables used for a duration of the loads of 1 year maximum).

This means a global factor of:

F = 1,1 x 1,05 x 1,2 x 1,54 = 2,13

The ultimate design strength is calculated under the load of the structure with a vertical load of the 1/2 of a 13 to axle.

The polymers used shall resist to the physicochemical conditions of the soil. In this case the use of treated soil with lime and cement induces the requirement to resist to a pH of 11.

As the choice of the polymer has been driven by the mechanical behaviour, it has been decided to separate the geosynthetic from the treated soil by 2 HDPE géomembranes on both side of the reinforcement. This means that the friction angle is 11°.

3.2 *Analytical method*

According the results of the real size experimentation "Rafael" (see §2.2) a specific design method was developed.

Considering the assumption of a geosynthetic stiffness of $J = 2900\,kN/m$ and $\varphi' = 30°$, $c' = 0$ the results of the design are the following:

- vertical displacement of the surface $d_s = 10{,}5$ cm with a dilatancy of 3% and $d_s = 16{,}5$ cm without dilatancy;
- maximum strain of the geosynthetic $\varepsilon_{max} = 1{,}8\%$;
- service tensile strength $T_{max} = 54\,kN/m$ under the structure own weight and $T_{max} = 87\,kN/m$ under the 1/2 axle load.

It shall be considered that the "Rafael" method has been developed for granular materials. This means that the cinematic of the displacements of the soils is conform to the figure 2.

In this case, the failure zone is a cylinder having the diameter of the cavity. The vertical load applied by the soil on the geosynthetic can be considered as uniform; the deformation of the geosynthetic is parabolic and the dilatancy of the soil reduces the vertical displacement at the surface compared to the one at the level of the geosynthetic.

Nevertheless the road fill material in Meaux is treated and in case of failure it will be most probably brittle and create a rigid bloc above the geosynthetic (Figure 4).

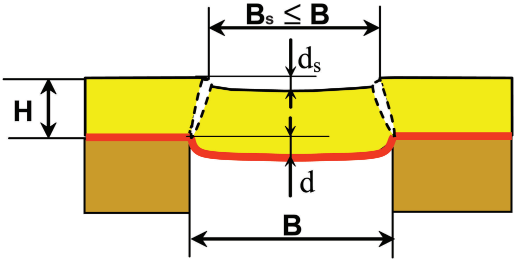

Figure 4. Cinematic principles in case of treated soils.

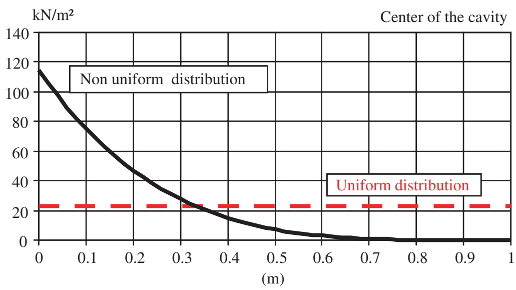

Figure 5. Distribution of vertical stresses: uniform and non-uniform assumptions.

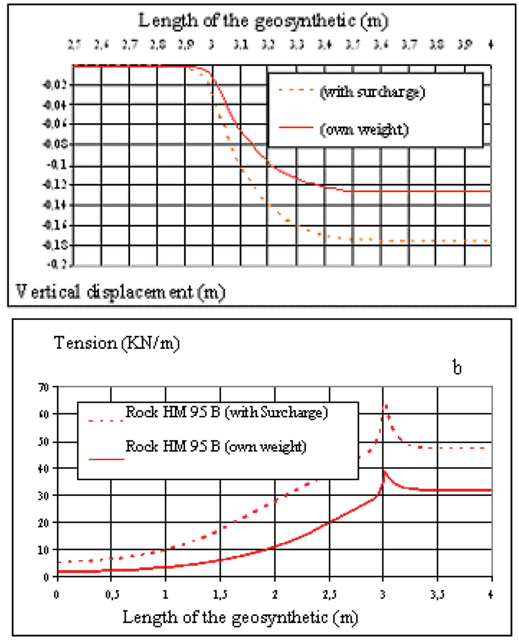

Figure 6. Distribution of the displacements (a) and of the tensions (b) in the geosynthetic reinforcement.

