Georeinforcement solution for a motorway crossing an old landfill

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ABSTRACT
A section of a German motorway (autobahn) has to be relocated. The new route crosses an old closed waste disposal.
This old landfill contains heterogeneous unsorted non-compacted materials, some of them including toxic components. The waste was completely insulated from the environment by a capping system twenty years ago.
The fixed gradient of the new route cuts the capping system, i.e. construction had to take place on the waste, the latter being problematic due to many reasons.
Ideally this should be avoided, but then two requirements have to be met: on the one hand the motorway bearing layers should be as thin as possible to avoid waste contact; on the other hand their deformability has to be low enough to equalize differential settlements due to the waste heterogeneity below.
A promising solution was the application of high-strength, high tensile stiffness geosynthetic reinforcements to stiffen the system: this is the objective of this publication.
Multiple design studies have been performed based on analytical procedures in the German reinforcement Code EBGEO and in the British reinforcement Code BS 8006. Some of them had to be modified and further developed. Totally four methods were used. The final solution includes knitted geogrids from Aramid (AR) and laid/welded geogrids from high-tenacity Polyester (PET). The paper describes and comments the problems, the search for an optimized solution, the design methods and modifications applied, the final solution with the corresponding reinforcements and some execution aspects.

1. INTRODUCTION

The present bridge on the German Autobahn A1 over the river of Rhine near Cologne will be replaced by a new one due to increasing heavy traffic. Because of that a section of one kilometer of the present Autobahn A1 approaching the bridge has to be relocated. The new route crosses an old closed waste disposal; there are no other options due to the surrounding property.
The landfill has been under operation from the 50ies until the 80ies. It contains heterogeneous unsorted non-compacted materials from that time, some of them including in depth toxic components. After closure twenty years ago special measures found place to insulate it completely from the environment.
Unfortunately, the planned and not changeable gradient of the new A1 route cuts the landfill capping system, consequently the construction of the motorway bearing layers had to start on the "naked" waste with unknown degree of contamination inclusive of gas emission at any point of the one kilometer route – a very problematic situation.
The idea arose to create a thinner motorway bearing system meeting two controversial requirements: on the one hand to minimize the intervention into the waste due to ecological and labor protection reasons (i.e. the Autobahn bearing layers should be as thin as possible); on the other hand to keep the deformability of the layer system low enough to meet the stringent German Autobahn limitations regarding surface deformations (i.e. the bearing system should be stiff enough to equalize differential settlements due to the heterogeneous waste below).
The owner asked for verification by analytical procedures being common in European Codes beside any possible numerical analyses.
Different options have been checked. Due to brevity the focus herein is on a geosynthetic reinforcement solution, which appeared most promising. Multiple design studies have been performed based on analytical procedures in the German reinforcement Code EBGEO and in the British reinforcement Code BS 8006. Some of them had to be modified and further developed to include the influence of different embedment below the bearing reinforced layers. It became obvious that only high-strength, high tensile stiffness geosynthetic reinforcements could help to solve the problem. Totally four design methods were used, and the most conservative results in terms of reinforcement needed were taken over as decisive.
The final solution includes two geogrid families: knitted geogrids from Aramid (AR) and laid/welded geogrids from high-tenacity Polyester (PET).
Execution of the project started in spring 2019.

2. GEOMETRICAL OVERVIEW

The geometrical situation with the motorway positioning and embedment is illustrated in a simplified way in Figure 1. Figure 1, left, shows the original planned solution: 0.7 m standard superstructure plus 2.0 m compacted granular bearing layer ("cushion") resulting in a total system thickness of 2.7 m. In this case the system cuts the waste almost over the entire relocated stretch of one kilometer. Figure 1, right, shows an example of an intended alternative solution keeping the standard superstructure, but reducing the "cushion" to 1.3 m, thus reducing the total system thickness to 2.0 m. In this case the system enters the waste only over about 20% of the stretch.

