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The new federal highway (Autobahn) A26 in Germany with high geosynthetic reinforced embankments on soft soils

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ABSTRACT: In 2001 the construction of the Federal Highway (Autobahn) A 26 in north of Germany was started. In this area the underground is of very low bearing capacity as it consists of soft layers (clay, peat) with a thickness of up to 13 m. Because of financial, technical and ecological reasons a soft soil replacement was even not under discussion. The pre-loading procedure (consolidation method) was chosen for this construction. Short- and long-term stability is ensured by the use of high-strength woven geosynthetics for reinforcement at the embankment base. The vertical and horizontal deformations and the stress in the soil, caused by the pre-loading procedure, have to be controlled by special measurements. Additionally, the strain behaviour of the high-strength geosynthetic is measured below the higher parts of embankments.

Among others, a very sensitive issue was the construction of an embankment ramp with a height of up to 16 meters situated at a distance of only 20 m from an important railroad under traffic. Concept, measurement program (controlling by evaluation and feed-back of the construction process (DIN 1054)) and important findings regarding the geosynthetic's behaviour - especially the different behaviour of two geosynthetic layers installed at different height in the embankment base - are shortly presented.

1 OVERVIEW

To relieve main road B73 and neighbouring roads, federal motorway A26 with a length of roughly 33 km beginning in Stade and meeting federal motorway A7 near Hamburg is being constructed in four sections. Construction of the first section between Stade and Horneburg was started in 2001. The earthworks were completed in 2004.

This first section with a length of about 11 km begins in the north German coastal heath land near Stade and clears a height difference of app. 14 m in the terrain during the transition from the heath land to the Elbe valley ("old land", marsh) in direction to Hamburg.

2 SUBSOIL AND GROUND WATER CONDITIONS

Federal motorway A26 runs through the low-lying areas of the Elbe marsh. Due to the specific topography a natural drainage of this area is not possible. Surface water needs to be pumped via the Polder stations to the Elbe and its tributaries.

The A26-route is positioned on very soft, saturated Holocene layers of clay and peat resting on Pleistocene sands with a higher load-bearing capacity. At the A26-beginning near Stade, the heath land rises out of the Elbe marsh by a considerable height of app. 14 m. The soft Holocene layers of the marsh along the first section mentioned above, range in depth between 5 and 13 m. The peat layers, extending up to the terrain surface, range in depth between 1.5 and 7 m. The parameters of the peat and clay layers vary in the range of natural water content w_n = 100 to 800%, undrained shear strength $c_u(s_u)$ = 8 to 15 kN/m^2, constraint (oedometric) modulus E_{oed} = 0.3 to 1.2 MN/m^2. For further details see Blume et al. (2004).

The Holocene and Pleistocene layers each include their own, independent ground water storeys. The artificially regulated ground water level in the Holocene layer extends up to the surface of the terrain. In the Pleistocene layers there is artesian ground water. The low permeability of the Holocene clay layers situated directly above the Pleistocene layers prevents the ground water from reaching the surface.

3 CONCEPT, CONSTRUCTION TECHNIQUE AND GEOSYNTHETICS

For the first section of A 26 from Stade to Hamburg, the Federal Motorway Research Institute prepared a report assessing the construction possibilities in the geotechnical and hydrological situation described above. Because of economical, ecological and technical reasons a soft soil replacement below embankments was even not under discussion. Based on long years of experience gathered by the Federal Motorway Research Institute in road construction on soft soils, the heaping technique (pre-loading) in combination with the installation of EPS (expanded polystyrol) in some sub-sections was chosen. Due to economical reasons in many sub-sections the EPS was later on rejected and a solution with higher pre-loading and stronger geosynthetics was applied (see below).

Using the heaping technique, a pre-loading sand embankment compresses the subsoil causing a faster primary consolidation. When reaching about 90% of consolidation, the excess height is removed. No significant settlement is expected to occur after that. The greater the selected excess height, the lower the long-term settlement value (creep deformation) following removal of this height. This technique is feasible as long as the required total height of embankment (incl. of the excess height) does not result in insufficient local or global stability of embankment and/or soft soil. The stability (and consequently the allowed embankment height) can be increased significantly by the use of appropriate high-strength geosynthetic reinforcement in the base of embankment. This technique is known in Germany and other countries since more than 20 years (Alexiew & Blume 1999).

Because of the difficult subsoil conditions the following additional measures were required:

- Installation of a light geotextile on the terrain to separate the soft subsoil from the embankment fill and to produce an operating platform for the rigs for strip-drain installation (see below),
- Installation of vertical strip-drains to accelerate consolidation (installation depth starting at the operating plane, total length 6 to 12 m; drain spacing: 1.25 m). The drains end app. 2 m above the Pleistocene layer to prevent the artesian ground water from emerging at the terrain surface,
- Installation of high-strength low-creep geotextiles of sufficient design strength, low long-term strain and high coefficient of interaction with the sand of embankments at the embankment base on top of the strip-drains. As an optimal solution the geotextiles Stabilenka® 200/45, 400/50 and 600/50 were chosen.

