Design and construction of highway A143 above abandoned lignite mines

Conception et construction de l'autoroute A143 au-dessus des mines de lignite abandonnées

Prof. Dr.-Ing. Dr.-Ing. E.h. Walter Wittke
Prof. Dr.-Ing. W. Wittke Beratende Ingenieure für Grundbau und Felsbau GmbH, Aachen/Germany
Dr.-Ing. Martin Wittke
Prof. Dr.-Ing. W. Wittke Beratende Ingenieure für Grundbau und Felsbau GmbH, Aachen/Germany

ABSTRACT
The highway A143 is located near the city of Halle/Saale in Eastern Germany. 3 km of the southern section of this highway are located above abandoned and not properly backfilled room and pillar lignite mines as well as corresponding shafts and galleries. As a consequence of mining, cavities and loose zones are existing in the ground which lead to the occurrence of sinkholes.

Dynamic compaction by falling weights was carried out in the area of the new highway to destroy the existing cavities which on the short- or medium-term would have lead to sinkholes. Furthermore, the loose soil was planned to be compacted and homogenized down to greater depths.

The occurrence of sinkholes can however still not be outruled for the long-term. To prevent a sudden collapse of the pavement these sinkholes are planned to be bridged by a single-layer geosynthetic reinforcement, which was designed by geometrically non-linear 3D-FE-analyses.

One bridge and two pillars of an electricity line, which are also located in the area of potential sinkholes, were founded on bored piles. The piles were partly surrounded by a HDPE-membrane to reduce the negative skin friction which occurs in case of a sinkhole.

The northern section of the highway, which is currently under design is also partly located above abandoned mines. Because of the ground conditions and the greater depth of the old mines the ground in this section is planned to be improved by grouting.

RÉSUMÉ
L'autoroute A143 est située prês de la ville de Halle (Saxe-Anhalt) en Allemagne de l'Est. Trois kilomètres de la partie sud de cette autoroute se trouvent au-dessus des mines de lignite abandonnées. Ces mines ont été construites selon la méthode des chambres et cloisons et depuis l'abandon, les chambres et les cloisons ainsi que les puits et les galeries ne sont pas décemment remblayés. À cause de l'exploitation minière, des crevasses et des zones incertains sont existants dans le sous-sol, ce qui provoque la présence de dolines.

Aux environs de la nouvelle autoroute du compactage dynamique a été effectué, en pilonnant le sol en surface avec une masse, pour détruire les crevasses existants, qui auraient causé des dolines à court et à moyen-terme. En outre, il était prévu de compacter et homogénéiser les zones incertains à de plus grandes profondeurs.

Par contre, la présence de dolines à long-terme ne peut pas être repoussée. Pour empêcher un effondrement soudain de la chaussée, il est prévu de couvrir ces dolines par un renforcement géosynthétique d'une seule couche. Ce renforcement a été conçu au moyen d'une analyse par la méthode des éléments finis non-linéaire en 3D.

Un pont et deux pylônes électriques dans les zones de dolines potentielles ont des fondations sur pieux forés. Ces pieux ont été partiellement emballés par une membrane de PEHD, pour réduire le frottement latéral négatif, qui se présente en cas de dolines.

La partie nord de l'autoroute, qui est actuellement en conception, est également situé au-dessus des mines abandonnées. À cause des conditions du sol et la plus grande profondeur des anciennes mines, il est prévu d'améliorer le sol de cette partie par injection solide.

Keywords : Highway above old mines, Geogrid, Geosynthetic Reinforcement, Design, Bored Piles, HDPE, Dynamic Compaction, Grouting, Geometrically non-linear FE-Analyses

1. PROJECT

The highway A 143 is located west of the city of Halle (Saale) in Germany. The southern part of this highway, which extends from the junction Halle-Süd to the federal road B80 is already completed and in operation. After completion of the northern part, which is presently under design, the highway A 143 will connect the highways A 38 in the South and A 14 in the North.

