Construction of a motorway section on potential sinkholes: reinforcement with an original very high tensile strength geogrid

Auray, G.
Texinov

Garcin, P.
Egis Géotechnique

Vapper, V.
AS Talter

Keywords:

ABSTRACT: The E20 Tallinn-Narva motorway section, between Kukruse and Jõhvi in Estonia is exposed to potential sinkholes with an estimated 4 m maximum diameter at the subgrade level. Sinkholes could appear because of oil shale mines, one of the first energy resources in Estonia. The solution chosen by the Client (Estonian Road Administration) and designers is to build this part of the road, composed of around 2 meter high embankments, on a special reinforcing geosynthetic layer. There were strict specifications for this project including: calculations for 99 years service life, maximum deformation of the road surface = 16cm for the 4m sinkhole diameter, design according to the BS8006:1995 standard and exceptional tensile strengths needed to achieve the project requirements, especially more than 1350 kN/m in machine direction. This 7 km long motorway section will need around 330000 m² of this geogrid. The paper will present this exceptional case study which started in summer 2009 and analyze some design conditions of the project for the geogrid, including durability (especially the creeping partial factor). The project will be finished in autumn of 2010.

1 GLOBAL PROJECT PRESENTATION

The project is based on a European Fund structure. The E20 motorway is connecting Estonia from west to east and is an important road for European transport. The aim is to provide safety traffic conditions and good road quality and environment for the local users and the European transportations on this motorway.

The client is the Estonian Road Administration, helped by the Estonian public design office: Technical Center of EstRoads (AS Teede Tehnokeskus) and the private design office: SEIB Ingenieur – Consult Gmbh & Co.KG. The construction is done by a group of 4 Estonian building companies lead by AS Talter together with partners AS Teede Rev-2, AS Tref and AS K-Most.

For safety conditions, the project includes collector roads, grade separates junctions, pedestrian and cycling roads, bus traffic, central guard rails. For environmental conditions, the project expects the limitation of negative impact with protection of the waters and collections of rainwater, noise barriers, by pass of the main town and villages. Landscaping will be very important with various trees and bushes preserved and planted as much as possible.

For the 7 km long section between Kukruse – Jõhvi the embankments and bridges needs to be secured because of old mines galleries:

- embankments are reinforced by foundation on a specific geogrid
- bridges are founded on deep piles.

This section represents approximately 330 000 m² of a very high tensile strength reinforcing geogrid. This is an exceptional building site for this quantity and this level of reinforcement: 1350 kN/m in machine direction. The building site should be finished in beginning of 2010 for the geogrid part.

Figure 1. Building site sign and geogrid installation

2 GEOTECHNICAL SITUATION

In Estonia, an important activity is based on mining and processing of oil shale. Estonian soil has got resources in this potential raw material for energy production.

Figure 2. Oil shale mine similar type under the building site.

The Kukruse - Jõhvi section was a traditional mining exploitation area until the 1960's. Knowing this potential risk a complete geotechnical study was carried out including geological radar and boreholes. The galleries discovered are located 3m to 14m under the ground level, their height vary from 1,6 to 3,5m and they can be 2m to 90m wide. Some of them are reinforced with piles to prevent them from collapsing but it still represents a dangerous area for the motorway project. In fact, some sinkholes are regularly discovered in this region.

Figure 3. Cracks due to sinkhole and sinkhole on the site

To ensure security of the construction and the operating of the motorway, it was decided to use a reinforcement geogrid. This technology is already well-known in the field of geosynthetics, Gourc et al (1999), Villard et al (2002). This project is suitable for this application.

3 PROJECT SPECIFICATIONS

The specifications for this project are very strict. For the 7 km section with potential 4 m diameter sinkholes, the allowed subsidence on the road surface is maximum 16 cm in 99 years, without maintenance, for a 2 meter high embankment. The main reinforcing direction of the geogrid should be sufficient to ensure these long term conditions including tensile strength and elongation. The reinforcement should also provide sufficient safety margin to ensure that larger sinkholes can be bridged temporarily for 4 weeks. All calculations have to be made according to British Standard BS 8006:1995.

The design office in charge of the project calculated that the tensile strenght for the geogrid which respect these parameters should be as following :

- 1350 kN/m in longitudinal direction
- 135 kN/m in cross direction.

And a low deformation material should be used to answer the limited elongation.

Some other designs were done later in the project by teams of geosynthetics producers and international design offices to confirm that these conditions give sufficient safety factors for the application, and that a high tenacity polyester product could answer to the maximum elongation required. Finally the client, consulting company and the building company retained the following patented product: Texinov Geoter® FPET 1350/135 made with high tenacity polyester.

