Reduction of lateral trust at bridge abutments by means of geosynthetic encased columns (GEC): case study and analyses

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ABSTRACT: Geosynthetic encased granular columns (GEC) as pile-similar elements are an efficient solution for foundation of embankments on soft soils. The decisive difference to conventional compacted gravel columns is the high-strength tubular geotextile encasement as engineered element. It provides controlled radial confinement thus reducing settlements and increasing stability. Due to the encasement GECs can work even in extremely soft soils. A high bridge approach embankment for a new highway was built on GECs in a soft soil area overlaid by an old unsorted landfill in Germany. Thereby a second, additional function being rarely used was assigned to the GECs: to reduce the lateral pressure of soft soil in depth on the adjacent piles of the bridge abutment. Simplified analytical procedures were applied to evaluate and limit the lateral pressure. An extensive measurement program was adopted to gain verified experience in this specific matter. Main project data, geotechnical circumstances, engineering philosophy, design and construction are described. Most important results from more than two years of measurements are shown and commented. Consequently, summarizing conclusions and recommendations are presented.

KEYWORDS: geotextile encased columns, reduction of lateral earth pressure, soft soil, bridge approach

1 INTRODUCTION

The new German Federal Road (Bundesstrasse) B212n ("n" for "new") in the Northwest of Germany is conceived as a bypass of the City of Berne (Figure 1, left) upgrading the local Federal Road network and relieving the lower class roads in the region. It needs to be noted that the allowed driving velocity on a Federal Road is 100 km/h, thus the requirements in terms of serviceability are quite stringent. The total length of B212n is 10 km and comprises nine bridges and viaducts with high embankments as bridge approaches. The project construction started in 2009 and in 2017 the entire road needs to go to operation. Generally the soil material in northwest of Germany consist of soft saturated soils (holocene clay and peat, alluvium) with a thickness of 10 to 15 m followed by pleistocene sandy layers and high ground water levels (GWL) near the terrain. Consequently, similar to other Motorways and Highways in the region, the entire B212n is positioned on embankments with varying heights which the highest ones comprise the bridge approaches. Typical solution in such cases is building the embankments with high-strength basal geosynthetic reinforcement in combination with strip drains and temporary overloading (pre-consolidation) (Blume et al. 2006, Alexiew & Blume 2010, Alexiew & Blume 2012). However, at Berne project, this scheme could not be applied especially for the higher embankments (typically the bridge approaches) due to the tight schedule of the project and the lack of time for consolidation under preloading. Moreover, the corresponding risk of unacceptable post-construction creep settlements needed to be considered. Finally, for the approaches the foundation on so-called geotextile encased columns (GEC) was found to be the optimal solution due to technical, technological, financial and ecological arguments and reasons of time. The GECs are pile-similar elements consisting of compacted sand or gravel encased by high-strength, low-strain, round woven geotextile tubular encasements as an engineered element controlling their behavior. For more details, see e.g. Alexiew et al. (2012), Alexiew & Thomson (2014).

This paper focuses on the crossing of the river Hunte with two bridge approaches (Figure 1, right) of about 7 m height above the terrain. The GEC system has not only been used as usual to ensure the global and local stability (Ultimate Limit State - ULS) and to minimize and equalize settlements (Serviceability Limit State - SLS) of the approach embankments, but also to protect the rigid sensitive bridge abutment piles against high lateral pressure resulting from the embankment load in the soft soils.

Figure 1. The new Berne bypass B212n:
left: overview as per 2014; right: bridge approaches at the river Hunte

The natural geotechnical circumstances on both sides of the river are very similar (Figure 2), but an additional uncommon problem arose on the North side: there was an old unsorted landfill instead of clay just in the trace of the new B212n below the bridge approaching zone (Figure 2). This paper will further focus only on the mentioned zone.

The two main topics, which are further discussed in detailed are the "embankment on GECs in the landfill area" issue and the "lateral stress relief" issue at the piled bridge abutment adopting GECs for this purpose as well.