Close to the city of Teutschenthal, south of the federal road B80, the highway is located above abandoned lignite mines. Here lignite was mined by means of room and pillar mining until the 1950s in depths of up to approx. 20 m.

North of the federal road B80, the highway in a limited section is again located above abandoned mines. Here, lignite and kaolin were mined out mainly by room and pillar mining in different depths of up to approx. 50 to 60 m, also until the 1950s. Furthermore, old open-cast mines for lignite and kaolin are located in the area.

2. GEOLOGY AND OLD MINING ACTIVITIES

In the considered section, the highway is located in an agricultural area. The mined lignite seams were located in depths of approx. 10 to 50 m. The overburden of the old seams consists of tertiary sands and clays, the latter of which partly was also mined (kaolin). The tertiary sediments along the major part of the highway are covered by quaternary sands and marls. Groundwater must be expected in the tertiary and quaternary sands.

The main subsidence caused by the old mining activities south of the federal road according to the mining authorities already has occurred (Bergamt Halle (1995)). Nevertheless the

Proceedings of the 17th International Conference on Soil Mechanics and Geotechnical Engineering
M. Hamza et al. (Eds.)

doi:10.3233/978-1-60750-031-5-2390

underground above the seams is loosened and not all openings caused by mining have collapsed. Therefore, sinkholes can occur, especially in the area of former galleries and shafts as well as in the shadow of broken pillars. Before construction of the highway in this area, approx. 3 to 4 of these sinkholes occurred annually. It is obvious that also during construction several sinkholes occurred (figure 1).

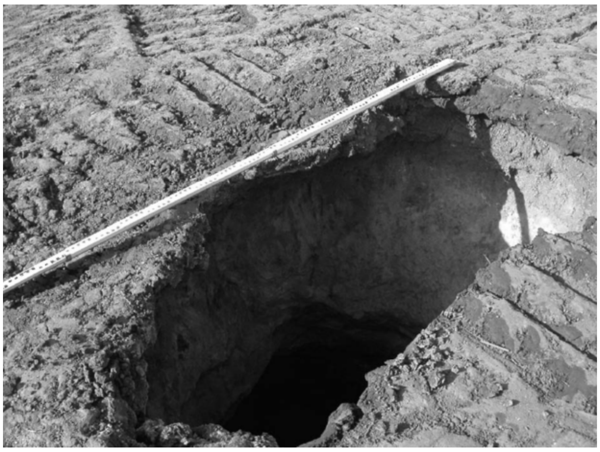

Figure 1: Sinkhole during construction.

The situation north of the federal road B80 is in principle similar. As a consequence of the more clayey overburden however, it cannot be outruled that the main subsidence caused by old mining is still ongoing in this area.

3. DESIGN CONCEPT

In order to protect the new highway against subsidence and collapse as a consequence of sinkholes, different measures were and are planned to be taken respectively.

South of the federal road B80 the method of dynamic compaction by falling weights was used in order to demolish cavities which are located near the surface and which reveal a potential for sinkholes within the near future (figure 2). The dynamic compaction also leads to a compaction of the loosened zones in the ground as deep as possible.

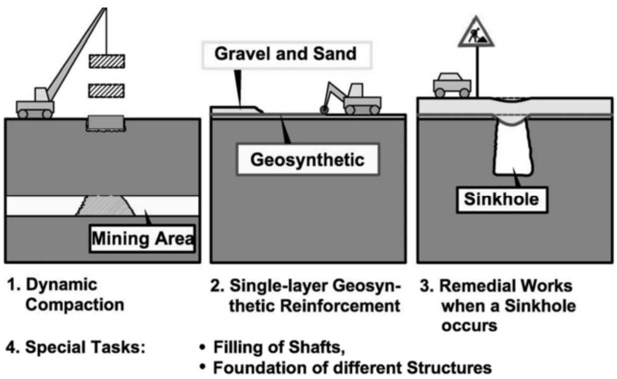

Figure 2: Design Concept

The occurrence of future sinkholes can however also not be outruled after dynamic compaction has been carried out. Consequently, a single-layer geosynthetic reinforcement was placed underneath the highway in the respective areas. It is planned that by means of this measure a sudden collapse of the pavement will be prevented and that the subsidence of the pavement due to a sinkhole underneath the reinforcement layer is kept within acceptable limits (figure 2).