The guarantees on the product are very important and it was a necessity to control all the parameters during production. The geogrid producer passed the standard CE marking for geosynthetics and engaged also tensile tests in a well-known German laboratory for geosynthetics, to ensure a continue Quality Control Plan.

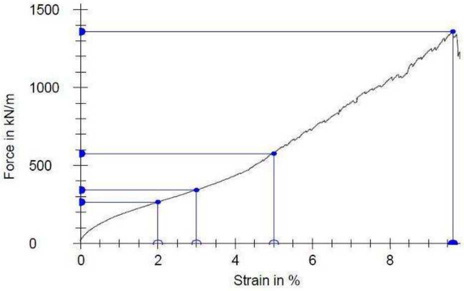

Figure 4. Tensile curve of the geogrid.

The tensile strength and the elongation are regularly checked all along the project duration. This laboratory is part of the only one to have the capacity to test such a high tensile strength product.

4 DESIGN

4.1 *Product validation*

The validation of the product was according to BS 8006:1995 standard. The parameters, the elongation and tensile strength calculation are quickly recalled hereafter. The creep partial safety factor is required for a service life of 99 years.

The assumptions linked to the product are the following:

- high tenacity **Polyester**
- the elongation at break is 12%

The BS 8006:1995 calculation method main assumptions are the following:

- Linear elastic membrane behaviour
- membrane under uniform loading

With calculation parameters:

- q: traffic load at surface
- ds: deflexion at surface = 16 cm
- Ds: surface deflexion diameter
- Dg: sinkhole diameter at the geogrid surface
- H: embankment height
- θ = internal fill embankment friction angle.
- q': horizontal stress on geogrid q'

The figure 5 gives some of the calculation parameters.

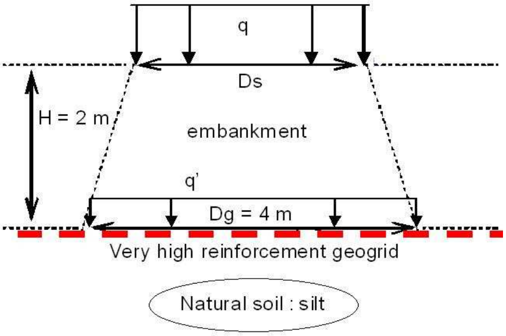

Figure 5. Parameters according to BS8006:1995 standard.

The vertical stresses are transferred into horizontal stresses in the geogrid.

The geogrid deformation ε is given in the following formula:

$$\varepsilon = 8\times(ds/Ds)^2 \times (Dg+2\times H/\tan(\theta)^6/(3\times Dg^6)$$

The geogrid tensile strength is function of the root of the elongation divided by 6.

The geogrid deformation at service, tensile strength and the secant stiffness modulus are sum up in the table 1.

Deformation at service (%)	Tensile strength (kN/m)	Secant stiffness modulus J (kN/m)
4	1350	11250

Table 1. Geogrid deformation at service, tensile strength and secant stiffness modulus

The creep partial factor is taken into account in the tensile strength assessment, after service tensile strength calculation.

4.2 *Longitudinal Anchorage*

The geogrid is installed in the axle of road. The anchorage is longitudinal and is given hereafter. The anchorage is only ensured by the embankment vertical load σn on the geogrid.

The friction angle within the embankment is 35° and 20° for the silty ground soil. The friction angle coefficients at the interfaces are:

- between embankment and geogrid: 0,7 tan $\varphi_{g/embankment}$ = 0,7 tan (35°)
- between silt and geogrid: 0,7 tan$\varphi_{g/silt}$ = 0,7 tan (20°).

The anchorage length La is given by:

$La = FS\ anchorage \times T/[0{,}7.\ (\tan\varphi_{g/embankment} + \tan\varphi_{g/silt})\ .\ \sigma n]$ + sinkhole diameter

With:

- $\sigma n = \gamma embankment \times H = 19\ kN/m^3 \times 2\ m = 38\ kPa$.
- FS anchorage = 1,3
- La = 10,5 + 4 = 14,5 m.
- Anchorage length La = 14,5 m

5 BUILDING SITE REPORT

Once the security was controlled, the short delivery time where confirmed and production could start.

Some precise information to organize the building site was proposed to the building company based on the document of the French Committee of Geotextiles and Geomembranes called: recommendations for the use of geotextiles in reinforced soil constructions.

Figure 6. Aerial view of the building site.

A great performance of delivery and installation on the building site of 25000m² each week is carried out.

Figure 7. Installation of the geogrid.

This exciting building site has no equivalent today in terms of tensile resistance, surface and delivery conditions.

Figure 8. Geogrid starting to be covered.

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