Protection of road and railways embankments against collapse involved by sinkholes

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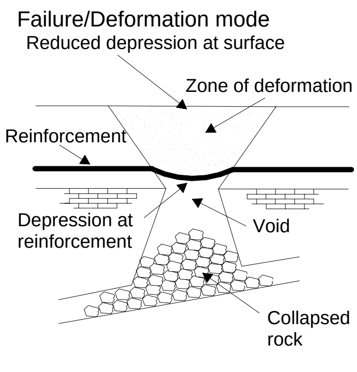
ABSTRACT: The consequence of subsidence beneath road and railway embankments can range from a reduced serviceability to a total structural collapse. In some countries the development of sinkholes or another forms of subsidence causes serious difficulties for roads and railways. At the begin of the 1980, together with the development of high strength geosynthetic reinforcements, a new art bridging of cavities or voids was created. Some examples of this kind of realised road and railways protections in France and Germany against collapse involved by sinkholes are presented in the papers.

1 INTRODUCTION

One of the first applications of high strength geosynthetic reinforcement for bridging of sinkholes took place in 1987-1989, The Edinburgh City Bypass, Cook 1989. There was installed a woven geotextile made from high tenacity polyester with the ultimate tensile strength of 1000 kN/m in four layers for bridging sinkholes with a diameter up to 12 m. The height of the road embankment was about 12 m. The design method used in this project based on the assumption, that only 20 % of dead and traffic load would be act on the reinforcement level due to the arching effect. The membrane equation was used to predict the tensile force in the reinforcement for the acceptable deflection of the pavement of $d_s/D_s \leq 0.01$, (for designation of d_s and D_s s. Figure 1).



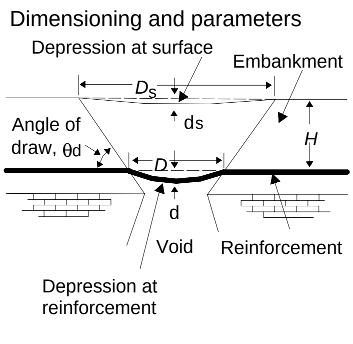


Figure 1. Conceptual role of reinforcement and parameters used to determine reinforcement

The introduction of the BS 8006, firstly as a draft and later in 1995 as the code of practice, BS 8006 1995 encouraged engineers and owners to use geosynthetics for the protection against collapse in areas prone to subsidence. The published results of investigations and trials Giroud et al

1990, Genske and Lepique 1993, Alexiew 1997 and Gourc et al. 1999 helped in 1990-2000 in the spreading of this method of bridging sinkholes in the engineering practice.

The progress in the software (PLAXIS or FLAC) helped engineers to analyse more accurately the stresses and strains in the soil and reinforcement and to predict with a higher accuracy the deformation on roads or railway surface in a case of void development, Kempton et al 1996, Gourc et al 1999.

2 DESIGN PRINCIPLES OF VOID BRIDGING WITH GEOSYNTHETICS

The voids according to their form could be classified into two groups:

- infinitely long voids or cracks with defined width B: overspend with an uniaxial reinforcement, installed crosswise to the direction of the void.
- circular voids i.e. sinkholes or craters with defined diameter D: bridged uniaxial or biaxial

The void width B or diameter D has to be predicted for the planed installation level of reinforcement. A very important factor is the relative thickness of the reinforcement covering H/D or H/B according to the arching effect, s. Figure 1. The Authors use in Germany for the design of the reinforcement following strategy:

- for sinkholes or long voids with H/D or H/B ≤ 1: method BS 8006 , BS 8006 1995
- for sinkholes or long voids with H/D or H/B > 1: Giroud's method, Giroud et al 1996.

Both methods are modified or adapted by authors to the German Practice:

- design method: ultimate limit states - according to: DIN V 1054-100 1996
- estimation of the characteristic value of tensile strength of geosynthetic reinforcement: EBGEO 1997.