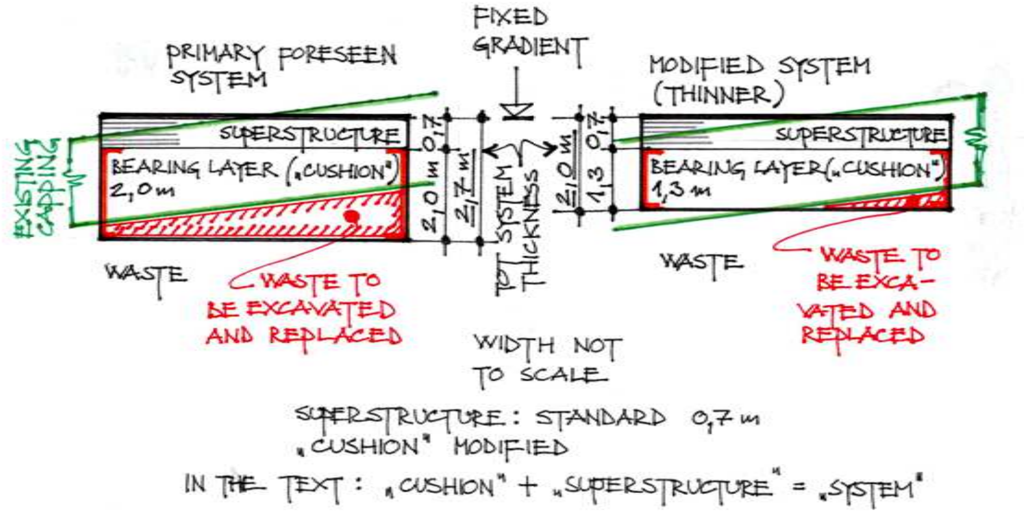

Figure 1. Positioning and embedment of the motorway: original "thick" solution, left, and alternative "thin" system, right

3. DISADVANTAGES AND ADVANTAGES

The crucial disadvantage of the "thick" original solution is the almost permanent contact to the waste during construction and the huge amount of waste material to be excavated, transported and relocated to another waste disposal according to German low. The consequences are: special protective equipment for the personal inclusive of oxygen flasks, working over the entire stretch under a ventilated closed tent with special filters to avoid any emission into the atmosphere, special transportation trucks for the relocation and high cost to deposit the waste in the other landfill. Despite the high costs and sophisticated logistics, the construction time would be very long.
An alternative "thin" solution can eliminate over 80% of the stretch the above problems. The disadvantage: technical measures have to be taken to ensure a sufficiently low deformability of the "thin" system on the generally heterogeneous waste.

4. SEARCHING FOR AN OPTIMIZED "THIN" SYSTEM

Many options were checked and discussed about the best way of creation of a "thin" system: from foundation on short piles in the waste to e.g. chemical stabilization. Financial, technological, ecological and construction time factors had to be considered focusing on the point: how thin can/may the new system be? Where is the optimum? For the sake of brevity no details can be discussed here.
Finally, the optimum seemed to be an unbound bearing layers system depicted as illustration in Figure 1, right, adding proper geogrid reinforcements (not shown in Figure 1) to ensure sufficiently low deformability.

5. THE ISSUE WITH THE ACCEPTABLE DEFORMATIONS

It was agreed with the public owner that total settlements of the Motorway A1 on the landfill over larger areas are not decisive since they practically do not influence the trafficability (comfort and safety of riding). The real point was the possible differential settlements on the heterogeneous waste over a shorter distance of say some meters i.e. the relative deflection.
A plausible criterion was the limitation fixed in EBGEO (2011) for high category roads in terms of relative deflection $d_S/D_S <= 0.01$ (d_S is the absolute maximum settlement in the midpoint of deflection, D_S is the length of deflected stretch). A similar criterion is recommended also in BS 8006 (2010).

Additionally, it was decided to keep d_S < 40 mm, because this is the foreseen thickness of asphalt concrete layer on the motorway surface; thus, small easy corrections would be possible by local mortising and repaving.
The design had to meet both criteria above.

6. DESIGN PHILOSOPHY AND OVERVIEW

6.1 *Basic requirements regarding the methods applied*

The public owner asked for the application of analytical design methods despite any numerical analyses (the latter is outside the scope of this paper). They had to be popular and accepted in Germany and/or in the European Union, consequently, the German EBGEO (2011) and the British BS 8006 (2010) were a good choice. They both include procedures for the calculation of absolute and relative deflections in geosynthetic reinforced systems e.g. when bridging sinkholes or for piled embankments.