In this case, the stress applied on the geosynthetic is non-uniform and most probably more important on the side of the cavity than in the center. To evaluate the influence of the rigidity of the soil a new design approach has been used.

3.3 *Model using a specific FEM code*

The failure mode of a cohesive soil is a difficult task and the FEM codes have difficulties to take into account the mechanisms including cracks and large deformations.

A tentative of simplified model has been realised in Lirigm to understand and analyse the effect of a non uniform distribution of stress on the membrane deformation of the geosynthetic.

When the failure occurs, it can be considered that the soil will be mainly supported by the periphery of the geosynthetic. The distribution of the vertical stress taken into account for the preliminary design is presented in the Figure 5.

The maximum stress of the soil is estimated to 110 kN/m^3 (compression resistance of the treated soil). The total load on the geosynthetic corresponds to the weight of the fill and the traffic load ($q = 22.95$ kN/m).

A Finite Element Code has been used (Villard et Giraud, 1998). Specific tools have been developed to allow modelling the fibre structure of the geosynthetic, the friction and the sliding between the geosynthetic and the soil in anchorage area and reaching large displacements.

The action of the non-uniform vertical load on the geosynthetic has been realised by applying forces on the nods of the model (no model of the embankment fill).

The main difference with the "Rafael" model (§2.2) is the distribution of the vertical forces and the consideration of the possible slippage of the geosynthetics in the anchorage area. This changes the deformation from a parabolic shape to a more flat shape and creates larger displacements of the geosynthetic and changes in the tension.

Most of the results are presented in the figure 6. Under the own weight, the displacement of the geosynthetic is around 12 cm. If it is considered that the dilatancy of the soil is equal to 0, the displacement at the surface is the same (12 cm).

In this case, the needed anchorage length is 2.5 m if the friction angle between soil and geosynthetic is 25°. This length will be more than double in the case of a friction angle of 11° (friction between the geosynthetic and the geomembranes). The tensile load is 40 kN/m under the own weight and the horizontal displacement of the anchorage is 1 cm.

An other validation, using FLAC model, realised by Scétauroute confirms these results (Blivet et al., 2006) and the design of the structure.

Photo 3. View of the composite reinforcement geosynthetic.

3.4 *Innovative bi-modulus reinforcement geosynthetic used for optimisation of the structure*

To optimise the answer to the requirements on both the maximum displacement at the surface and the long term safety against failure, an innovative solution has been designed and developed.

The reinforcement geosynthetic developed is a bi-modulus composite realised with combined aramid and polypropylene cables knitted on a non-woven support (Photo 3). The principle of this product has been patented in many countries of Europe, America and Asia.

The product stress–strain curve is characterised by 2 zones (Figure 7 – table 1). Between 0 and 4.5% the strength of the aramid cables is added to the one of the polypropylene yarns. This allows reaching a very high stiffness, with a linear curve. After 5% the geosynthetic behaves following the performance of polypropylene yarns until failure.

Considering the first part of the curve under the own weight of the structure, the factor of safety is greater than 2.6 and the displacement is in accordance with the above requirements. This allows limiting the elongation of the geosynthetic to 1.5%.

Considering the ultimate tensile strength of the geosynthetic, it allows to secure a factor of safety greater than 3.1. This value is considered in accordance with the expected service life (maximum of one year).