In France is generally used the Perrier's method, Papiau et al 1995. The diagram for the design of the reinforcement with this method is schematically presented in Figure 2.

The design begins with the definition of the acceptable surface deformation d_s or d_s/D_s, s. Figure 1. In BS 8006 1995 the maximum differential surface deformation d_s/D_s is defined as follows:

- principal roads: $d_s/D_s \leq 1\%$
- non-principal roads: $d_s/D_s \leq 2\%$.

For railways the acceptable inclination of the track could be defined according to the German Railways Regulations DS 804 1996 as follows: $d_s \leq 0{,}002 \cdot L$, with L = rail space (i.e. 1500 mm).

The allowable elongation of the reinforcement is directly connected with the acceptable deformation on the surface, i.e. with the ratio H/D resp. H/B. This means, that the tensile characteristic of a given reinforcement (mobilised tensile force - elongation) and creep behaviour must be carefully analysed, in order to optimise the system. In Figure 2 are schematically presented some characteristics of Fortrac® -geogrids for a short time load made from polymers like: aramid (A), polyvinyl alcohol (M) and high tenacity polyester (PES) together with the Perrier's diagram.

It must be emphasised, that not only short term loads define the tensile force in the reinforcement. The creep behaviour of the used reinforcement must be taken into account at the design, too. The graphical presentation of the influence of the creep on the tensile force in the reinforcement and the depression of the road surface includes Figure 3. The acceptable deflection of the road surface (serviceability state for the given load time) is usually relevant for the selection of a polymer type (i.e. stiffness and creep behaviour). The following principle are generally used in Germany and France for the design of the reinforcement:

- sinkholes or long voids with a smaller diameter D or width B up to 2,5 –3,0 m: permanent bridging designed moistly for 60 years

- sinkholes or long voids with a larger diameter D or width B greater than 3,0 m: temporary bridging designed for min. 1 week or for up to 1 month (time needed to back-fill voids by injection).

The characteristic value of the tensile strength (ultimate tensile strength) is estimated according to the EBGEO 1996 using following formula:

$$F_{Bk0} = \frac{F_{Bd}}{A_1 \cdot A_2 \cdot A_3 \cdot A_4 \cdot \gamma_B} \qquad (1)$$

F_{Bd} = tensile force in reinforcement for the given load time and acceptable elongation (i.e. acceptable depression in the surface d_s/D_s), A_1 = creep factor for the defined load time, A_2 = mechanical damage factor, A_3 = connection factor, A_4 = environmental factor, γ_B = partial safety factor for flexible reinforcement according to DIN V 1054 –100 1996.

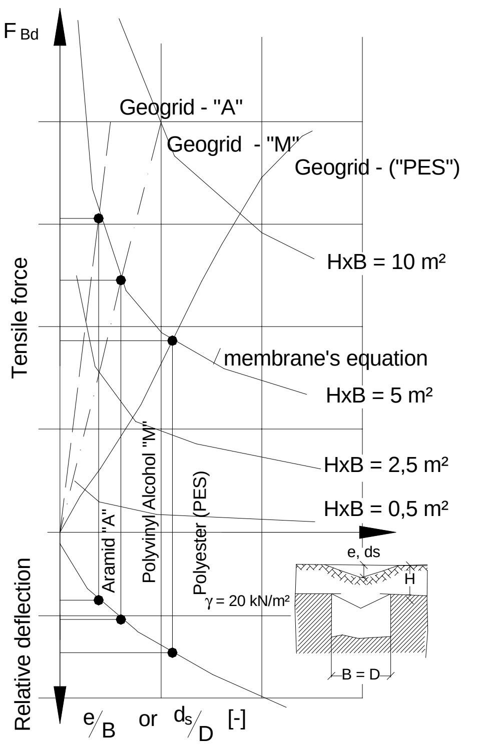


Figure 2. Diagram for the design of the reinforcement with Perrier's method, schematically for a short time load, i.e. immediately after development of a sinkhole

