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OVERSPANNING A VOID BY SPECIALLY PRODUCED GEOGRIDS

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ABSTRACT: A section of 'Federal Roadway B 180' at Neckendorf near Eisleben, Germany, is once again in service after being blocked for years. The roadway was destroyed across its entire width in 1987 by a sink-hole. The sink-hole is 30 meters deep and 8 meters in diameter. Although the hole has been refilled, the danger of a new subsidence due to deep underground caverns still exists. In order to put the road into operation again, the sink-hole had to be bridged to ensure acceptably low deflection values of the roadbase even under heavy truck loads.

Due to lower costs and 'ductile' deformation behavior, a geogrid-reinforced gravel cushion was preferred to a concrete bridging plate. A geogrid with very high strength (UTS = 1200 kN/m) and high modulus (40 000 kN/m at 3% elongation) was necessary acc. to the design calculations. For this purpose the geogrid was specially produced. The project is the first of its kind using very high-modulus geogrids. The road has been in use since October 1993 without any further deformations.

This paper describes the reinforcement concept, design philosophy, dimensioning, materials used and safety measures (control system) installed, and provides details and photographs of the reconstructed roadway.

INTRODUCTION

Problem description. In the region of Eisleben, Germany, stable soil layers of 20 m up to 40 m thick often overlie water-soluble soils. Due to ground-water flow in these soils natural caverns up to ten meters wide can develop. This well known phenomena may result in the creation of nearly vertical cylindrical "chimneys" in the soil mass above the cavern. The soils above can collapse into the cavern with a resulting sink-hole at the surface.

The collapsed soil material leaves an irregular shaped crater at the ground surface with dimensions of up to 20 m wide and 10 m deep. The subsidence occurs over relatively short periods of time while additional settlements may continue due to the loose nature of the collapsed soils within the "chimney".

A large sink-hole which developed due to this phenomena distroyed the 'Federal Roadway 180' at Neckendorf near Eisleben in 1987. The roadway collapsed across is entire width with the loss of soils initially in the lower portion of zone 1 and later settlement occurring in zone 2 as seen in Figure 1. A temporary bypass for the heavily traveled Roadway B 180 was built in 1987 - 1988, however, the bypass caused serious difficulties for the existing levels of traffic. A more permanent solution had to be developed which provided a smooth flow of traffic along the original roadway alignment in addition to creating a non-hazardous roadway for the commuters.

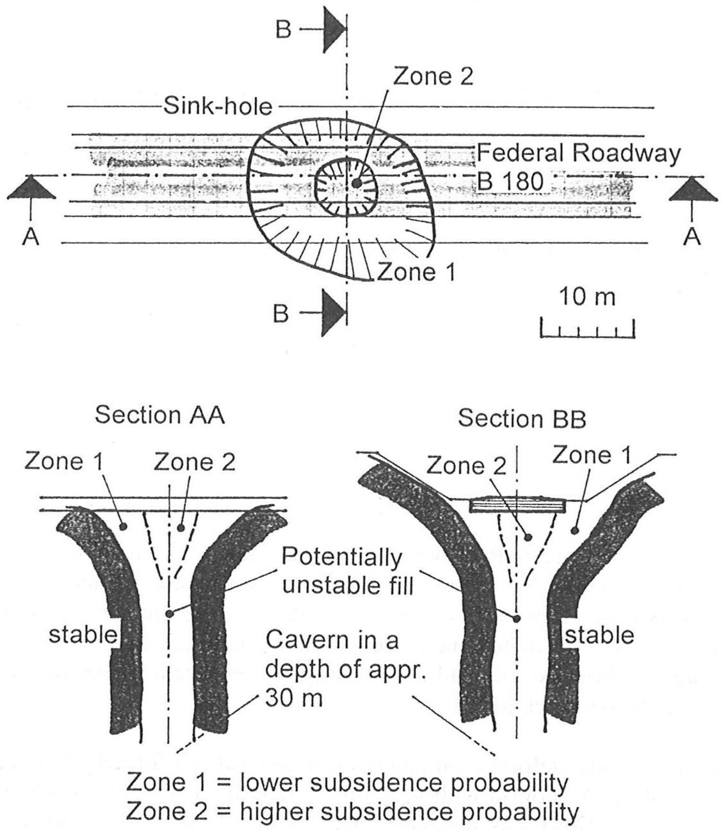

Figure 1: Geometry and zones of the sink-hole

In order to stabilize the upper part of the "chimney" the crater was completely filled by loosely placed imported stone/sand materials. After about two years it was determined by geodetical measurement that no further settlements occurred on the surface of the fill. However, information was not available regarding the density and stability of the collapsed soil and the new fill in the sink-hole, nor about the ongoing processes in the deep cavern due to ground-water flow. Therefore, for reasons of safety, the roadway remained blocked until 1993.