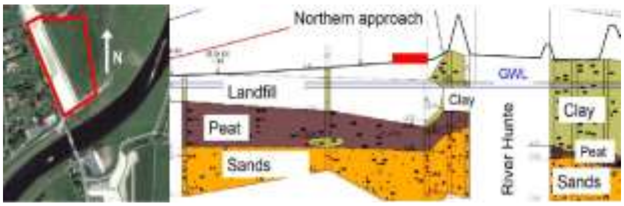

Figure 2. Landfill area below the Northern approach, left; typical geotechnical profile along the B212n, right

2 GEOTECHNICAL OVERVIEW

The geotechnical situation below the Northern approach is depicted in a simplified way in Figure 2, right (to the left of the river Hunte in the Figure). Note that the picture is not in scale. The terrain is at about mNN +2.00 ("mNN" = 0.00 m is the average sea level). From top to bottom there is a thin artificial mixed fill cover layer (not shown), followed by the unsorted waste of about 4 to 5 m thickness which had replaced the natural clay (still existing on the South side of the river) over the years. The waste is underlaid by about 4 to 5 m of peat followed by the pleistocene sands. The groundwater level (GWL in Figure 2, right) is at about 2 m below the natural terrain. It is under seasonal and tidal influence and varies about +/- 0.5 m, and is present also in the landfill. There is a second water horizon in the sand below the peat and clay (those act as hydraulic barriers) with some artesian pressure. The typical geotechnical parameters of the materials are summarized in Table 1. Note that due to the significant local scattering of the peat parameters some analyses were performed on the conservative side with $\phi = 15°$ and $c' = 3$ kN/m².

The waste in the landfill comprises an unsorted mixture not only of "classical" municipal waste (inclusive of e.g. refrigerators and furniture), but also e.g. construction debris, old tires etc.

According to the German recommendations for landfills E 1-7, E 1-8 and E 2-19 (GDA Empfehlungen) geotechnical calculations can be performed handling waste as geotechnical material (soil), thus using e.g. classical methods as Bishop or Janbu, and using "classical" geotechnical parameters also for waste. The waste parameters in Table 1 were assumed based on the German experience summarized in recommendation E 2-35 (GDA Empfehlungen) and project experience. The assumed values are relatively conservative in terms of ϕ' and c'. The major part of the landfill is below the GWL, see above and Figure 2, right.

3 THE "EMBANKMENT ON GECs IN LANDFILL" ISSUE

The existence of the waste below the Northern embankment was a significant technical and environmental problem and challenge. To construct the embankment on top – without "touching" the waste - in combination with strong basal geosynthetic reinforcement (being under other circumstances a possible solution, see above) would take years of consolidation time; additionally, the heterogeneity of the waste could result in unpredictable absolute and differential settlements. During conceptual studies, two options were primarily under consideration: first, to excavate and re-dispose the waste and replacing it by another "harmless" homogeneous neutral fill; second, to construct the bridge approach as geogrid reinforced embankment on rigid piles installed through the waste and the peat down to the sands (Alexiew 2005). Due to financial, technical, ecological and legal ground reasons, the first option was rejected soon. The second option appeared ecologically very risky due to the water path at the interface pile with surrounding soil: that would result in hydraulic contact of the contaminated water inside the landfill to the clean groundwater horizon in the sands below; either the contaminated water could infiltrate down or the artesian water could infiltrate up. Both phenomena have to be strictly avoided. Consequently, this option was rejected as well. However, a feasible solution needed to be found in the end.

Table 1. Parameters of the materials for the Northern approach

Material (Layer)	Undrained unconsolidated			Consolidated			
	Unit weight γ/γ' (kN/m³)	Angle of internal friction ϕ_u (°)	Cohesion c_u (kN/m²)	Unit weight γ/γ' (kN/m³)	Angle of internal friction ϕ' (°)	Cohesion c' (kN/m²)	Permeability k (m/s)
Embankment (Sand)	19.0/11.0	-	-	19.0/11.0	32.5	0	
Peat	11.8/1.8	0	12.0	11.8/1.8	30	10	$1x10^{-8}$
Waste	12.0/2.0	-	-	12.0/2.0	20	10	$1x10^{-5}$
Sand	20.0/12.0	-	-	20.0/12.0	35	0	

As mentioned above, the GECs installation in clay and peat material were found as the optimum solution. Therefore, it seemed self-evident to check this option for its appropriateness also in the landfill area.

