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Final design of an overbridging for railways endangered by cavities at Groebers

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ABSTRACT: Sinkholes beneath roads and railways can cause serious difficulties in some regions in Germany. The introduction of high strength geosynthetic reinforcements and new polymers created better possibilities to reduce the foundation risk. The actually being under construction works railway node at Groebers includes 8 tracks and is about 800 m long and 120 m wide. This new railway section is situated in a post-mining area. Two of the tracks belong to the high speed line (300 km/h). A new developed overbridging system consisting of: warning layer, two orthogonal installed geogrid layers (ultimate tensile strength: 1200 kN/m) and a cement stabilized bearing layer (to achieve a stable arch) was built and tested in 1998. The results of this full-scale test were decisive for the approval by German Railways. Some results of the test and of static calculations performed by FEM for the final project will be presented in the paper.

1 INTRODUCTION

The new railway node at Groebers, being constructed today, is located on an old post mining area prone to subsidence. The 8 tracks should be founded on an embankment with the width at the base of ca. 120 m and the height of 4-5 m. Two of these tracks will be used for the high speed line (300 km/h).

The observed and predicted diameter of sink holes in this post mining area was estimated for the design purposes with up to 4,0 m. Unfortunately, the location of the all possible existing cavities in the underground (depth of about 30 m under surface) is not known.

During the first stage of the project many foundation methods ware analyzed (for example: deep foundation on piles, stiff reinforced concrete plate, dynamic compaction after deep excavation, etc.). All of these methods were too expensive or practical not acceptable. Finally, especially for this project developed concept was chosen. This complex concept is based on geosynthetic reinforced gravel cushion coupled with an arching effect in the upper positioned stabilized bearing layer (CSBL). The overbridging system for the Railway Node Groebers consists of two main protection measurements:

- injection of cement slurry in the cavities with the known position, for example: old pits or mine galleries (this phase of the project is now in the finishing stage)
- construction of a special developed geosynthetic overbridging system including a warning layer on the base and a cement stabilized bearing layer above the geosynthetic reinforcements.

This system was designed for the duration of 60 years and must be able to overbridge sink holes with a diameter up to 4,0 m 1 month long (i.e. during the injection works needed for filling the developed cavity).

The integrated warning layer must be able to detect the position and the diameter of sink holes and to control the propagation of the occurred cavity. The required resolution of the designed warning system was defined as: 1 signal from 1 m^2.

The geosynthetic reinforced gravel cushion (GRGC) (founded on the warning layer) serve as a tie rod supporting the stable arch in the CSBL. The allowable deformation on the track level after the sink hole development was defined according to the German Railway Regulations modified as follows:

- ($\Delta s/L$) ≤ 1: 500 with: L
- track interval (1500 mm), $\Delta s \leq 3{,}0$ mm
- allowable difference of settlements, (especially for this project modified value).

The extension limits of the overbridging system in the cross-section and in the longitudinal axis were estimated basing on the results of the full-scale field test and results of static calculation. The rules of the limits of the system in the cross-section of the railway embankment are presented in the Figure 1.

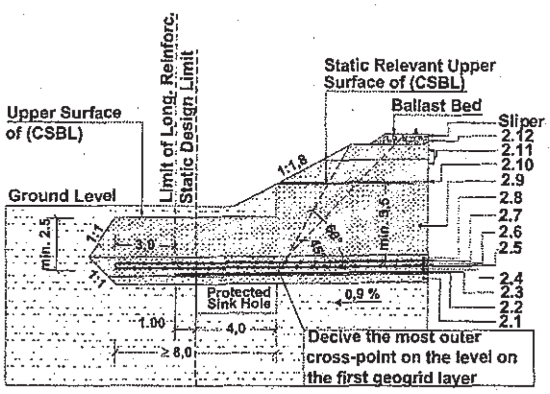

Figure 1. Overbrigding system in cross-section, rules of extension of the protection system at the edges of railway embankment

2 DESIGNED OVERBRIDGING SYSTEM

2.1 *Cement stabilized base layer*

In order to achieve a stable and weather resisting base for construction works the overbridging system will be founded on a cement stabilized base layer with the thickness 0,40 m, Figure 1 and Table 1. The excavated existing clayey silt (middle plastic, consistency: weak to stiff) will be reused with a cement amount up to 4,5 %. The cement stabilized base layer will be inclined in order to drain off the rainwater.