RECONSTRUCTION

Concept and design philosophy. In 1992, 'Straßenbauamt', the administration responsible for Roadway B 180, decided to put Roadway B 180 into adequate operation again because the provisory bypass was not considered to be acceptable any longer due to increasingly intensive traffic.

The present understanding regarding the global mechanical behavior of the filled sink-hole over time was not sufficient. A reliable long-term prognosis was not possible. However, based on the history of the sink-hole and measurements after filling it seemed to be plausible to predict a higher probability for a new collapse in zone 2 and a lower subsidence probability in zone 1. The worst case scenario would be for a catastrophic failure of the complete "chimney" consisting of zones 1 and 2 (Figure 1).

Generally two possible technical solutions were in discussion: a steel-reinforced concrete bridging plate and a geosynthetic-reinforced gravel cushion. The concrete plate was not considered an acceptable solution for two reasons: the extremely high costs for materials and construction and the possibility of a "brittle" rupture behavior in the event of exceeding the bearing capacity. It was determined that the advantage of small deformations in a pre-rupture stage did not compensate for the disadvantages described above. Consequently, the consultant 'KUHN-Engineering GmbH, Leipzig', preferred the solution with a strongly geosynthetic-reinforced gravel cushion. The preliminary design calculation resulted in the requirement of a very high tensile strength, tensile stiffness and low creep of the reinforcement.

Dimensioning, design and materials. The final dimensioning and design by the engineering consultant took place in early 1993 in collaboration with the engineers at HUESKER Synthetic GmbH & Co. Generally three possible dimensioning procedures were analysed: Giroud (1982), Giroud et al. (1990) and British Standard 8006 (1995), all based on the well established "membrane theory" for the reinforcement layer. BS 8006 was at this time still a draft.

The method in accordance with Giroud (1982) seemed to be very conservative. Further it has the disadvantage, that no prognosis for the deflection of the road surface can be made.

The method in accordance with Giroud (1990) is less conservative, because soil arching has been assumed. Unfortunately there is again no possibility to predict or to take into account the deflection of the road surface according to this method. In addition, it seems very risky to assume a stable soil arching under the dynamic influence of traffic.

The method in accordance with BS 8006 (1995) - res. the draft in 1993 - is based on the experience in Great Britain in mining and similar areas prone to subsidence. First, no arching and, second, another failure mechanism are assumed in the ultimate limit state (Figure 2 according to Figure 73 and 74 in BS 8006 (1995)).

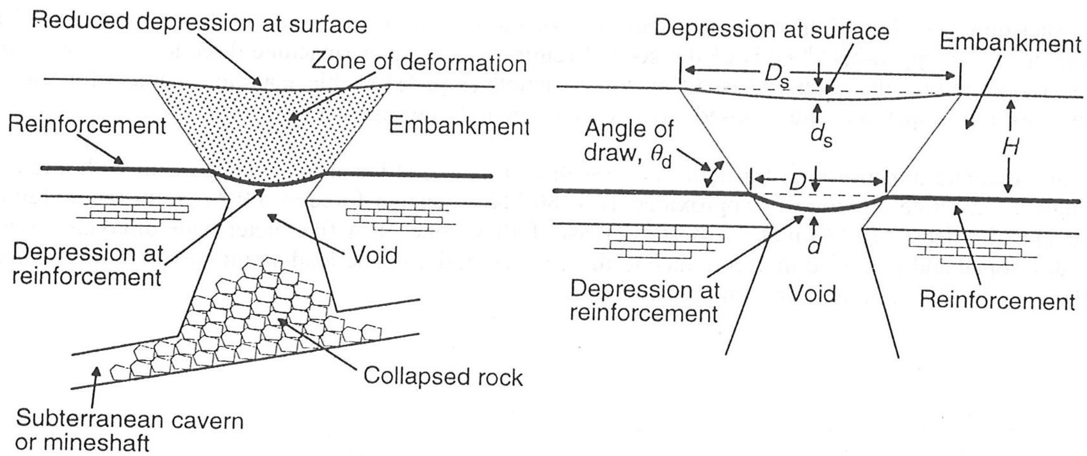

Figure 2: Dimensioning concept in accordance with BS 8006 (1995)

Further details about dimensioning equations etc. can be seen in BS 8006 (1995).