Three main points arose:

A. Is there any experience with GEC installation in an old unsorted landfill using either the so-called replacement and/ or displacement installation methods (Alexiew et al. 2012). Note that the displacement method (i.e. displacing the subsoil without any excavation of it) has to be preferred to avoid any extraction and handling of waste.

B. What about the durability of the geotextile encasement in the harsh landfill environment?

C. How to avoid a hydraulic contact between the contaminated water inside the landfill and the clean water in the sand sublayer?

Regarding A and B: First experiences have been gained in a project in the Netherlands at Westrick where a railroad embankment has been built on GECs on top of an old unsorted landfill. The GECs were installed through the waste down to a sandy terrace (Nods & Brok 2003, Alexiew & Raithel 2015). The displacement method was successfully used avoiding any extraction of old waste. However, there was almost no demolition rubble e.g. concrete blocks. For the encasement (seamless high-strength tubular geotextiles) Polyvinyl alcohol (PVA) was used as raw material due to its high chemical resistance in a wide range of media. Based on this solution and the gained positive experience, it was decided to apply the same concept, technology and materials for the Berne project.

Regarding C: There had been other projects in Northern Germany with embankments on GECs whose toes entered by typically 0.5 m sand layers under artesian pressure like herein at Berne. The hydraulic contact had been successfully blocked using a sand-bentonite mixture of low permeability as a plug in the first meter at the toe of the GEC as fill material. Pore water pressure measurements and visual observation at the surface showed that no water paths does exist at the interface GEC to soils. A possible explanation is the presence of some protruded bentonite on the outer side of the geotextile encasement (difference to piles). It was decided to apply the same solution but installing sand-bentonite plugs of 2 m height in the transition zone from sand to peat to be on the safe side.

Keeping in mind the presence of demolished concrete and other unknown big rigid inclusions, a concept was developed to guarantee the proper installation of the GECs through the waste. Static penetration tests were foreseen in a tight pattern over the landfill contour. They are relatively cheap and quick in this case and simulate "en miniature" the penetration of the GEC installation tubes. They allow the identification of e.g. buried concrete blocks, which could stop also the penetration of a steel tube even using a powerful vibro-hammer (Alexiew & Thomson 2014). In the case of such insuperable objects, the GEC position should be changed.

Another point was the handling of the contaminated water in the landfill. During GEC installation and later on under embankment load and consolidation, contaminated water will raise to the surface. It is usually drained away and up into the sand embankment by the sand fill in the GECs working as "mega drains" and then led away over the terrain. The latter was not acceptable in this case due to contamination. Thus, the landfill water has been collected in a closed pipeline system.

The GEC system was designed and calculated using the established design procedures (Raithel 1999, EBGEO 2011, Alexiew et al. 2012). The material parameters are listed in Table 1. The foreseen GEC diameter D was 0.8 m with an average area ratio of 12% (area ratio = area of GECs to total foundation area) being in the common range of 10% to 20%. A higher area ratio was planned only for six GEC rows just behind the bridge abutment on piles as horizontal stress relief (see above). As horizontal reinforcement on top of GECs, a high-strength woven Robutec® 1000 of PVA was selected due to chemical resistance and low creep.

4 EXPERIENCE FROM THE GEC SOLUTION IN THE LANDFILL AREA

After the construction of a sand working platform a pilot GEC installation by displacement method started with the foreseen diameter of 0.8 m for optimizing logistics, technological details, type and regime of vibro-hammer etc.

The "scanning" of the waste area by static penetration started as well. It was found out quite quickly that the installation of steel pipes with 0.8 m diameter could not easily penetrate sufficiently the waste. Consequently, the concept was changed to GECs with a diameter of 0.6 m and the system re-designed. In this modified solution, the area ratio is about 12%; as encasement the seamless tubular geotextile Ringtrac® 100/500 PM from PVA with an ultimate tensile strength (UTS) in the ring direction of 500 kN/m was used. A simplified partial overview of the final solution as executed in the zone adjacent to the bridge abutment is illustrated in Figure 3. There is an exception of the "normal" area ratio of 12.4%: a group of six GEC rows was designed and installed just behind the abutment (solid-colored in Figure 3, right) at a smaller center-to-center distance of the GECs, resulting in a higher area ratio of 17.5%. Diameter and encasement are the same as for the "normal" case. This is the "screen" against higher lateral pressure on the bored piles of the abutment (stress relief, see above and details in Chapter 5).