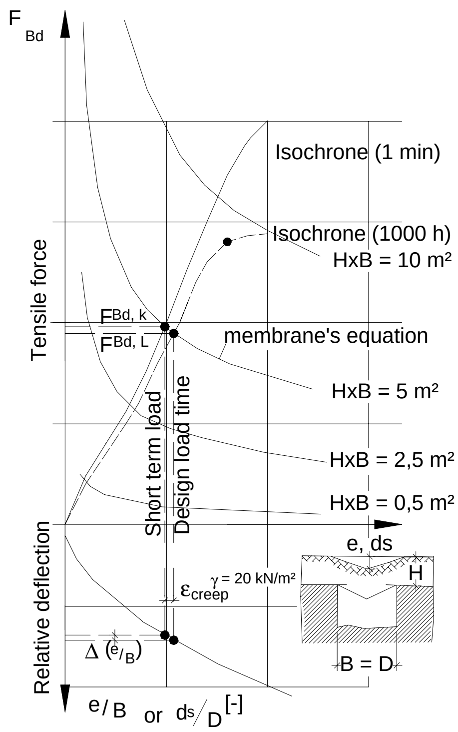


Figure 3. Diagram for the design of the reinforcement with Perrier's method, isochrones: schematically for estimation of tensile force immediately after sinkhole development (short time load) and for design load time (long term condition)

The values of A_1 and A_4 for geogrids made from high tenacity polyester and aramid are included in the tables 1 and 2.

Table 1. Creep factors A_1 of geogrids made from high tenacity polyester and aramid

	Load time										
	1 hour	1 day	1 week	1 month	1 year	2 years	3 years	5 years	10 years	60 years	120 years
Polyester A_1 [-]	1,20	1,28	1,33	1,37	1,43	1,47	1,49	1,50	1,53	1,56	1,67
Aramid A_1 [-]	1,21	1,25	1,43	1,50	1,54	1,70	1,72	1,75	1,82	1,98	2,00

Table 2. Environmental factors A_4 for geogrids made from high tenacity polyester and aramid

pH–value of the soil	2,0 to 4,0	4,1 to 8,9	9,0 to 9,5
Polyester A_4 [-]	1,10	1,00	1,15
pH–value of the soil	3,0-5,0	5,1-8,9	9,0-10,0
Aramid A_4 [-]	1,05	1,00	1,20

The A_2 values for high strength polyester or aramid geogrids PVC - coated (ultimate tensile strength > 400 kN/m could be assumed depending on the granulation of the soil layer as follow:

- fine sand (d_{max} = 2 mm): A_2 = 1,02
- medium gravel (d_{max} = 60 mm): A_2 =1,05
- angular gravel or cobbles from crushed rock (d_{max} = 100 mm): A_2 = 1,10 –1,15

d_{max} = the maximal diameter of soil grains.

3 EXAMPLES OF BRIDGING WITH HIGH STRENGTH GEOSYNTHETICS

3.1 *Federal Road B 180, Neckendorf near Eisleben, Germany, 1993*

The road was destroyed in 1987 by a sinkhole with a diameter of 8 m and the depth of about 30 m. Although the cavity was refilled, the danger of a new rest subsidence due to the underground erosion and rearrangement of soil mass still exists. Due to lower costs and required “ductile” deformation behaviour, a geogrid – reinforced gravel cushion was designed. A final dimensioning included three procedures : Giroud 1982, Giroud et al 1990, BS 8006 1995 (at this time still a draft). The analysis resulted in the need for an uniaxial reinforcement with a tensile strength in machine direction of 1180 kN/m at 3,0 % (failure zone 1) and 470 kN/m at 1,8 % (failure zone 2), s. Figure 4.