Notice, that only the method in accordance with BS 8006 (1995) allows for a prediction of the surface deflection (depression), connecting failure mode, reinforcement extension and surface depression.

Summarizing the typical assumptions, results and background experience of the methods mentioned above, logically the method in accordance with BS 8006 was found to be the most suitable for the final dimensioning of the system.

It was decided that a geogrid was preferred as the geosynthetic reinforcement as opposed to a geotextile due to the generally higher bond coefficients (anchorage capacity) achieved with geogrids over geotextiles. Notice, that in all dimensioning procedures mentioned above, formally the bond coefficient is not

taken into account. Nevertheless, from the engineering point of view a better system behavior has to be expected due to the immediate mobilizing of the tensile forces in a reinforcement with a high bond coefficient. Additionally, in the case described herewith, the good interaction is of greater importance than usually due to the limited "anchorage" lengths. The partial factors of safety for the reinforcement were adopted from FGSV (1994), which was a draft in 1993. Note: FGSV (1994) does not include dimensioning procedures for overspanning voids.
The logic of dimensioning and design can be shortly described as follows: The geogrid-reinforced cushion had to bridge over the more probable potential failure-zone 2 in cross and longitudinal directions (Fig. 1) with a maximum relative deflection of 0.015 (d_s/D_s, Fig. 2) perpendicular and/or parallel to the road axis. In this case a two-way spanning was required with sufficient anchorage length in both directions. The geogrid reinforced gravel cushion was supported in both directions along the edges of zone 2.

In the worst case where total failure of zone 1 would occur the geogrid-reinforced cushion had to bridge only the longitudinal direction (parallel to the road axis). This case was required to span the sink-hole only one-way, because the "edges" of zone 1 are too far away from the cushion to maintain a relative deflection of less than 0.015. In this worst case a relative deflection of 0.07 parallel to the road axis can be accepted only temporarily. At the first indications of the sink-hole the traffic would be stopped immediately. The deflection (bending) in cross direction was not a concern due to the linear alignment of the roadway at the area of reconstruction.

As shown in Figure 1, the axis of the road is positioned excentrically to the zone 2. It could lead to negative bending moments (tension of the upper side of the reinforced cushion in cross direction) and/or to local torsional deformations. Also, a torsion could take place under asymmetric traffic load in the worst case of collapse of the complete zone 1.

An exact dimensioning of the reinforced cushion for these cases is not possible. So it was decided to lengthen the "wrapped-back" ends of the second reinforcement layer (machine-direction = cross to the road axis) more than the required "usual" anchorage length (Fig. 4) to achieve a reinforcement for tension on the cushions upper side and a closed cross-reinforcement "ring" against torsion.

The analysis and dimensioning for both cases resulted in the need for an uniaxial geogrid with a tensile strength in machine direction of approximately 1180 kN/m tension force at 3.0 % strain (case: failure zone 1) and at least 470 kN/m at 1.8 % strain (case: failure zone 2). A five meter wide uniaxial geogrid was developed and produced in accordance to these specifications. The load-strain curve for this product in the machine direction is shown on Figure 3.

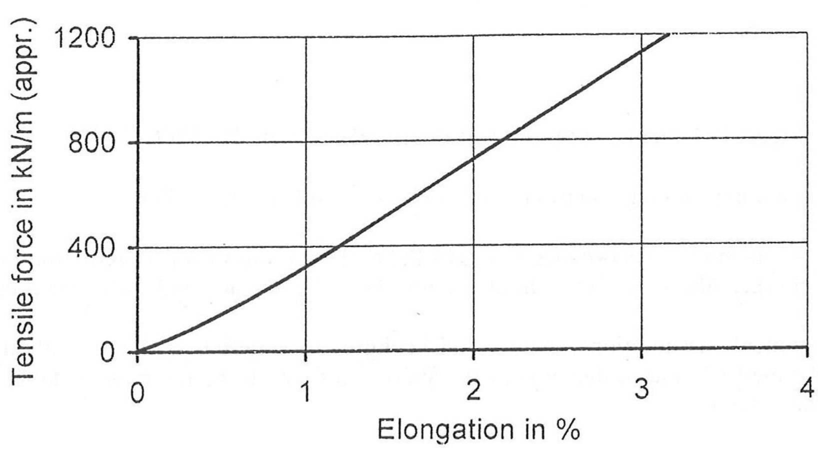

Figure 3: Load-strain curve of geogrid-reinforcement (MD)