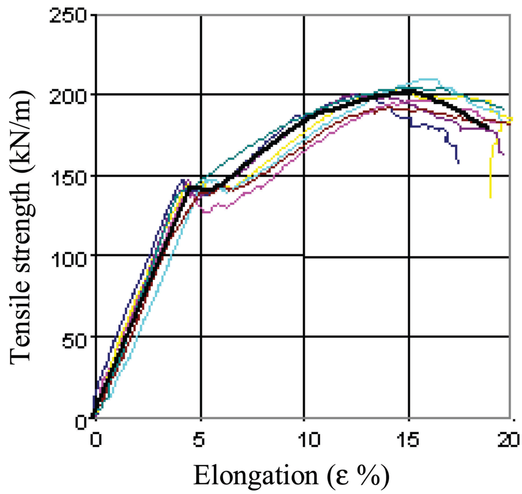

Figure 7. Stress-strain curve of the reinforcement geosynthetic.

Table 1. Main characteristics of the reinforcement geosynthetic.

Maximum tensile strength for the first part of the curve	145 kN/m
Maximum elongation for the first part of the curve	4.75%
Stiffness at 4.75% elongation	3 052 kN/m
Maximum tensile strength for the second part of the curve	200 kN/m
Maximum elongation for the second part of the curve	15%

The optimisation of the design of this product has been finalised by the Grenoble University (Lirigm) using the FEM. The tensile behaviour of product has been tested by a French accredited laboratory.

3.5 *The design of the structure*

The design is realised considering a brittle failure of the soil above the cavity.

This induces a non-uniform distribution of the vertical stresses on the geosynthetic. The main analysis has been realised using a Finite Elements Method developed by the University of Grenoble (Lirigm) which allows taking into account the friction behaviour and the eventual slippage at the anchorage level.

The photo 4 shows the installation of the geosynthetic under the road structure.

4 CONCLUSION

The interest of using geosynthetics for reinforcing platforms above soils with risk of subsidence has been clearly shown.

Photo 4. Installation of the reinforcement composite between 2 layers of geomembranes.

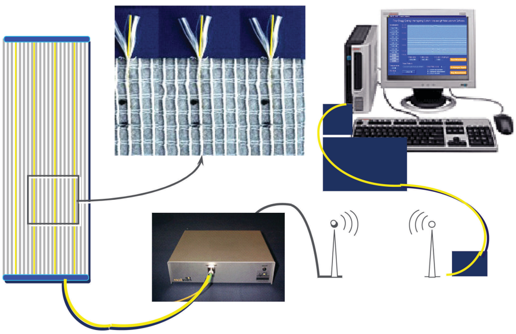

Figure 8. Principle of the Geodetect product, including optical fibbers allowing the strain measurements and the close monitoring of the site.

This solution has many technical advantages but has also economical interests, like it has been shown in the case of Meaux bypass. The bimodulus geosynthetic solution allowed to enlarge the injection borehole pattern from 5 m × 5 m to 10 m × 10 m, which represents for this project a total win for the owner of more than 8 millions €.

In addition, considering the recent development of innovative geosynthetic which offer the possibility of realisation of strain measurements and detection, it might allow an increased reduction of costs by avoiding totally the injections. This is the case of the recently developed Geodetect product (figure 8) which has been installed by the French railways under the railway in Arbois (France) above a geological fault area.

REFERENCES

J.C. Blivet, P. Garcin, A. Hirschauer, A. Nancey, P. Villard (2006): Reinforcement with geosynthetic over probable sinkholes: example of southwest Meaux bypass Rencontres Géosynthétiques Montpellier, pp. 281–288.

Blivet J.C., Khay M., Gourc J.P., Giraud H. (2001) "Design considerations of geosynthetic for reinforced embankments subjected to localized subsidence". Proc. Geosynthetics'2001. Conference, February 12–14, 2001, Portland, Oregon, USA, pp. 741–754.

Delmas Ph.., Gourc J.P., Villard P., Giraud H., Blivet J.C., Khay M., Imbert B., Morbois, A., (1999), "Sinkholes beneath a reinforced earthfill – A large scale motorway and railway experiment", Proc. Conf. Geosynthetics'99, Boston, Massachusetts, USA, April 1999, Vol. 2, pp. 833–846.

Villard P., Giraud H. (1998) "Three-Dimensional modelling of the behaviour of geotextile sheets as membrane". Textile Research Journal, Vol. 68, N° 11, November 1998, pp. 797–806.