These requirements meets the geogrid 1200/50-10 made from aramid with the ultimate tensile strength 1200 kN/m (machine direction), 50 kN/m (crosswise) and mesh size 10 mm. The construction details in the cross-section and on the plan view of the reinforced cushion are shown in Figures 4 and 5. Due to the importance and heavy traffic on this road the road administration decided to install on the upper layer of geogrids a control and warning system, consisting of steel wires and four control shafts. The nearly inextensible wires are installed in tubes (in order to reduction of friction) and connected to the pull-out gauges in the shafts. The elongation of the geogrids could be controlled by the wires, because:the extend of wires pull-out from the shafts = the elongation of geogrids. The installation works of the second geogrid layer and the control wires presents the Figure 6.

For the cushion soil a well graded gravely sand (0/56 mm) compacted to a relative Proctor’s density of ≥ 103 % was selected. The reconstructed section of the Federal Road B 180 is in operation and monitoring since October 1993. To the date no decisive deformation has been monitored. It should be mentioned, that the described high strength geogrid reinforced gravel cushion was the first structure of this kind in Germany.

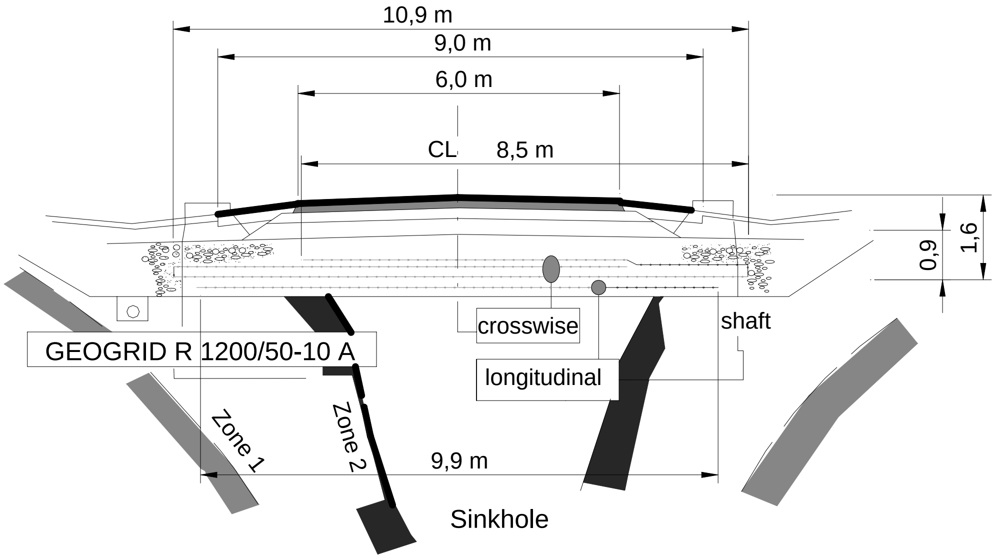


Figure 4. Cross section of reinforced gravel cushion, Road B180 Neckendorf near Eisleben, 1993