2.2 *Leveling layer*

On the cement stabilized base, a leveling layer of gravel (0/16 mm) with the thickness of 0,10 m is provided. Aside from the leveling function, this layer should be as well a drainage for the rainwater, especially during installation works.

2.3 *Warning layer*

On the exact profiled surface of the leveling layer a warning layer (a special developed composite) will be installed in panels (max. 5 m x 40 m) and put together in situ to a large matrix, which will cover the whole foundation base. The warning layer consists of two non-woven in-between them an orthogonal grid (0,25 m x 0,25 m) of electrical wires (PTFE-coated) is fixed.

The warning layer should be understood as a large matrix, in which the position and the state of each node will be held under control. For that purpose each wire will be separately connected to a computer controlled device. The warning system will be additionally supported by extensometers (glass fiber PP-coated). This special designed by GLOETZL warning layer should monitor the deformation of the embankment base.

The change in the electrical resistance of the wires and their rupture will be exactly detected. The location of the defected node points will be positioned and displayed in a clear graphical form, like a topographical map

2.4 *Ballasting layer*

In order to force the deflection of the warning layer simultaneous with the development of sink holes and to achieve the break of the wires as soon as possible, the warning layer will be ballasted by a gravel layer (0/16 mm) with the thickness of 0,30 m.

2.5 *The first geogid layer (installed crosswise)*

On top of the ballasting layer the first geogrid layer will be installed crosswise to the longitudinal axis of

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

Designation	Soil art	Parameters					
		Proctor's density D_{PR} (%)	Unit Weight γ_k (kN/m³)	Angle of Friction φ_k (°)	Cohesion c_k (kN/m²)	Elasticity Module E_k (MN/m²)	Water Permeability*** k_F (m/s)
Blanket layer	KG 1*	103	≤ 23	≥ 42	-	≥ 100	$\leq 1{,}0 \cdot 10^{-6}$
Frost protection layer	KG 2*	100	≤ 23	≥ 42	-	≥ 100	$\geq 1{,}0 \cdot 10^{-3}$
Cement stabilized bearing layer	SU/TL** min. 4,5 % Pectacrete	100	≤ 22,5	≥ 35	≥ 150	≥ 350 ± 100	-
Bedding layer	Gravel 0/32, KG 2$^{(1)}$ TL 918 062	100	≤ 23	≥ 42	-	≥ 100	$\geq 1{,}0 \cdot 10^{-3}$
Ballasting layer	Gravel 0/16	100	≤ 23	≥ 42	-	≥ 100	$\geq 1{,}0 \cdot 10^{-5}$
Leveling layer	Gravel 0/16	100	≤ 23	≥ 42	-	≥ 100	$\geq 1{,}0 \cdot 10^{-3}$
Cement stabilized base layer	SU/TL** min. 4,5 % Pectacrete	97	≤ 22,5	≥ 35	≥ 150	≥ 200	-

* - TL 918 062 – Technical terms of delivery of soil materials for railways structures (Requirements of German Railway)
** - SU/TL- clayey silt or silty clay, classification according to DIN 18 196
*** - k_F – according to DIN 18 130

the embankment with an overlap of 0,25 m. No connections or overlaps are allowable in the unroll direction, i.e. only one roll for the whole length in the given position of cross-section can be installed, max roll length 150 m. To optimize the installation works and to minimize the usage of geosynthetic products, the installation plans for each product were prepared. The configuration of the embankment is also presented in special prepared cross-sections, which are positioned in distance of 25 m.

According to static calculation and the performed field test the following requirements for the geogrid used were defined:

- ultimate tensile strength: $F_k \geq 1200$ kN/m (md)
  $F_k \geq 100$ kN/m (cmd)
- elongation at break: $\varepsilon_{max} = 2,5 \pm 0,5$ % (md)
  $\varepsilon_{max} = 5 \pm 1,0$ % (cmd)
  (md) - machine direction
  (cmd)- cross machine direction
- design tensile strength: $F_{Bd} \geq 500$ kN/m (md) by total elongation $\varepsilon_t \leq 1,7$ % (for loading time t = 1 month)
- increase of the elastic elongation after 10^5 loads cycles and load level 500 ± 100 kN/m: $\Delta\varepsilon_e \leq 0,20$ % (md)
- mesh size: ≥ 10 mm.

