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A geosynthetic overbridging system in the base of a railway embankment located on an area prone to subsidence at groebers: Construction experience

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ABSTRACT: High strength geosynthetic reinforcements offer an economical possibility to reduce the foundation risk in areas prone to subsidence. Currently constructed railway junction Groebers extending over an area of 120 m x 800 m is the first place, where German Railways are using geogrids to overbridge sinkholes. Two of the eight tracks are designed for the speed of up to 300 km/h. The overbridging system with a design life of 60 years guarantees for the serviceability of the railway tracks during a load time of 1 month after the development of a sinkhole. It consists of: a warning layer, two geogrid layers and a cement stabilized bearing layer. Planning and specification are based on the results of a full scale test and FEM calculations. The final requirements, a typical sections, a specially developed installation-device and first experience are presented in the paper.

1 INTRODUCTION

The new railway node Groebers is located on an old mining area prone to subsidence. As two of the rails are designed for trains running up to 300 km/h very strong deformation limits are defined. Field observations and experience about sinkhole development in this area led to a design value for the diameter of sinkholes to be protected of 4.0 m. Unfortunately, the location of all existing cavities is not known. Considering various concepts German Railways finally decided to install a foundation system incorporating: a warning layer and high strength geogrid reinforcements and cement stabilized bearing layer. Details of the superstructure, installation technique and first experience are presented in the following.

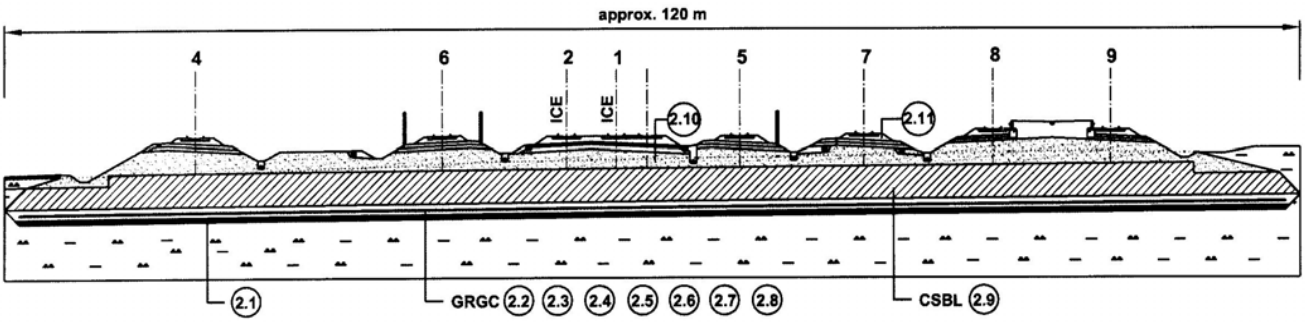

Figure 1. Cross section Junction Groebers

2 SUPERSTRUCTURE OF THE FOUNDATION SYSTEM

The foundation system can be divided into two main measurements:

a) Injection of cement slurry in all cavities with known or detected position (these works are already finished)
b) Construction of a specially developed overbridging system with a design life of 60 years and loading time of 1 month.

During the design life the serviceability of the railways has to be guaranteed for at least 1 month, i.e. time needed for injection works. In this project the serviceability is controlled by the allowable deformation of the track, $\Delta S/L$ has to be smaller than 1:500 ($\Delta S \leq 3.0$ mm = allowable settlement difference over L = 1 500 mm rail spacing).

The overbridging system consists of following main elements (Ast, Hubal 2001, Ast, Sobolewski, Haberland 2001):

- cement stabilized base layer
- geogrid reinforced gravel cushion (GRGC) incl. warning layer and extensionmeters
- cement stabilized bearing layer (CSBL).

2.1 *Cement stabilized base layer*

Local material consisting of clayey silt is mixed with a cement stabilizer (up to 4.5%) in an on site plant. A 0.40 m thick foundation layer is then placed with an uniform inclination in the cross-direction of 0.9% in order to drain off the rainwater, Figure 1, Figure 2, Table 1.

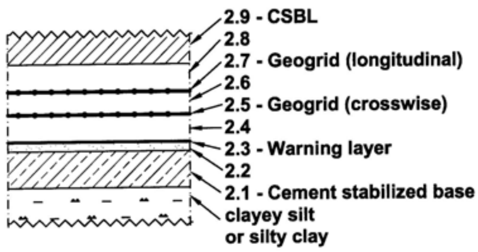

Figure 2. Detail geogrid reinforced gravel cushion (GRGC)

2.2 *Leveling layer*

A 0.10 m thick leveling layer of gravel (0/16mm) is then placed on top of the cement stabilized base.