Generally, the installation with the diameter of 0.6 m pipes was unproblematic and efficient, and the productivity was in the common range. However, for about 5% of the GECs in the landfill the position had to be changed, usually by 0.3 to 0.5 m, e.g. when an adjacent static penetration indicated an insuperable (impenetrable) object before reaching the design depth. In some cases despite the tight pattern of "pre-scanning" static penetrations, a running GEC installation had to be stopped and the position had to be changed. The strong horizontal reinforcement mentioned above is able to compensate and redistribute these position deviations.

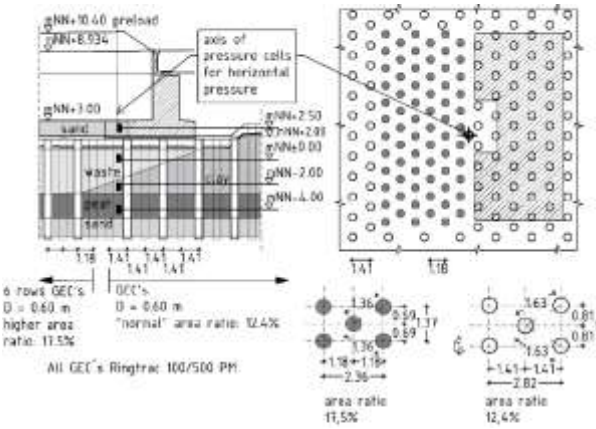

Figure 3. Simplified overview of the GEC foundation adjacent to the Northern bridge abutment; all dimensions in meters; "mNN" means height above mean sea level in meters (for the pre-loading embankment GEC's have been installed also in the abutment area)

An automated measurement program was applied consisting of automatic settlement gauges (SG), piezometers (P) and earth pressure cells (EPC). A specific point is the installation of EPCs for registration of the total horizontal normal stresses in the zone just behind and below the bridge abutment. Their axis and positions are depicted in Figure 3.

Figure 4 shows typical settlements in the landfill zone approximately in the embankment axis about 12 m behind the bridge abutment, completely over waste and peat (see Figure 2, right & Figure 3, left). They were measured using automatic SGs. The settlements are generally quite small. They reflect quickly the changes in embankment height, which is usual for projects with GEC foundation (Alexiew & Raithel 2015). Some additional settlements occur under constant load. They are relatively larger in the early stages of construction - despite the lower load - then later (compare e.g. months 2 to 6 with the time after month 25). Note that between the 25th and the 42nd month (in 17 months) the settlement increases only by 3.5 cm reaching its final value; no more settlement (e.g. due to creep) takes place after that. Analogues results were gained also using simple settlement plate gauges at regular intervals over the entire approach embankment axis.

It is worth keeping this "no creep settlement" behavior in mind because of the specific presence of unsorted mixed waste as foundation soil and the peat (generally tending to creep under load). Note that a strong secondary settlement reduction - although not down to zero as here - using GECs has been observed in many other cases as well (Alexiew et al. 2012, Alexiew & Raithel 2015).

Summarizing the "embankment on GEC in landfill" issue:

- A GEC foundation system can be used in an unsorted mixed landfill including also e.g. construction debris.
- The displacement method of installation can be adopted avoiding any waste excavation.
- GEC diameter of max 0.6 m is recommended if large demolished concrete is expected.
- "Pre-scanning" by static penetration is recommended if huge inclusions or debris are expected.
- The use of PVA for the GEC-encasements and the horizontal reinforcement on top of them solves the durability issue.
- Contact of contaminated (landfill) and clean water can be avoided.

- A “surplus” of contaminated water due to GEC installation and consolidation can be handled in a closed circuit.
- A proper strong horizontal reinforcement can neutralize the effect of GEC-repositioning if needed.