Old shafts, which are located in the area of the highway were specially treated by dynamic compaction and afterwards grouted with cement grout. Special foundations were required for an electricity mast and a bridge in the area.

4. DESIGN OF GEOSYNTHETIC REINFORCEMENT

In principle, single- and multiple-layers geosynthetic reinforcement can be applied for bridging of potential sinkholes. A single-layer reinforcement usually reveals lower material costs and leads to smaller efforts during construction. In the given case, a single-layer reinforcement was selected, which is embedded in a layer of sand and gravel (figure 3). The top of the pavement is located 2 to 6 m above the geogrid. The structure is planned to bridge sinkholes with a diameter of up to 4 m until the corresponding area of the highway is renewed.

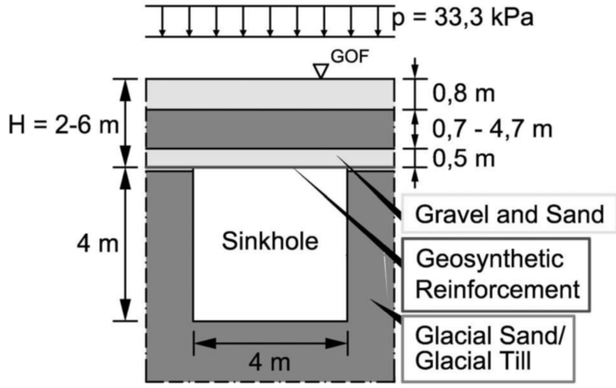

Figure 3: Statement of Problem

To design the single-layer reinforcement, 3D-FE-analyses were carried out, in which the geogrid and the ground were modelled realistically (Lüke et al (2002), Wittke et al (2004)). A geosynthetic reinforcement bridges a sinkhole like a rope or a hammock. Thus, the main force is tension. This behaviour is modelled in the FE-analyses by the implementation of rows of pin-jointed beam elements in two directions (figure 4). To provide vertical support, the originally horizontal reinforcement must rotate. Thus, the tensile forces in the geogrid get a vertical component. It is obvious that the forces in the geosynthetic reinforcement can only be evaluated, when the state of equilibrium is analysed for the deformed system (geometrically non-linear analyses). Furthermore, the anisotropy of the geogrid must be taken into account in the analyses. Corresponding analyses were carried out for the FE-mesh represented in figure 5 with the computer code FEST03 (Wittke et al (2004), Hu (1995)).

The results of the analyses show that a sinkhole with a diameter of 4 m in the given case can be bridged by means of a single-layer geosynthetic reinforcement, and thus a very economic method of construction could be applied. The resulting subsidence (figure 6) and the forces in the reinforcement are within acceptable limits (Lüke et al (2002), Wittke et al (2004)). A decisive factor for the selection of the applied geogrid was a small deformability, especially in the range of small strains.