2.3 *Warning layer*

The warning layer is installed in panels and connected to a large matrix, which covers the whole foundation area (Ast & Haberland 2002). It is composed of two non-woven embedding PTFE coated electrical wires, forming an orthogonal grid with a mesh size of 0.25 x 0.25 m. A change in the electric resistance of the wires or their rupture serves to locate deformation zones or local failures of the subsoil. The connected controller and server transform the received data to a clear signal, which is displayed like a topographical map of deformation. Additionally installed glass fiber extensionmeters are acting as back-up system.

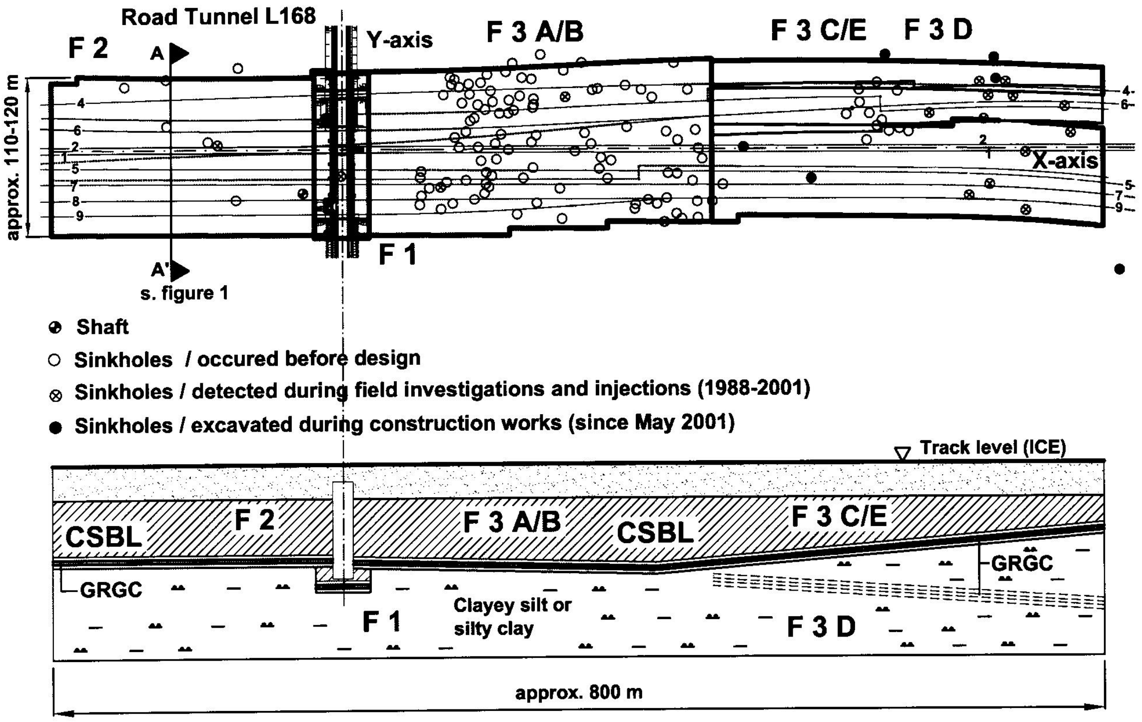

Figure 3. View plan Junction Groebers

2.4 *Ballasting layer*

In order to force the deflection of the warning layer with the development of a sinkhole as soon as possible, the warning layer will be loaded with a 0.30 m thick ballasting layer of gravel (0/16mm).

2.5 *The first geogrid layer (installation crosswise)*

The first geogrid layer is installed crosswise to the embankment axis with an overlap of 0.25 m and without overlaps in unroll direction. In order to optimize the installation procedure and to minimize the quantity of reinforcement each sheet is placed according to a specific code number corresponding to installation plans. Static calculations and experience gained during the full-scale test performed in 1998 (Alexiew, Elsing & Ast 2002, Ast & Watzlaw 1999, Ast & Hubal 2001, Ast, Sobolewski & Haberland 2001, Ast & Haberland 2002) resulted in following requirements on geogrids:

(c) md = (cross) machine direction

- Ultimate tensile strength: $F_k \geq 1200$ kN/m (md)
  $F_k \geq 100$ kNm (cmd)
- Elongation at break: $\varepsilon_{max} = 2.5 \pm 0.5\%$ (md)
  $\varepsilon_{max} = 5 \pm 1.0\%$ (cmd)
- Design tensile strength: $F_{bd} \geq 500$ kNm (md) @ $\varepsilon_t \leq 1.7\%$ (for loading time t = 1 month, creep elongation $\Delta\varepsilon_t \leq 0.50\%$)
- Increase of elastic elongation after 10^5 load cycles and load level 500 ± 100 kNm: $\Delta_{\varepsilon e} \leq 0.20\%$ (md)
- Mesh size: ≥ 10 mm

These parameters are proven for the chosen geogrid Fortrac® R 1200/100-10 AM made from aramide (md) and polyvinylalcohol (PVA) (cmd).

Outside the edge of the outermost potential sinkhole to be overbridged the geogrid has to be anchored with an anchorage length of 7,0 m. In order to economize excavation volume one part of this length is installed in a wrap around.

2.6 *Bedding layer*

The first geogrid layer is covered with 0.25 m round shaped gravel (0/32 mm) to separate the upper and the lower reinforcement layer.

2.7 *Second geogrid layer (installed longitudinal)*

The second geogrid layer is installed in the longitudinal direction of the embankment axis with an overlap of 0.25 m. The longitudinal overlap requires a length of 11 m which is 7 m for the anchorage plus 4 m for the diameter of one sinkhole. A 0.10 m thick interlayer of gravel (0/32 mm) is placed in the overlap zone to achieve uniform bond conditions between the overlapped geogrids.

2.8 Upper bedding layer

The second geogrid layer is covered with 0.30 m gravel (0/32 mm). The upper surface of this layer represents the upper limit of the geogrid reinforced gravel cushion (GRGC). Unless mechanical function this layer serves as a buffer against alkaline water, which can escape in small amounts from the above placed CSBL.