The cross-section of the roadway and reinforced cushion is shown on Figure 4, while plan views of the geogrid reinforcement and control wires (see section "Control System") are shown on Figure 5. The lowest layer of geogrid reinforcement (longitudinal) was designed primarily for the one-way spanning reinforcement required in the " zone 1 failure case" and secondarily as half of the two-way spanning reinforcement required for the "zone 2 failure case". The second layer of geogrid was designed to provide the second half of the two-way spanning reinforcement required for the "zone 2 failure case". The upper layers are the wrapped back ends of geogrid from the second layer which ensure adequate anchoring and creation of a closed reinforcement ring for resistance against torsion.

For the cushion soil a well graded pure gravely sand (GW) according to German standard DIN 18196 with minimum grain size 0.1 mm and maximum grain size 56 mm was prescribed. It had to be compacted to a relative proctor density of $D_{Pr} \geq 103$ %, ensuring good mechanical properties and compound behavior of the gravel-geogrid system.

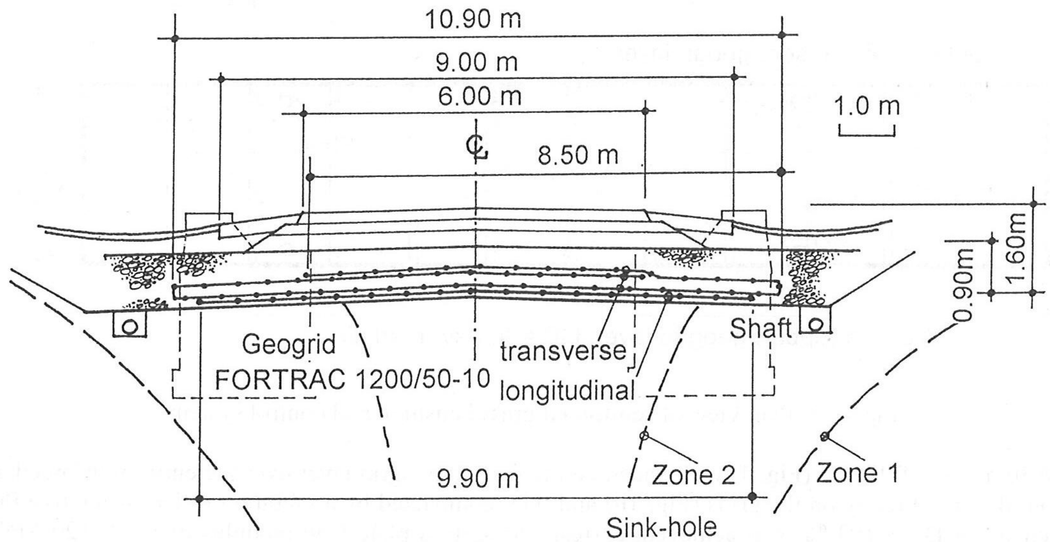

Figure 4: Cross section of reinforced gravel cushion

CONTROL SYSTEM

Due to the importance and the heavy levels of traffic on the Federal Roadway B 180, the complexity of the problem and the impossibility to analyse exactly all theoretical possible situations (the modes "failure zones 1/2" are more or less predictions of probabilistic type) the road administration and the consultant decided to install a control and warning system, consisting of steel wires and control shafts as shown on Figure 4 + 5. The nearly inextensible wires are connected to electrical gauges in the shafts. The wires (before pulling tight) can be seen on Figure 6. If the elongation /displacement of any of the four wires indicates a deflection and/or bending of the reinforced structure corresponding to an elongation of 3 %, a warning system will be activated and the traffic will be stopped in both directions at a safe distance on both sides of the critical area. The critical 3 % was selected in accordance with the dimensioning predictions and the stress-strain curve of the geogrid reinforcement.

EXPERIENCE IN THE STAGE OF CONSTRUCTION.