These requirements fulfills a geogrid with ultimate tensile strength 1200 kN/m - 100 kN/m made in (md) from aramid and in (cmd) from PVA (polyvinyl alcohol). The similar product was already used in 1994 to protect the embankment of the Federal Road B 180 near Eisleben in Germany against danger of subsidence (Alexiew 1998).

The anchorage length of the geogrid incl. the wrapped around part was estimated to be not less than L_A = 7,0 m. This anchorage length is required outside the edge of the most external sink hole, which should be overbridged by the first geogrid layer, Figure 1.

2.6 *Bedding layer*

The first geogrid layer will be covered by the bedding layer with the thickness of 25 cm consisting of round shaped gravel 0/32 mm and compacted to 100 % of Proctor's density.

2.7 *Second geogrid layer (installed longitudinal)*

The second geogrid layer will be installed in the longitudinal direction with cross overlaps 0,25 m. The length of the overlaps in the longitudinal direction (the main tension direction) was ordered to be not lower than 11, 0 m (L_A = 7,0 m, required anchorage length (7,0 m) and D =4,0 m, predicted diameter of sink hole). Due to required high friction between the overlapped geogrids (δ_k = 37,5°) an interlayer of gravel (0/32 mm) with the thickness of 10 cm was designed.

2.8 *Upper bedding layer*

The second geogrid layer will be covered by a gravel (0/32 mm) layer with the thickness of 30 cm. The upper surface of this layer presents the upper surface of the GRGC. Unless mechanical function this layer serves as a buffer against alkaline water, which can escape in small amounts from the above lying CSBL.

2.9 *Cement stabilized bearing layer (CSBL)*

This layer has a very important function, because here a stable arch with defined geometry must be

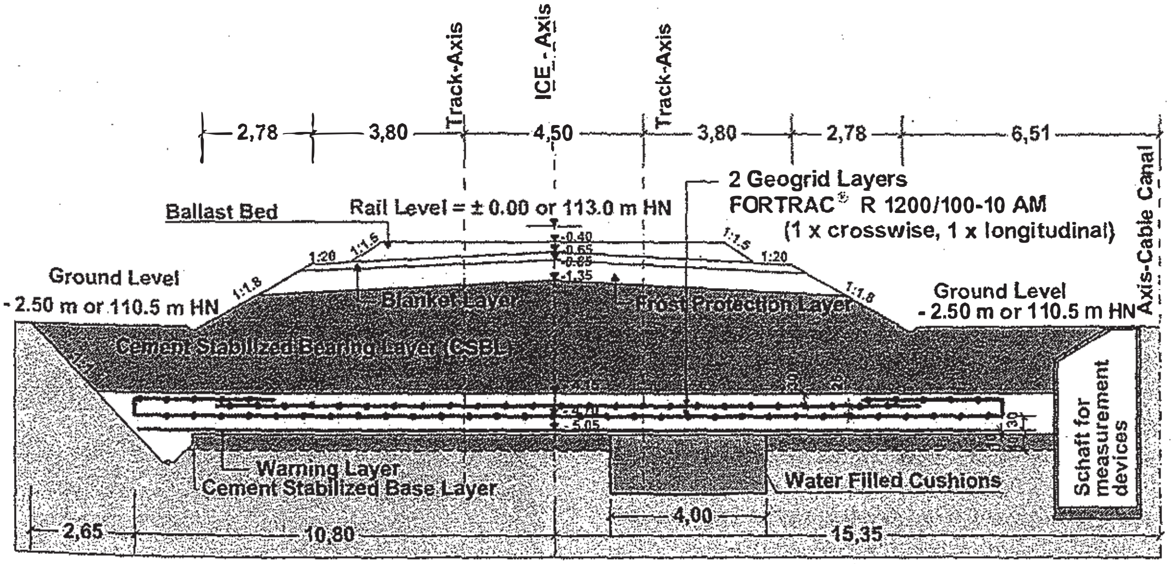

Figure 2. Full-scale field test, "Railway Node Groebers", cross-section, 1998

formed itself and to be stable during the design time of 1 month. The requirements on the mechanical parameters of this layer are compiled in the Table 1. The second important part of requirements relating to geometry is given below:

- thickness in the active stress zones under tracks: min. 2,95 m, Figure 1
- the thickness outside the active stress zones under tracks: min. 1,95 m, for further details, Figure 1.

2.10 *Non-woven- separation layer*

On the top of CSBL or cement stabilized embankment a non-woven (PP, 350 g/m²) will be installed for separation and protection of the prepared surface of cement stabilized embankment.