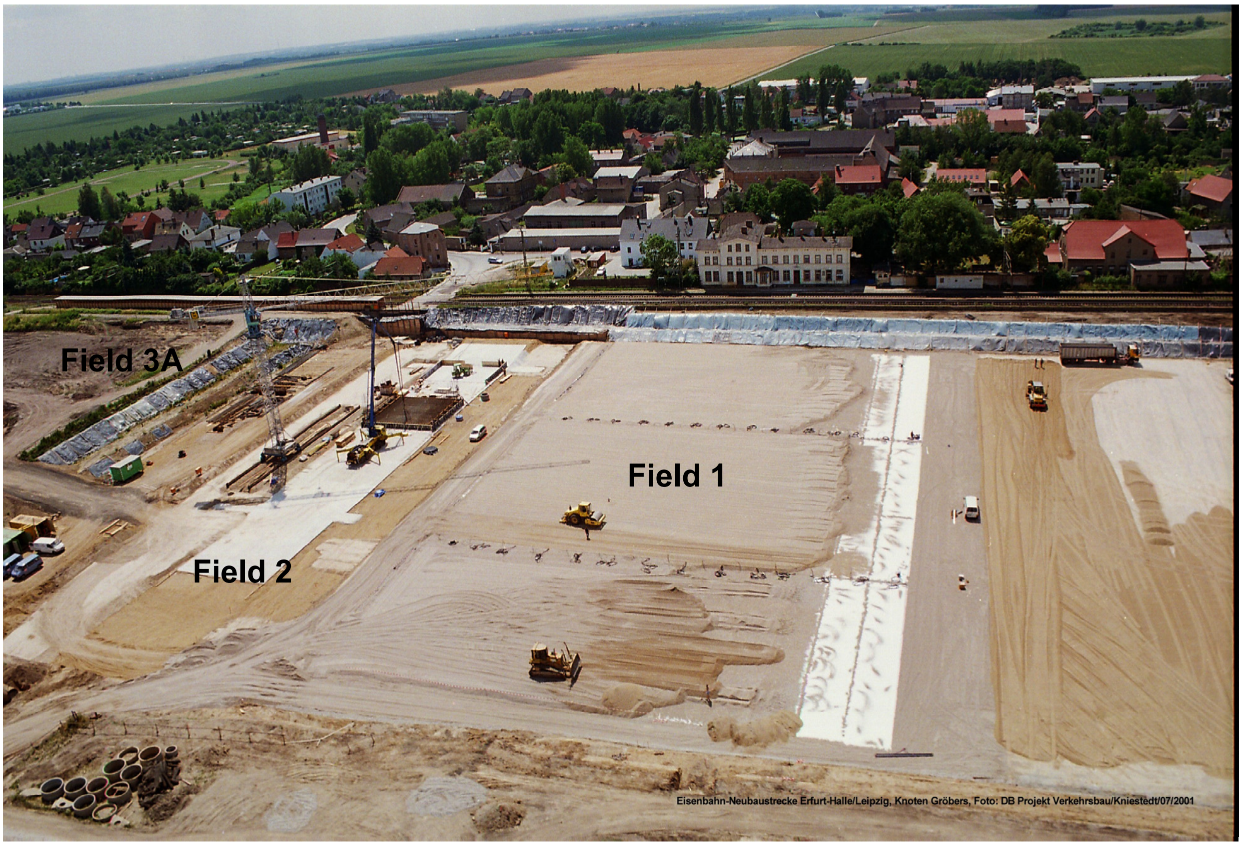

Figure 4. Areal photo Junction Groebers, July 2001

2.9 *Cement stabilized bearing layer (CSBL)*

This layer has a crucial function: In case of a sinkhole development a stable arch has to form in this material. It has to rest at least for a time of 1 month, hence the mechanical properties of this layer are of high importance (s. Table 1). Related to the stress distribution and the geometry of the load transfer the min. thickness of the CSBL is 2.95 in the active stress zones and 1.95 outside the active stress zones. At locations where the CSBL is positioned deeper than statically required it is covered with an additional layer of cement stabilized soil.
Table 1

Table 1. Requirements on main parameters of soil layers of the embankment structure

Designation	Soil art	Parameters		
		Proctors's density D_{PR} (%)	Angle of Friction φ_k (°)	Cohesion c_k (kN/m²)
Blanket layer	KG 1*	103	≥ 42	-
Frost protection layer	KG 2*	100	≥ 42	-
Cement stabilized bearing layer	SU/TL** min. 4,5% Pectacrete	100	≥ 35	≥ 150
Bedding layer	Gravel 0/32 KG 2 (1) TL 918 062	100	≥ 42	-
Ballasting layer	Gravel 0/16	100	≥ 42	-
Leveling layer	Gravel 0/16	100	≥ 42	-
Cement stabilized base layer	SU/TL** min. 4,5% Pectacrete	97	≥ 35	≥ 150

* TL 918 062 – Technical terms of delivery of soil materials for railway structures, DB AG
** SU/TL – clayey silt or silty clay, DIN 18 196

2.10 *Non-woven-separation layer*

On top of the cement stabilized embankment (finished surface) a non-woven from PP, 350 g/m² is laid for separation and protection.

2.11 Frost protection and blanket layers, tracks

Requirements of these layers and the track construction are based on German Railway Regulations DS 836, see Table 1. Construction of a non-ballasted concrete track is optional.

3 CONSTRUCTION WORKS

3.1 *Construction sequence*

As the total area endangered by sinkholes is about 120 m x 800 m the foundation base is divided into 3 main sections, so called fields F1, F2 and F3 A-E. The six main operations to be carried out are:

- field investigation and injection works performed from the existing ground level
- excavation and preparation of the embankment base
- laying and networking of the warning layer (680 sheets ≅ ca. 90 000 m²) incl. the placement of the ballasting layer
- installation of the reinforcement (479 rolls ≅ 213 000 m²) and a complying gravel layer
- placement of CSBL
- installation of the tracks including frost protection and blanket layers.

3.2 *Injections and preparation of the embankment base*

Between 1998 and 2001, before earth movements started, preliminary injection works were carried out operating from the existing ground level. The locations of injection works were positioned according to the results of simultaneously performed deep soil investigation.

The soil improvement works have been continued in May 2001 with the begin of the excavation. Now they are performed operating directly from the excavated base for the embankment. Since the start of excavation works following forms of sinkhole have been noted:

- opened sinkhole, especially after heavy rains Figure 5
- arch shaped sinkholes discovered on differential depth Figure 6
- old sinkholes self-filled with a mixture of cover soil and upper soil layers.

Figure 5. Open sinkhole

Figure 6. Arch shaped sinkhole

In order to avoid further accidents during construction works Figure 7, every excavation level has to be checked. For this reason simple testing of the bearing capacity on the excavated base is performed with the dipper before opening the new section to traffic.

Cavities detected during the excavations are specially treated:

- the upper zone (4 to 6 m) is excavated, stepped and refilled layer by layer with cement stabilized soil. After a final check and the approval of the owners supervisor the cement stabilized base layer is installed (ref. 2.1).