The geogrids were delivered with the project installation lengths pre-fabricated. The geogrids flexibility and relatively low mass per unit area (high specific strength) resulted in an easy handling and installation on site by a four man construction crew. The grid's flexibility made it possible to fabricate the measurement/control shafts (Fig. 7). Additional partial layers of grid cut to smaller widths were installed in both directions around the shafts to compensate the cut-offs in these zones.

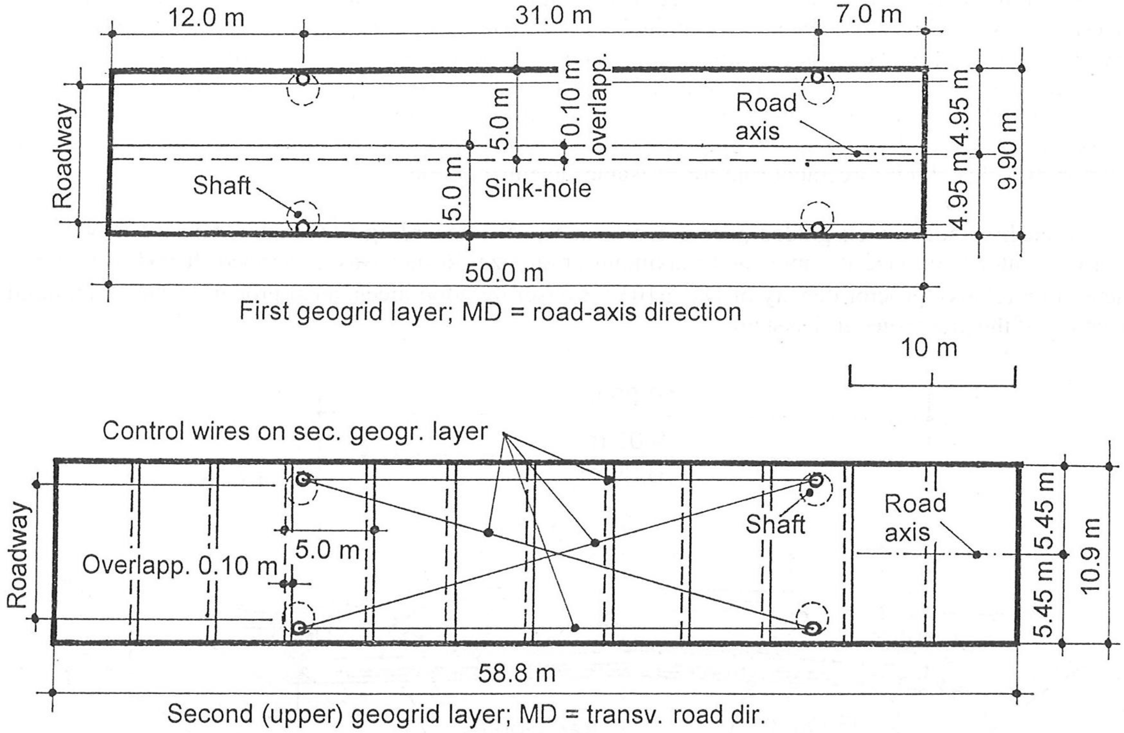

Figure 5: Plan view of reinforced gravel cushion and control system

The 0.30 m thick fill layer (Fig. 4) was placed on the second geogrid layer over the entire reinforced area without driving directly on the grids (Fig. 10) and then compacted by a vibrating roller. A relative Proctor density of $D_{Pr} > 103$ % was achieved, corresponding to a plate load modulus of $E_{v2} > 120$ MN/m² after re-loading according to German standard DIN 18134. These high compaction and strength values were easy and rapidly to achieve due to the effective support by the high-modulus grids. Then the free lengths of the second geogrid layer (Fig. 8) were wrapped back, tensioned and temporarily fixed by steel pins, generating the third reinforcement layer. The same procedure for placement and compaction of the fill was executed in 2 x 0.30 m lifts up to the full height of 0.90 m of the cushion (Fig. 4). The cushion was overlaid by a standard road structure for German Class II-roadways, including gravel and asphalt layers. The asphalt overlay was reinforced by a biaxial polyester grid to prevent cracks due to small deformations of the structure. The reinforced cushion was completed in less than a week by the German contractor TEERBAU GmbH in October 1993.