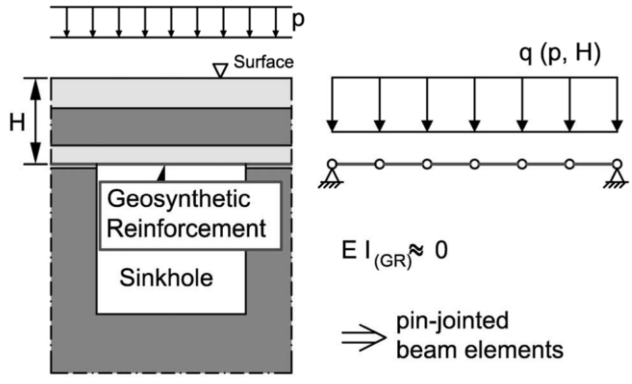

Figure 4: Load Bearing Behaviour

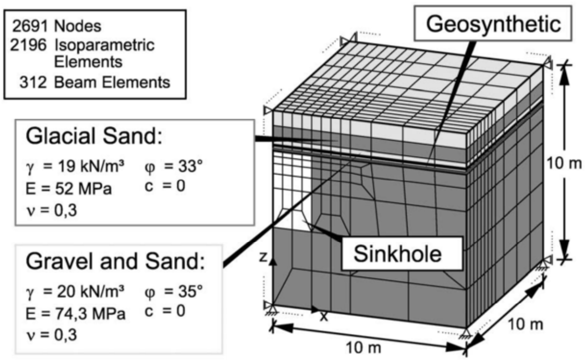

Figure 5: 3D-FE-Mesh

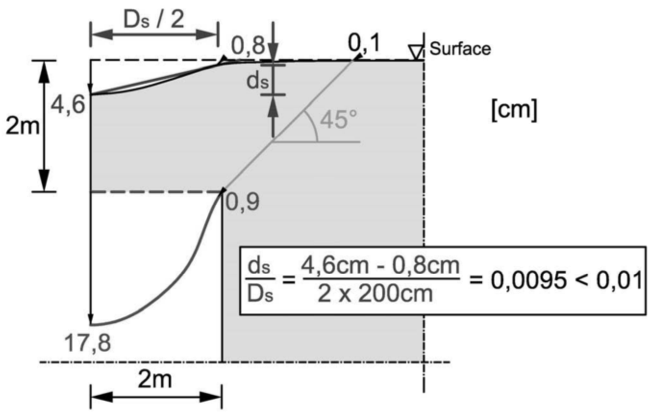

Figure 6: Displacements (y = 0)

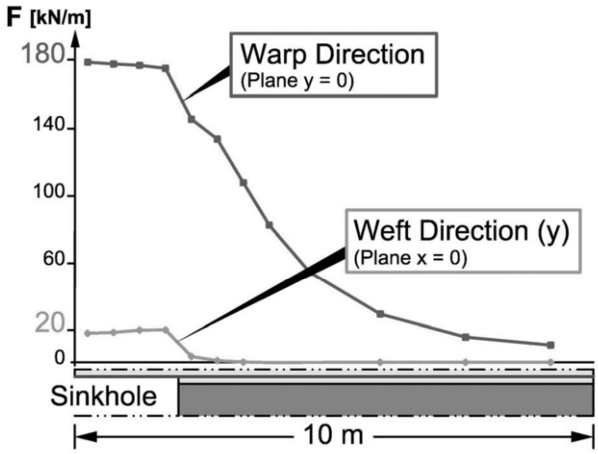

Figure 7: Forces in the Geosynthetic Reinforcement

5. BRIDGE AND MAST FOUNDATION

One mast of an electricity line and a bridge crossing the highway are also located in the area south of the federal road B80, which is prone to sinkholes. These structures were founded on piles reaching below the lignite seams. The occurrence of sinkholes adjacent to the bored piles would lead to high loading due to negative skin friction, which becomes decisive for the design of the piles. Consequently, the piles were coated with a HDPE-membrane in those sections, which are located above the mined-out lignite seams, in order to reduce the negative skin friction. Large-scale loading tests were conducted in order to determine the negative skin friction to be expected (Figure 8).