2.11 *Frost protection and blanket layers*

The requirements on these "classical layers " of the railway tracks are based on the German Regulations, Table 1.

2.12 *Track for high speed line*

First of all the tracks including the high speed line will be constructed as ballasted tracks for the speed up to 250 km/h. The option with non-ballasted track designed for the speed of 300 km/h was taken into account in the design.

3 FIELD TEST

The objectives of the performed full-scale test were as follows (Ast & Watzlaw 1999):

- proof of the serviceability the systems after the development of sink hole with the predicted diameter of 4,0 m
- verification of the bearing behavior and load-bearing capacity of the system, especially the geometry of the arch and the tensile forces in geogrids
- verification of hard- and software of the warning layer.

The full-scale test was located in the axis of the high speed line and was designed for the two planned tracks, Figure. 2. For the simulation of the cavity a rectangular pit with dimensions: 4,0 m x 9,0 x 1,50 m was excavated an twenty one water filled rubber cushion were installed on its bottom. The free space between cushions was filled with gravel 0/8 mm. Finally, the temporary sheet pile wall was removed, Figure 3. The construction works of the embankment (layer by layer) were supervised by EBA (Federal Railway Approval Office) and all delivered products were controlled by the supervisor according to DIN 18 200.

During construction works many geotechnical measuring devices were installed above the warning layer, on the both geogrid layers and in the cement stabilized bearing layer (CSBL):

- 60 Displacement tranducers on 1. and 2. geogrid layers, for deflection and elongation of geogrid layers. The first geogrid layer with installed measurement devices is exemplaryly presented in Fig. 4
- 6 Plastic tubings for settlement measurements with horizontal inclinometer probe. Tubings are embedded in the interlayer of gravel on 1. and 2. geogrid layer, in the body and on the upper surface of CSBL
- 120 earth pressure cells for biaxial stress measurements in different layers across the sinkhole
- 8 triaxial geophone installed in different layers.

The following stress, strain and settlements were monitored by GLOETZL (Ast, unpubl.):

- settlement on the upper surface of frost protection layer and within the deeper layers of CSBL and the interlayers on the geogrids
- compression stress in the cement stabilized bearing layer (CSBL) above the geogrid layers
- compression stress at the edge of the cavity
- tensile force in the anchorage zones of geogrid layers outside the cavity
- velocity of vibration of the cement stabilized bearing layer.

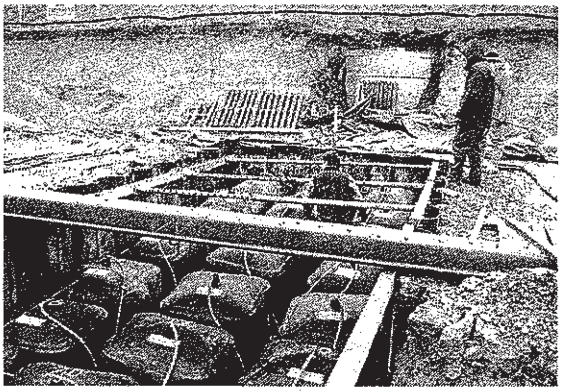

Figure 3. Rubber cushion filled with water to simulate the development of cavities: 4,0 m x 4,0 m and 4,0 m x 8,0 m