EXPERIENCE UNDER TRAFFIC

The reconstructed section of the Federal Roadway B 180 is in operation since October 1993. As of December 1996, no deformation, settlement, or cracks have been observed. The roadway continues to be monitored for deflection through the use of the measurement/control shafts.

CONCLUSION

A deep sink-hole was refilled and bridged by a geogrid-reinforced soil cushion. Briefly described are the design philosophy, soil reinforcement materials, and construction technique used to repair the collapsed roadway. The geogrid design methodology, according to English and German guidelines and standards

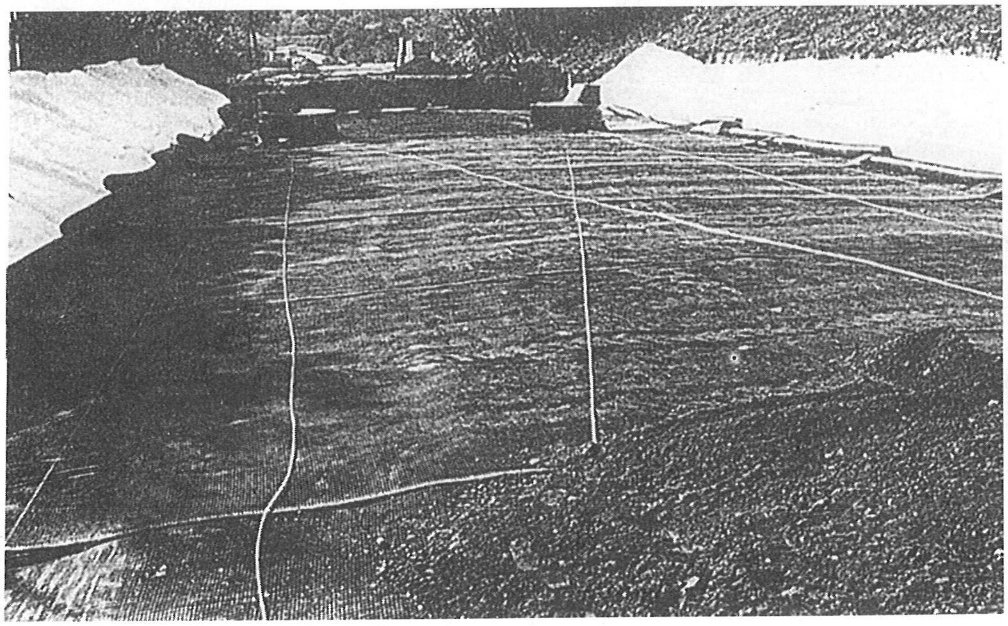

Figure 6: Second geogrid layer and measurement wires

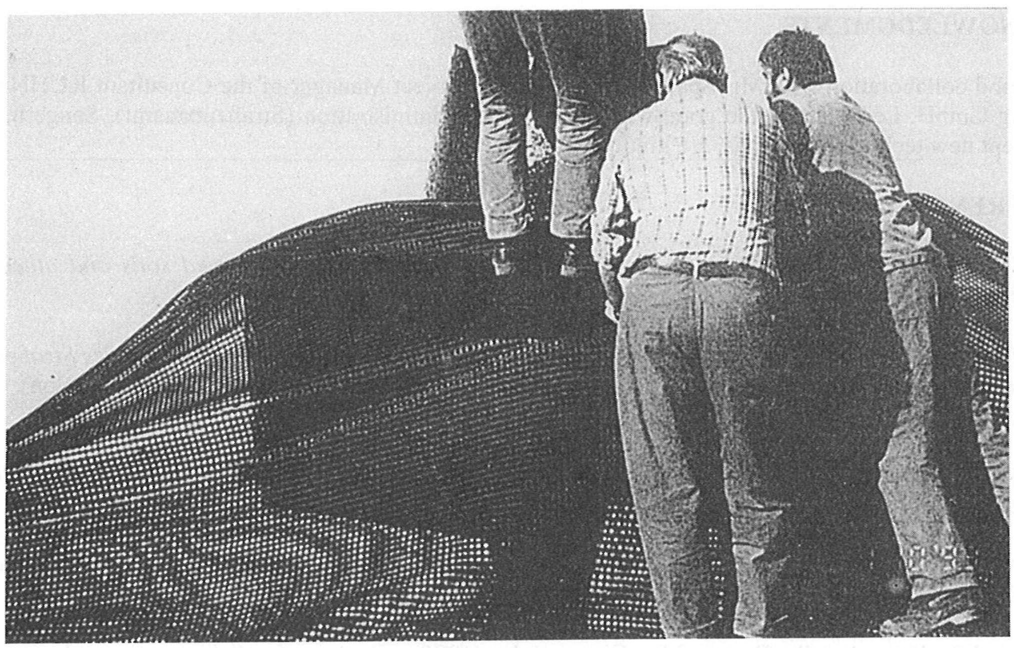

Figure 7: Field fabrication of geogrids around the measurement / control shafts

resulted in the need for an extremely high-modulus high-strength uniaxial geogrid having a machine direction UTS of 1200 kN/m and elongation at break of about 3 %. The grid was specially developed and produced for this project, and has been used later for other projects, too. A measurement/control system was installed to monitor potential future deflection due to the safety