6.2 *Assumed boundary conditions*

A precise picture or map of possible softer spots on the waste surface which could provoke motorway deflections was not available. Note that the existing landfill capping system was not allowed to be disturbed for a detailed investigation prior to start of construction. It was known that the topmost landfill layers consist mainly from construction debris, and the oldest bottom layers from unsorted, possibly softer, municipal and industrial (chemical) waste.
To make the long story shorter: it was assumed that a "softer" spot can have a maximum diameter of 3 m. The next question was: how soft can it be? In a preliminary geotechnical report for the softest waste material an oedometric modulus E_S = 5 MPa was estimated. Thus, in terms of Winkler's constant (coefficient of embedment) k_S , the conservative assumption was made k_S = 1 MPa/m.
Further on, because the relative deflection is the focal point here, the material surrounding the soft spot was assumed as absolutely stiff/non-deformable. The scheme is shown in Figure 2. Note that the thickness T of the bearing layer ("cushion") is variable, and consequently the total system thickness T_{tot} as well.
All analytical analyses below are based on these boundary conditions and assumptions.

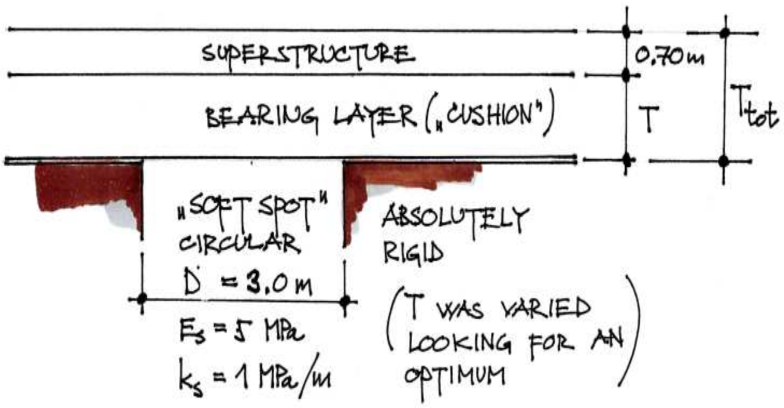

Figure 2. Boundary conditions and model for analytical design

6.3 *Design procedures applied*

The situation in Figure 2 is very similar to the situations known as "bridging sinkholes" and "column supported embankments on soft soil".
However, there are differences here to the "classical cases"/models.
Regarding the model "bridging sinkholes": there is a soft soil here in the area to be bridged instead of air. This soft soil will provide some support to the geosynthetic reinforcement. Because of that the procedures available in EBGEO (2011) and BS 8006 (2010) were modified to allow for taking in a simplified way the advantageous upward counter pressure generated by the soft soil support. A general advantage of the model is the a priori implemented circular support on the border of the problematic zone.
Regarding the model "piled embankments": in the "classical model" the support provided is either by linear (trench walls) or by punctual (piles, columns) elements. In the case herein the support is circular at the borders of the soft spot. Thus, some simplified geometrical approaches were implemented in the designs herein. The general advantage of the model as included in EBGEO (2010) (but not in BS 8006) is the "automatic" consideration of upward counter pressure by the soft soil via k_S (see above).

6.4 *What was done in terms of analytical analyses*

Four analytical design procedures were used with the modifications mentioned in Chapter 6.3:
Design 1: the British bridging sinkhole model (BS 8006 2010) after modification for the support by the soft soil (Figure 3, left);
Design 2: the French bridging sinkhole model RAFAEL (EBGEO 2011) after modification for the support by the soft soil (not shown);
Design 3: the piled embankments method as per EBGEO (2011) assuming a linear trench wall support (Figure 3, right);
Design 4: the piled embankments method as per EBGEO (2011) assuming a punctual support with a modified geometry (not shown).