Figure7. Accident during excavation, July 2001

Figure 8. Stepped excavation and refill with cement stabilized soil

Figure 9. Placement of cement-stabilized base layer

3.3 *Quality management of geogrid production*

The geogrid production is controlled as follows: control testing of delivered yarns: tensile strength, titer according to ISO 2062 / 95 VA, every 5000 kg

- control testing of geogrid: tensile strength according to EN DIN ISO 10 319 unit weight accord. to DIN EN 965 and mesh size, every 1000 m of product
- external supervision of geogrid production according to DIN 18 200: tensile strength according to EN DIN ISO 10 319, unit weight accord. to DIN EN 965 and mesh size, 2 tests yearly

- independent control contracted by customer: tensile strength according to EN DIN ISO 10 319, each 10000 m² of product
- final control by EBA (Federal Railroad Agency), in situ: every installed roll including all required documents.

3.4 *Installation of geosynthetic layers*

Each roll of warning layer and each roll of geogrid delivered to the construction site is signed with a specific code number given on the roll etiquette. This identification makes it possible to install geosynthetic sheets at its designed position. The etiquette gives further information about the product: producer and type of product, raw material, date of production, roll length, width and weight. The examined rolls were signed with special attached label.

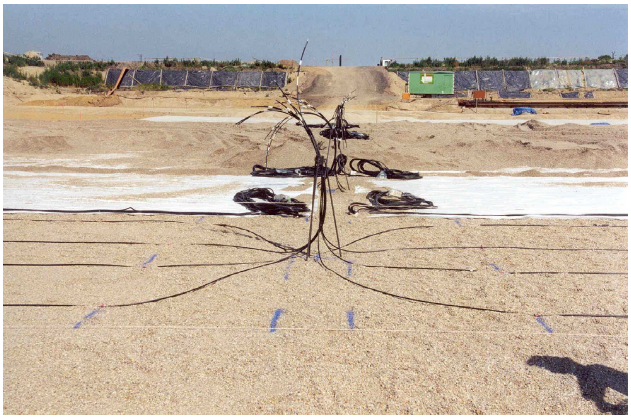

Figure 10. Installation of extensionmeters and warning layer using an especially developed device

Figure 11. Warning layer & extensionmeters - electrical cable system: protected in PVC-pipes

Figure 12. Installation of first geogrid layer, cross-wise in Field F 2

Figure 13. Rolls of the longitudinal reinforcement installed in Field F 2.

The relative light weight warning layer are laid by hand Figure 10. Electric cables from one section of the warning layer & extensionmeters are collected together and protected in PVC-pipes Figure 11. As the geogrid rolls have a maximum weight of about 1500 kg and a maximum length of 150 m these have to be installed by machine. Besides that, the geogrids have to be installed with slight pre-stress in order to guarantee an immediate stress mobilization of the reinforcement. For this purpose an installation device has been especially developed Figure 12. It enables to transport, to unroll and to pre-stress under monitoring of the tensile force. Desired pre-stress even at the end of a geogrid layer is possible with an additionally attached 3m long woven. The required tensile force for installation is fixed to a minimum of 3.0 kN/m (15 kN over 5 m roll width). All geosynthetics are installed with a tolerance of ± 2cm. The very high level of the quality of installation works could be seen in Figure 12 and 13. The real position of each installed geosynthetic layer is controlled by the owners supervisor and fixed in post-installation planes.

3.5 *Cement stabilized bearing layer (CSBL)*

This layer can be understood as a stiff plate or block located above geogrid reinforced gravel layer. The thickness of this element is equal to 2,95 m in the active stress zones and outsides 1.95 m. For the CSBL the excavated material is mixed with a cement stabilizer (up to 4,5%) in an on site plant and placed layer by layer, each with thickness of 0,30 m Figure 11 and 14.

The required control parameters of this layer are given in Table 1. Only vertical PVC-pipes with collected electrical cables could be installed in CSBL. The placement of the cement-stabilized bearing layer are also strongly controlled by the owners supervisors.

Figure 14. Placement of Cement stabilized bearing layer (CSBL)

4 CONCLUSION

The use of high strength geosynthetic reinforcements offers designers and owners the possibility of economic design of overbridging systems. The presented foundation system (incorporating geogrids with an UTS of 1200 kN/m) is able to maintain the serviceability of a railway embankment, even on a location with high potential for the development of sinkholes. It combines a bearing system with a computer operated warning system enabling a permanent control of the situation.

A number of innovative concepts for the design production and installation incl. a high-level quality management system have been generated and applied in this project. Some of these ideas should be used in future projects.

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