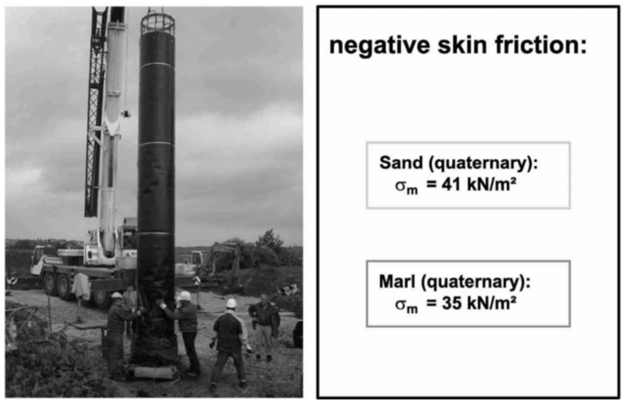

Figure 8: Bored Pile coated with HDPE-membrane, Result of Loading Tests

6. DYNAMIC COMPACTION WITH FALLING WEIGHTS

At the beginning of the dynamic compaction works, a field test was carried out, in which the parameters, such as weight, falling height, number of blows etc. were varied. Based on the results of this test, the parameters for the regular compaction works were defined as given in figure 9.

		Phase			
		1.	2.	3.	4.
Weight	[t]	30	25	25	25
Height	[m]	25	20	6 - 8	6 - 8
Number of Blows	[-]	3	2	1	1
Grid	[m]	3,5 x 3,5	3,5 x 3,5 *)	3,5 x 3,5	3,5 x 3,5 *)

*) points with offset
- dimension of weight: 2m x 2m

Figure 9: Parameters for Regular Dynamic Compaction

Part of the monitoring program of the regular compaction works were measurements of the crater depths and the execution of dynamic probing (DPH-Tests), before and after compaction. In the design phase the achievable depth of compaction was estimated by means of the following, commonly known empiric formula:

$$t_{max} \sim \alpha * (G * h)^{0.5} \quad (1)$$

The results of monitoring during construction showed that compaction could be achieved to depths of 16 m to 20 m. The parameter α for the given case results to $\alpha = 0.5$ to 0.75.

During construction a large number of sinkholes occurred. In order to provide a high standard for operational safety, the area to be compacted was therefore compacted by means of a remote-controlled vibration roller, before the dynamic compaction works were started (fig. 10 and 11).

Figure 10: Remote-controlled Vibration Roller


Figure 11: Dynamic Compaction Works

7. DESIGN OF NORTHERN SECTION OF HIGHWAY

As explained above, the section of the highway, which is located north of the federal road B80 is presently under design. Due to the large depths of the old mines and the inhomogeneous ground conditions, the protection of the highway and corresponding bridges in the area is planned to be provided by means of grouting. In order to limit the required effort for the grouting works, the location of the old shafts, galleries and excavated seams were identified by means of review of old documents and explorations by means of test pits and drillings. Due to the detailed explorations, the location and depth of the old shafts, galleries and excavated seams is known in great detail. This allows for direct treatment of the corresponding area and thus for a limitation of the required number of grouting holes and the required volume of grout. The corresponding ground improvement works will be tendered in the near future.

8. CONCLUDING REMARKS

The highway south of the federal road B80 was successfully completed in 2004. The described design provides a safe and economic way for construction. Since the start of operation of the highway, no subsidence or sinkholes were reported.

The ground improvement works for the northern section of the highway A143 will be tendered soon. The corresponding results of execution will be presented at a later point in time.

ACKNOWLEDGEMENT

The author thanks the DEGES for the support and the excellent cooperation.

REFERENCES

Bergamt Halle: Bergbauliche Stellungnahme vom 14.08.1995.

Lüke, J; Wittke, M.; Delsemmé, D.: Bemessung einer Geokunststoffbewehrung zur Überbrückung von Erdfällen mit Hilfe von dreidimensionalen, geometrisch nichtlinearen FE-Berechnungen. Geotechnik 25, Nr. 1, 2002.

Wittke, W; Wittke, M.: Bridging of Sinkholes by Means of a Single-Layer Geosynthetic Reinforcement - Design on the Basis of 3D Geometrically Non-linear FE-Analyses. Balkema 2004.

Hu, Y.: Standsicherheitsuntersuchungen von untertägigen Hohlräumen im Fels nach der Finite-Elemente-Methode unter Berücksichtigung der geometrischen Nichtlinearität. Veröffentlichungen des Instituts für Grundbau, Bodenmechanik, Felsmechanik und Verkehrswasserbau der RWTH Aachen, Heft 29, 1995.