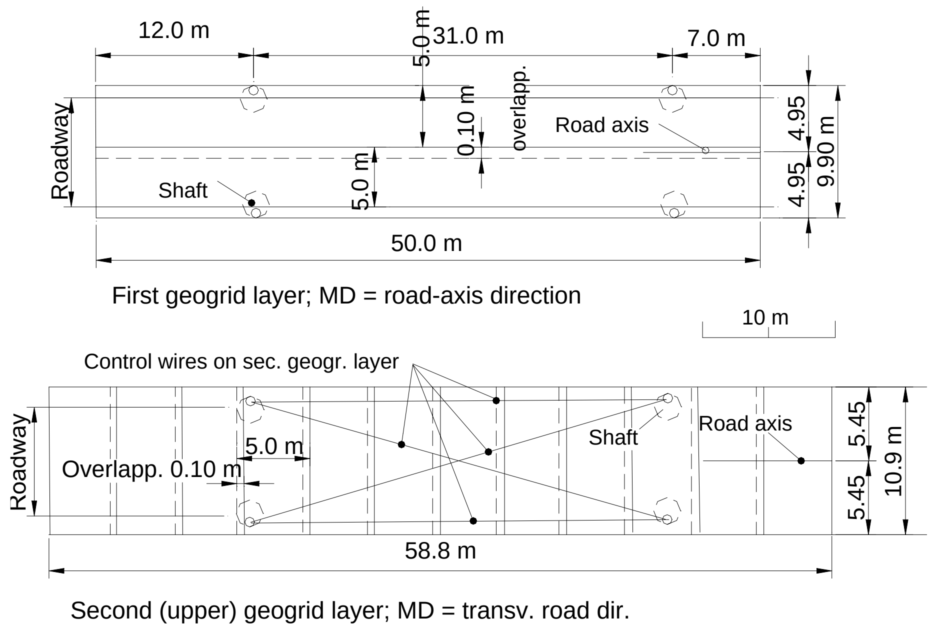


Figure 5. Plane view of reinforcement and control system, B 180 Neckendorf near Eisleben,Germany 1993

3.2 *A.29 motorway : Le havre/East Yvetot France 1994*

This section is mainly located AT the plateau of Caux, the geological base of which is consisting of the calcareous formation of the upper Cretaceous. In this location, underground cavities natural or anthropic may be develop. The karstic gaps result from the calcareous dissolution due to water circulation, and activated by a network of original fractures

For the major part of the cavities with a high potential sinking risk, a preventive system consisting of a geosynthetics reinforcement was installed. For the analysis, the Perrier method was used and resulted in the need for a uniaxial reinforcement with a tensile strength in machine direction of 270 kN/m at 5 % strain.

These requirements are met by the geocomposite Comtrac® D480/0 B20 made of polypropylene with a ultimate tensile strength of 480 kN/m (machine direction)

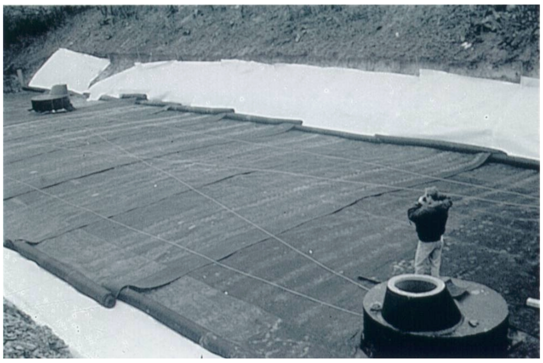


Figure 6. Installation of the upper layer of geogrid R 1200/50-10 made from aramid, Road B 180, Neckendorf near Eisleben, Germany,1993

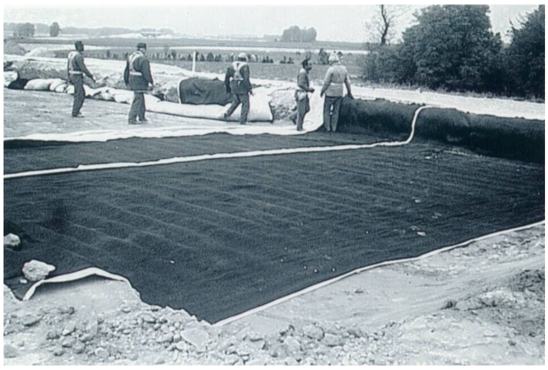


Figure 7. Installation of the cross layer of D 480/0-B20 made from polypropylene, motorway A29, Le Havre/East Yvetot, France, 1994

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3.4 *A.20 Bypass from Châteauroux France 1998*

The bypass of Châteauroux is located on a calcareous massif oolithique, which is based on cavities which may be empty or may be fill with some clay. The detection of these cavities has been difficult until now. The modification of the hydrogeology may lead to a washing out of the fine material and may develop potentials sinkholes.