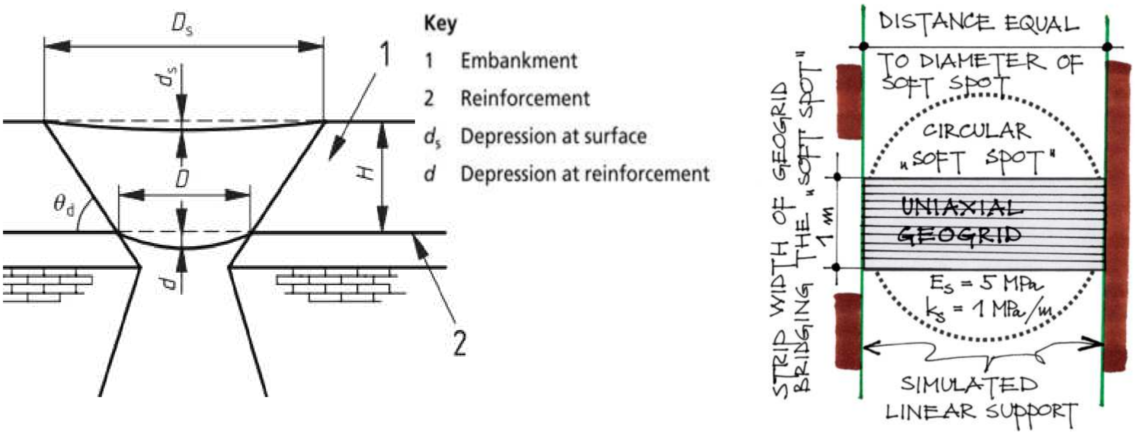

Figure 3. The BS 8006 model (but in the design with soft soil instead of air), left, the EBGEO model adopted here with linear support on the soft spot border, right

In all cases a geogrid reinforcement was implemented at the border plane between waste (resp. capping fill above the waste, Figure 1) and motorway system (i.e. at the bottom of the "cushion", Figure 2).
These "bottom" geogrids are uniaxial and installed parallel to the autobahn (motorway) axis.
As a fill for the "cushion" a well graded highly compacted coarse crushed material was foreseen.
Series of multiple design calculations were performed varying both the cushion thickness T from 0.90 to 1.30 m (i.e. the total system thickness T_{tot} from 1.60 to 2.00 m, Figure 2) and the geogrids parameters (i.e. their long-term tensile modulus).
For every system thickness the geogrids with the highest tensile stiffness and strength resulting from the four analyses methods applied were chosen as decisive (controlling the design).
On the safe side the superstructure of 0.7 m was taken into consideration only as dead load (but not as geomechanically effective bearing component).
It became very soon clear that the geogrid tensile strains are in the range of typically less than 1 %, and that in the same time the tensile force to be mobilized at such a low strain level is significant. Consequently, the design went to geogrids from Aramid (AR) being one of the polymers with highest short- and long-term (after creep) tensile stiffness.
Strictly speaking steel could be also an interesting option in this case. However, because of different reasons not cited here for brevity such studies were stopped at an early stage.
The multiple analyses demonstrated that all thicknesses checked are possible, but for the thinner options the resulting AR-geogrids became simply unusually strong (and probably too expensive).
The advantage of a "very thin" system was almost no cutting of the waste surface over the entire stretch (Figure 1).
The disadvantage: a more sensitive system from the point of view of common engineering sense plus extremely high-grade AR-geogrids.

7. FINAL SOLUTION

Finally after balancing all advantages and disadvantages from technical, financial, technological and ecological point of view and the time available as well, a system with a total thickness T_{tot} = 2.0 m (Figure 2) was chosen. In this case the waste had to be cut over a distance of about 100 m from totally about 1000 m. A typical cross section is depicted in Figure 4.
Some comments on the final solution:
The "bottom" geogrid (No. 1 in Figure 4) is a knitted coated Aramid (AR)-geogrid (Type Fortrac AMT 400 BAB A1) with an ultimate tensile strength (UTS) of 300 kN/m and strain at UTS of typically 2.7 % installed parallel to the highway axis. It results from the design concept and analyses described in Chapters 6.3 & 6.4.