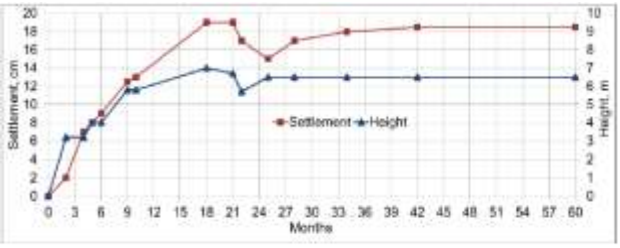

Figure 4. Embankment height and typical settlements in the landfill area vs. time

5 THE “LATERAL STRESS RELIEF” ISSUE

Lateral pressure at depth (horizontal normal stress σ_h) generated in soft subsoil by surface loads (e.g. embankments) can endanger adjacent rigid piles causing significant additional shear forces and bending moments. There are two possible ways to solve the problem. First, using more flexible insensitive supporting elements e.g. GECs instead of common piles. This option was adopted e.g. for the stacker/ reclaimer runways in a stockyard in Brazil (Alexiew et al. 2009). The second way is to reduce sufficiently σ_h below the loaded area by technical measures e.g. also using GECs. This option was chosen at the same time for both a project in Brazil (Schnaid et al. 2014) and behind the bridge abutments in this project.

The German pile design recommendations EA Pfähle (2007) comprise a simplified procedure to judge when a pile group is not endangered by lateral pressure from an adjacent embankment. The requirement is that the factor of safety (FOS) for the global (external) stability of the embankment in direction to the piles is at least 1.4. A global stability analyses according to EBGEO (2011) was performed resulting in the GEC group shown solid-colored in Figure 3, right. The same type of columns and geotextile encasement were kept below the rest of approach embankment, only the number of GEC rows and the area ratio were increased until reaching a FOS > 1.4. The result is six GEC rows and an area ratio of 17.5% (Figure 3). The increased shear strength within the column due to the load concentration above the column heads is considered within the global stability design as an equivalent cohesion (Raithel, 1999).

Additionally, based on regional experience, it was decided to limit the total σ_h to maximum 50 kN/m². A simplified analysis was performed also in this regard confirming the solution explained above.

To gain useful information on the appropriateness of GECs for lateral stress relief and to control the upper limit allowed of 50 kN/m² EPCs for total stress measurement were installed. Their positions are depicted in Figure 3. The EPCs were chosen in a way to allow for measurements in the sand fill (mNN +2.50), in the waste (mNN +-0.00), in the clay (mNN -2.00) and in the peat (mNN -4.00) (Figure 3).

A specific installation technique was applied to guarantee the correct total stress registration in all layers. In Figure 5, the total σ_h development over time is displayed.

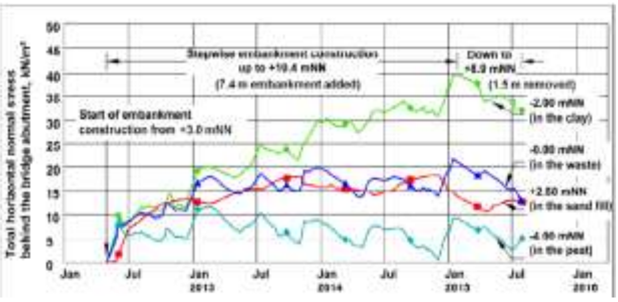

Figure 5. Total horizontal stresses σ_h at four levels and in four different layers behind the bridge abutment over time (see also Figure 4)

Note that because the sand fill at mNN +2.50 is quite above the average GWL at mNN +-0.00 (varying by about +-0.5 m),the total σ_h is not influenced by the GWL changes, it undergoes less deviations and the σ_h -graph is smoother in contrast to the other lower levels/ layers. It is by the way an indication of the proper installation and function of the EPCs. It can be assumed that in this sand fill layer the registered σ_h is not the total but rather the effective σ_h.

From the practical point of view, the most important fact is that the highest total σ_h of 40 kN/m² (as it has to be expected in the clay) is less than the half of total σ_h, which is expected without the stress relieving GEC group, demonstrating the correctness of design approach and the suitability of GECs as lateral pressure relief measure. The latter is also stated in Schnaid et al. (2014). The stress is also well below the max. allowed value of 50 kN/m².

Generally the “total σ_h-behaviour” of the clay and of the peat meets the expectations taking into account their position and permeability (Figure 3 and Table 1). From special interest are the measurement results for the waste being something of a rarity and positioning its behavior between the behavior of the clay and the peat.