During the first phase of this project, we could observe the development of sinkholes with a diameter up to 3,5 m and a depth of 20 m. Therefore, the customer decided to use a geosynthetic solution in order to assure the serviceability of the road.

The static calculations were performed according to the Perrier method:

<u>Assumptions:</u>

Traffic load : 20 kN/m²

Diameter of the sinkhole: 3,5 m

Biaxiale loading transferring system

<u>Results:</u>

Acceptable strain of reinforcement : max =1,5 %
Design tensile force: 150 kN/m

All above mentioned requirements were met by a woven polyester geotextile Stabilenka ®1000/100 with a ultimate tensile strength of 1000 kN/m in the machine direction.. The cross section of this embankment is shown in figure 8.

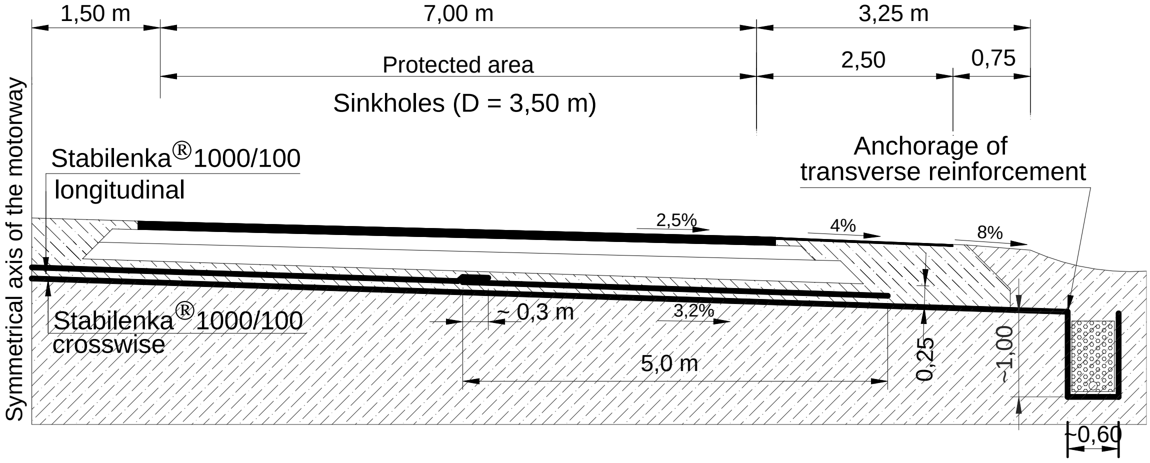

Figure 8: Cross section on the motorway A20

3.5 *Bypass Zeitz - Theissen, Germany, 1999*

The region of Zeitz - Theissen is an old mining area, in which the development of sinkholes was observed. A 460 m long section of the Zeitz-Theissen Bypass had to pass thought this difficult zone , where sinkholes with the diameter up to 3,5 m are expected. The road embankment in this section has a high of H = 2,0 m to H = 2,5 m. The static calculation were performed according to BS 8006 1995 and resulted as follows:

Assumptions:

-traffic load: w_s= 33,3 kN/m²

-acceptable surface deflection: d_s = 5 cm

-design load time: 2 weeks

-one way load shedding system: λ = 1,0

Results:

-acceptable elongation of reinforcement: ε_{max} = 4,3 %

-design tensile force: F_{Bd} = 283,4 kN/m.

Figure 9. Installation of the two layers of geotextile 1000/100 (first layer : road axis dir., second layer: Trans. Road. dir.) A20, France, 1998

All above mentioned requirements could be statisfied by woven geotextile made from polyester 1000/100 with the ultimate tensile strength of 1000 kN/m in the machine direction and crosswise of 100 kN/m. The cross-section of the protected embankment is shown in Figure 10.