The upper geogrid (No. 2 in Figure 4) is a laid/welded geogrid from high-tenacity Polyester (PET), Type Secugrid 200/40 R6 with an UTS of 200 kN/m and strain at UTS of typically 7% installed perpendicularly to the highway axis. The reason for this upper reinforcement was the possibility of reverse bending of the system over an asymmetric soft area. In such a case the "bottom" geogrid alone would be less efficient. Because there is until now to our best knowledge no analytical method for analyses of a "bending granular reinforced beam" the upper geogrid was estimated/chosen based on engineering judgment and due to its high resistance against installation damage between two highly compacted coarse fill layers (Figure 4).
Position No. 3 in Figure 4 shows a geocomposite containing neutralizing active coal. It was foreseen only for the stretch where the system cuts the waste.
For the sake of brevity no more details and aspects can be discussed here.

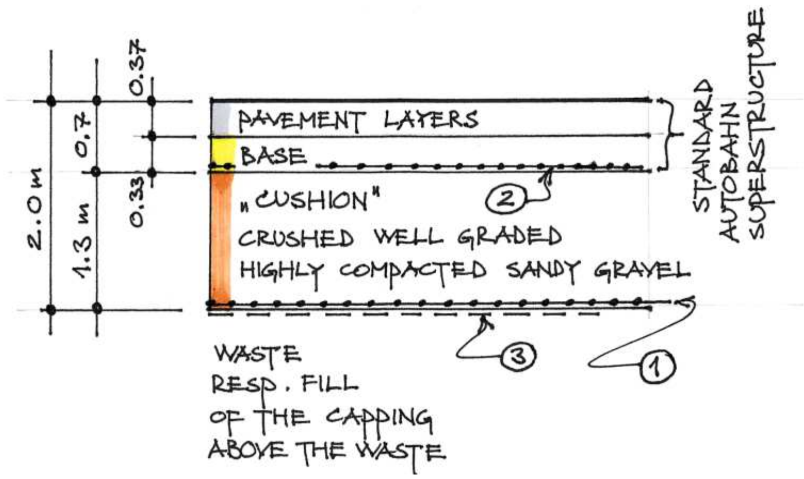

Figure 4. Simplified scheme of the final solution (1 - knitted AR-geogrid 400 parallel to the axis; 2 - welded PET-geogrid 200 across; 3 - geocomposite with active coal over a limited stretch)

8. EXECUTION AND TECHNOLOGICAL ASPECTS

Execution started in spring 2019. The installation of the "bottom" knitted AR-geogrids (Pos. 1 in Figure 4) was trained in advance separately to ensure a fluent installation later on site. Due to logistic reasons the "bottom" geogrids had to be installed in sections of 60 m. Since they are flexible they have to be installed under some pre-tension to avoid any waves/wrinkles which can compromise their immediate mobilization later on in the system. The specific point here was the "hanging" pre-tensioning "in air" - and not directly horizontally on the surface - to avoid the significant friction over 60 m and the generation of wrinkles in the geocomposite (Pos. 3 in Figure 4). Specific calculation analyses were performed to find the optimum of "hanging" and pre-tension. Such "hanging" technology (Figure 5) was developed and applied for the first time and was a challenge.
For the upper welded PET-geogrids (Pos. 2 in Figure 4) such specific points are not existent, they can be installed the common way.

Figure 5. "Hanging" installation under pre-tension of the "bottom" knitted AR-geogrids

9. FINAL REMARKS

The project described is in our opinion neither common, nor easy. Modified analytical design procedures had to be developed and applied.
Because every of the four design methods applied has advantages and disadvantages, they were used in a parallel way for every system thickness analyzed, and the "strongest" resulting reinforcement was taken over.
In terms of geosynthetic reinforcement two generally different types of geogrids are used, as we believe, in an optimal way. A special installation technique had to be also developed for one of the geogrids.
While writing this publication construction is successfully under run keeping the schedule.

ACKNOWLEDGEMENTS

Last but not least: the realization of this specific project with significant innovative components would be not possible without the tight and benevolent collaboration of consultants, building company and public investor. This is highly appreciated.

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