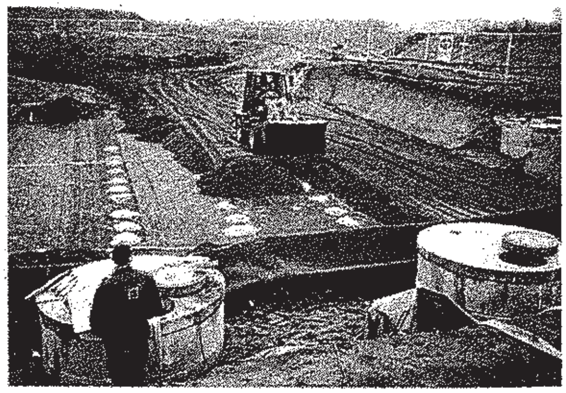

Figure 4. The first geogrid layer with installed measurement devices

At the first stage of the test a cavity with the dimensions 4,0 m x 4,0 m as the result of the discharge of water from 9 rubber cushions was simulated. After 7 days from the development of the cavity, the static load with q = 55 kN/m² on the top of embankment was applied and the dynamic loading test started. Finally, the cavity was enlarged to dimensions 4,0 m x 9,0 m and the dynamic loading test continued.
Figure 5 presents the used equipment DYSTAFIT with the diameter of loading plate of 2,5 m and vibrating mass up to 12,000 kg, (Neidhart & Watzlaw 1998). The dynamic loading test was performed with frequencies of 10 - of 27,5 Hz, mainly with 27,5 Hz. The measured inducted velocity of vibration was up to 30 mm/s. The corresponding dynamic maximal tensile force inducted by the equipment was not higher than 464 kN/m. After the enlarging of the cavity to dimensions: 4,0 m x 9,0 m, the protection system remained still stable. The energy transmitted into the embankment during the dynamic loading test was equal to the whole energy caused from passing trains during one months of operation of the both tracks, i.e. was equal to the energy transmitted in the embankment during the design time of the overbridging system. After finish of the dynamic loading test the embankment was cut through in the cross-section to the bottom in order to verify the measured parameters and to establish the real geometry of the arch, Figure 6.

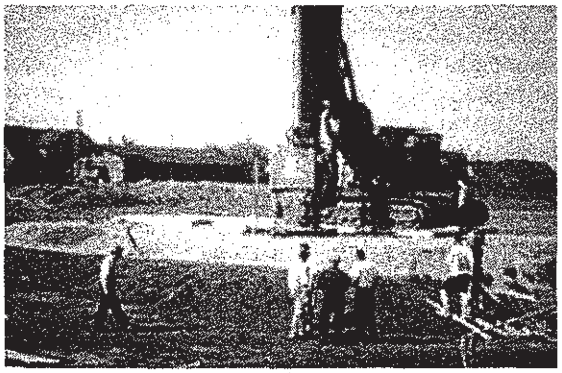

Figure 5. Dynamic loading with DYSTAFIT after simulation of the cavity with dimensions from 4,0 m x 4,0m up to 4,0 m x 9,0 m

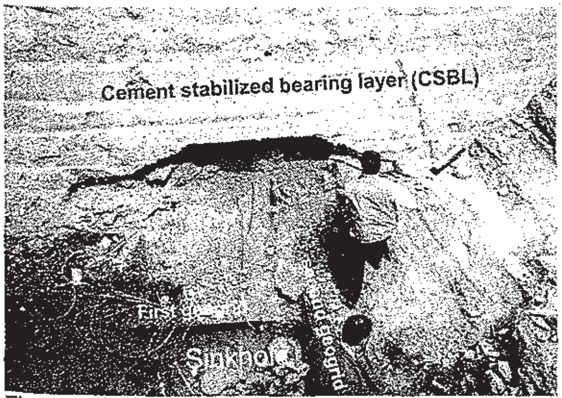

Figure 6. Embankment after cut trough to verification of measured parameter and arch geometry in CSBL

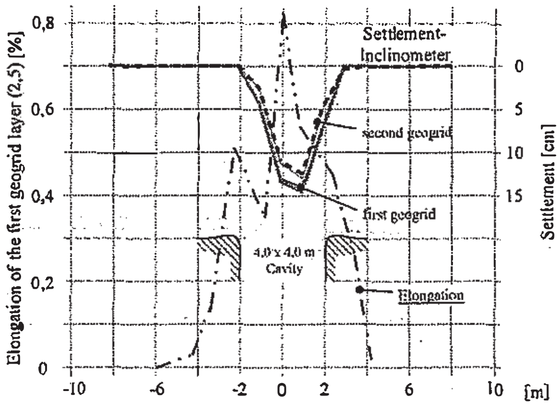

Figure 7. Measured deflection and elongation of the both geogrid layers after simulation of cavity: 4,0 m x 4,0 m

Some results of the measured parameters are given in the Figure 7. They correspond very well with the predicted values of the static calculations.

4 SOME ASPECTS OF FINAL DESIGN

The final design bases both on the requirements defined in the EBA Approval (Ast et al. in press) and the performed static calculation for the final geometry of the railways embankment. The mean objective of the FEM-calculations was to establish the geometry of stable arch, to verify the compression stress in the arch, to predict the deformation on the track level and to estimate the required tensile force of reinforcement. In reality the final design calculations present a more detailed repetition of the static calculations conducted in the previous stages of the project, (Ast, unpubl.). The static calculation were performed using PLAXIS 7.0. Some relevant cross-sections, i.e. one and two tracks lines, in each case for few selected positions of sink hole, were examined. The reinforcement was modeled by an elastic band (width: 1,0 m) with the stiffness module:

- for immediately developed load, i.e. direct after opening in the base $J_K = 65,900$ kN/m
- for the long time loading (in this case 1 month) $J_L = 29,411$ kN/m.