The woven geotextile with the roll width of 5,0 m was unrolled and stretched with a tensile force of 2 kN/m in the longitudinal direction. In Figure 10 is shown the stretch device developed by the authors during the pre-stressing phase and the installation of the bearing layer by an excavator.

In the typical cross-section were installed 5 sheets of the Stabilenka® 1000/100 with overlaps of 0,50 m. The overlaps in the longitudinal direction (direction of the mean tensile force) have a length of 10 m. The overlapped sheets were separated with a gravel layer (0,10 m thickness) for the purpose of increasing the friction.

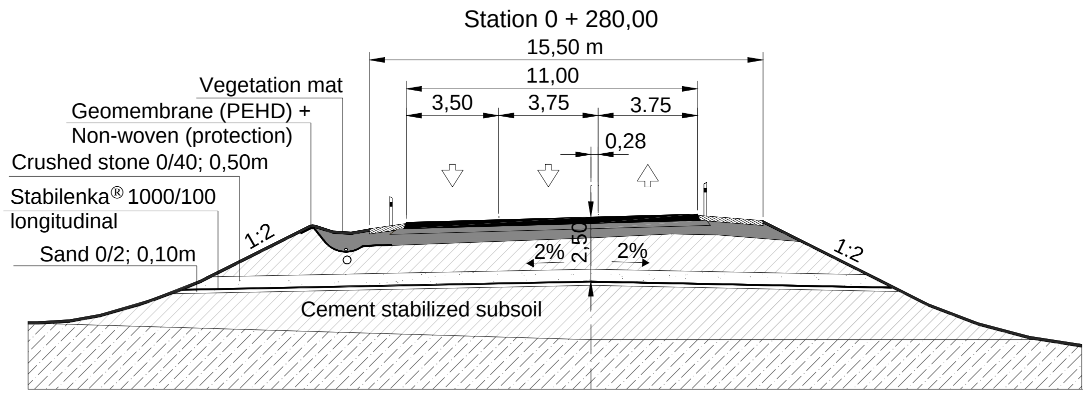

Figure 10. Cross-section of embankment protected against collapse by sinkholes, B 81, Bypass Zeitz – Theissen, Germany 1999

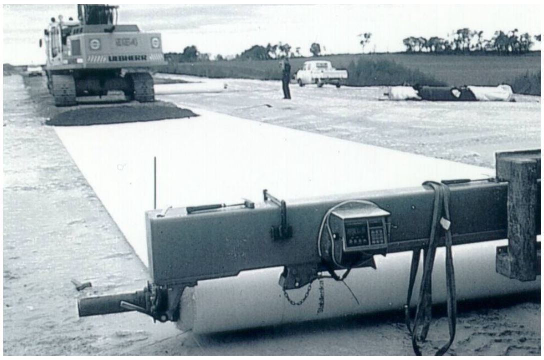

Figure 11. Stretched geotextile 1000/100 during installation, B 91, Bypass Zeitz – Theissen, Germany, 1999

Figure 12. Installation of the GNT between the layers using a long arm excavator. Angers, France, 1999

3.6 *Bypass from Angers, France 1999*

The road bypassing the town of Trelaze is crossing the site of the Angers Slate Quarries, made up mainly of badly filled open-cut quarries, mine shafts and underground tunnels.

Investigations provided precise knowledge and a precise inventory of the subbase, locating all the shafts on or near the road in plan form and in relief. In old vertical mining shaft, fill with soil have sawn serious settlement.

Given the level of service required for infrastructure, it was decided to put a reinforcement geosynthetic base into the shafts as preventive system.

The study showed that a device comprising of two layers of geosynthetic woven in high-tenacity polyester with a tensile strength of 1000 kN/m placed in a perpendicular direction allowed the surface deviation to be limited in the case of violent collapse. The product used is a woven geotextile 1000/100 with a tensile strength of 1000 kN/m (machine direction) with an strain at rupture of 9 %.

Figure 13. View of the tube allowing a futher endoscopy, Angers, France ,1999.

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