6 FINAL REMARKS

The new German Federal Highway B212n as a bypass of the City of Berne in Northern Germany is situated in a region well known for its soft soils and high ground water level. The B212n crosses the river Hunte, where high bridge approach embankments became obligatory. As the optimal solution, a foundation on geotextile-encased columns (GEC) was chosen.

There are two specific issues in connection to the long and about 7 m height Northern bridge approach embankment: first, the GECs are positioned in an old unsorted mixed landfill - this created significant technical and ecological difficulties; second, a group of GECs has to work as horizontal stress (lateral pressure) relief in depth protecting the sensitive rigid piles of the bridge abutment.

Both issues were solved successfully. Philosophy, concepts, solutions, experience, measurements and recommendations - especially for the landfill problem - are briefly presented.

Getting to the point: it is possible to cross a problematic landfill by GECs; it is possible to use GECs as stress relief system.

The technique also seems to be highly adaptable to uncommon problems.

7 REFERENCES

Alexiew, D. (2005). Piled embankments: Overview of methods and significant case studies, *Proc. 16 ICSMGE '05*, Osaka, pp 1819-1822.

Alexiew, D., Moormann, C. and Jud, H. (2009). Foundations of a coal/ coke stockyard on soft soil with geotextile encased columns and horizontal reinforcement, *17th ICSMGE '09*, Alexandria, Egypt, pp. 2236-2239.

Alexiew, D. and Blume, K.-H. (2010). Two reinforced embankments on soft soils: Experience after more than twenty years, *9th International Conference on Geosynthetics '10*, Guaruja, Brasil, pp. 1851-1854.

Alexiew, D. and Blume, K.-H. (2012). Motorway embankment in problematic coastal soft areas: Long-term experience with the basal reinforcement, *International Conference on Ground Improvement and Ground Control '12*, ICGI, University of Wollongong, Australia, pp. 911-916.

Alexiew, D., Raithel, M., Küster, V. and Detert, O. (2012). 15 years of experience with geotextile encased granular columns as foundation systems, *ISSMGE – TC 211 International Symposium on Ground Improvement '12 IS - GI,* Brussels, Belgium

Alexiew, D. and Thomson, G. (2014). Geotextile encased columns (GEC): Why, when, what, how? *Fourth International Conference on Geotechnique, Construction Materials and Environment '14*, Brisbane, Australia, ISBN: 978-4-9905958-3-8 C 3051. pp. 484-489.

Alexiew, D. and Raithel, M. (2015). Geotextile encased columns (GEC): Case studies over twenty years. *Ground Improvement Case Histories Vol. 1'15*, Elsevier, Buddhima Indraratna, Chu Jian, Editors (to be published).

Blume, K.-H., Alexiew, D. and Glötzl, F. (2006). The new federal highway (Autobahn) A 26 in Germany with high geosynthetic reinforced embankments on soft soils. *Proc. 8th International Conference on Geosynthetics '06*, Yokohama, Japan, pp. 912-916.

EA-Pfähle, Empfehlungen des Arbeitskreises "Pfähle", *DGGT*, Ernst & Sohn, 2007.

EBGEO (2011). Recommendations for Design and Analysis of Earth Structures Using Geosynthetic Reinforcements. *German Geotechnical Society (DGGT)*, Ernst & Sohn, Essen-Berlin, Germany.

GDA Empfehlungen E 1-7, E 1-8, E 2-19, E 2-35. *DGGT*, Essen, Germany.

Nods, M. and Brok, C. (2003). Geotextiel ommantelde zandpalen als fundering voor HSL bij Prinsenbeek, *Geokunst 01/2003*, pp. 80-83.

Raithel, M. (1999). Zum Trag- und Verformungsverhalten von geokunststoffummantelten Sandsäulen, *Schriftenreihe Geotechnik*, *Heft 6*, Universität Gesamthochschule Kassel, Kassel, Germany.

Schnaid, F., Winter, D., Silva, A.E.F., Alexiew, D., Küster, V. und Hebmüller, A. (2014). Geotextile Encased Columns (GEC) under bridge approaches as a pressure-relief system: Concept, experience, measurements, *10ICG '14*, Berlin, Germany, CD, no pages.