requirements for the Federal Roadway. The geogrid reinforced gravel cushion, which was constructed without difficulty due to grid's flexibility and 5 m width, was the first structure of its kind in Germany.

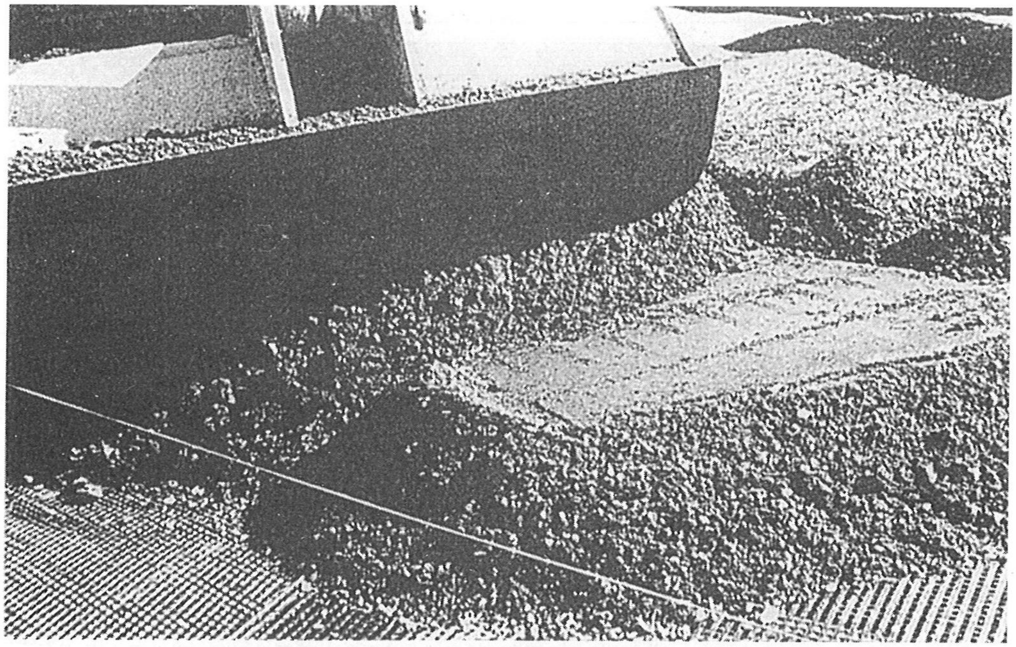

Figure 8: Placing the fill layer on the second geogrid layer

ACKNOWLEDGMENTS

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REFERENCES

British Standard BS 8006 (1995) *Code of practice for strengthened/ reinforced soils and other fills*, British Standard Institution, London Great Britain.

FGSV (1994) *Merkblatt für die Anwendung von Geotextilien und Geogittern im Erdbau des Straßenbaus* (Guidelines for the use of geotextiles and geogrids for (the) application in road construction), Köln, Germany.

HUESKER Synthetic GmbH & Co. (1993) *Data sheet and specification for geogrid Fortrac® 1200/50-10*, Gescher, Germany.

Giroud, J.P., (1982) *Designing of geotextiles associated with geomembranes.* Proceedings of the Second International Conference on Geotextiles, Vol. 1, Las Vegas, P. 37-42.

Giroud, J.P., Bonaparte,R., Beech, J.F., Gross, B.A., (1990) *Design of soil layer-geosynthetic system overlaying voids.* Geotextiles and Geomembranes 9, P. 11-50.