The cavity was modeled as longitudinal gap with the width 4,0 m, it means that the static calculations were performed for a planar problem. Principal the design based on DIN V 1054 – 100 (Edition 1995) and the German Recommendation, EBGEO 1997. The required design tensile strength of reinforcement was estimated for the predicted geometry of the stable arch using results of FEM-calculations, s. Figure 8 and 9. The principle of the estimation of the

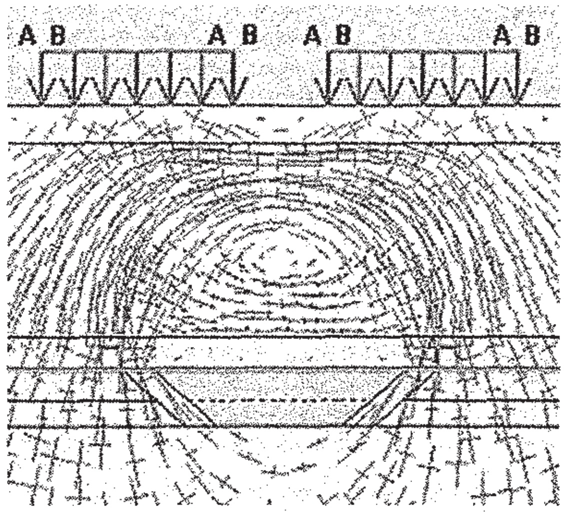

Figure 8. Cross-section, total stress, embankment with two tracks, gap width 4,0 m, Plaxis 7.0

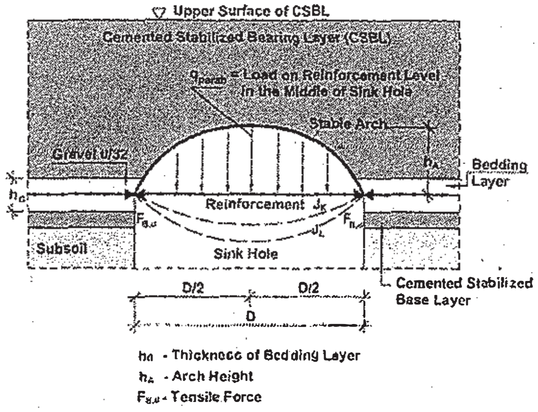

Figure 9. Principle of estimation the tenisle force in reinforcement for the known arch geometry

tensile force in the reinforcement is presented in Figure 9. The obtained maximal values of the tensile force are following: $F_{Bd,K}$ = 489 kN/m (short-time) and $F_{Bd,L}$ = 374 kN/m (design time - 1 months loading time).

For the check of the arch stability in CSBL the developed overbridging system (arch and tie member, Figure 9) was analyzed by FEM, using shear parameters of soil layers given in Table 1, (Ast & Hubal, in press.)

The max. inclination of the tracks for the serviceability state was estimated with 1:500, i.e. equal to the above given allowable value.

After the examination of the static calculation and project documentation by EBA (Federal Railway Approval Office) the EBA - Building Permit for the start of construction works in the first Part (Field 1 and 2) at the end of 2000 was given.

In this project about 250,000 m² of the aramid geogrid with ultimate tensile strength of 1200 kN/m and about 80,000 m² of warning layer by very strong requirements on quality will be installed. The quality management and the supervision plan of construction works and materials are very clearly defined.

5 CONCLUSION

The developed and verified in the full-scale test protection system presents a new foundation method of railway embankments in area prone to subsidence. This combined system: a geogrid reinforced gravel cushion (GRGC) and a stable arch in a cement stabilized bearing layer CSBL) enables to overbridge sink holes by very small track deformations (allowable inclination of tracks due to settlement difference: up to 1:500). The computer operated warning layer integrated in this system holds the foundation base under control and locates the position and geometry of developed sink holes. The during the study stage, full-scale test and final design developed procedures enable to construct railway embankments with the presented overbridging system as a safe an economic engineering structure.

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