One of the most critical sub-sections was the ramp leading up from the marshland to the heath land with a net height above terrain of up to 13 m. Here, after the removal of the excess height, the installation of EPS was planned. For this technique the use of high-strength geotextiles with an ultimate tensile strength (UTS) of 400 kN/m would have been sufficient. Later on it was decided due to technical and economical reasons not to install EPS but to use geotextiles of higher strength in combination with a measurement program.To guarantee sufficient global and local stability, the required design strength of reinforcement resulted via back-calculations in a required ultimate tensile strength (UTS) ≥ 1100 kN/m. Due to formal reasons in the contract, the contractor decided to install two layers of geosynthetics with UTS 600 kN/m each (Stabilenka® 600) instead of one single layer with UTS 1100 kN/m (Stabilenka® 1100). The latter had been recommended by the authors to be the more efficient solution based on their experience and various published data: in a double layer the lower one could be "overstressed" and the upper one "understressed", say not fully activated. However, for an easier installation "double rolls" of Stabilenka® were prefabricated, delivered and installed with a vertical spacing between the two layers of 0.5 m. The total height of the ramp (Fig. 1) was expected to amount to about 16 m incl. the settlements. Special geosynthetic lay-out and installation procedures were developed and applied especially for the front end of the ramp to ensure a 3D-stability of embankment accompanied by minimized deformations, which cannot be explained in detail herein.

4 GEOTECHNICAL MEASUREMENT PROGRAM

Construction of high embankments on soft soils is expected to result in significant vertical and horizontal deformations which chronological and spatial development must be controlled by means of measurements attending the construction process. The essential objectives of these measurements are:

- Monitoring, coordination and control of embankment heaping activities to achieve the final, specified height as quickly as possible while ensuring stability,
- Determination of waiting times for consolidation at a given height and - if necessary - additional heaping requirements, as well as the point in time at which removal of the excess height could be commenced,
- Safeguarding of existent adjacent infrastructure (e.g. high-voltage masts, railroads etc.).

The time-settlement, excess pore-water pressure and geosynthetic strain characteristics during the waiting times can be used to forecast the behavior following

release to traffic. These data also can be used to evaluate the success of pre-loading quickly and allow corresponding decisions regarding the construction process (which is a component of the DIN 1054-observation method mentioned earlier), thus the measurements should be evaluated regularly.

The measurement techniques must be suitable for determining vertical and horizontal deformations in the subsoil as well as changes in pore-water pressure and geosynthetic strains during the heaping phases and waiting times.

Planning and instrumentation, measurement procedures and continuous evaluation must be placed under the responsibility of a specialized, experienced company. A geotechnical expert must be put in charge of evaluating the measurement results and controlling the construction process correspondingly. For further details see (Blume et al. 2004).

4.1 *Geotechnical measuring devices*

Following measuring devices and systems which have already been tested in comparable projects are used (all measurements are conducted automatically and the results transmitted to remote points):

Electric devices for continuous measurement of settlement of the railway embankment near the high-ramp (see below); stationary, sequenced inclinometers for continuous, automatic measurement of horizontal deformation e.g. at the railway embankment (see below); mobile inclinometers for measuring horizontal deformation at the embankment base; pore water pressuremeters installed at different depths below the embankment; settlement measuring devices (pneumatic) installed at the base of embankment; earth pressure cells (pneumatic) for registering applied loads; inductive strain-gauges for measuring the strains in the reinforcing basal geosynthetics.

4.2 *Geotechnical measurement program for securing the railway and the A26-ramp leading to the heath land*

As mentioned above, the embankment ramp approaching the heath land was one of the most sensitive parts of the project (Fig. 1) due to the extreme height, very soft soils and the railroad which has to be kept in operation all the time.

The following special features need to be considered here:

- ensuring stability of the railroad trace (only about 20 m away),
- stringent limitations of its vertical and horizontal deformation under traffic,
- total height of embankment of up to 16 m incl. additional surcharge and settlement to achieve the planned height of 13 m after settlements,
- extremely soft soils,
- ensuring local and global stability of embankment at a low level of (especially) horizontal deformations of the subsoil due to the adjacent railroad,
- due to time constrains: achieving of maximum acceptable construction (heaping) velocity and short consolidation times.

The consolidation and deformation behavior of the system embankment/geosynthetics/soft saturated soil as well as the stability of the ramp leading to the heath land is monitored by means of a system described in section 4.1.

An important issue was the monitoring of the strains (and thus of the tensile force) in both geotextile layers to avoid an overstress (despite the design calculations) and to gain information about the expected differences in the behavior of the two identical layers (see section 3) of Stabilenka® 600 at a vertical spacing of 0.5 m. The strains were measured by specially developed, waterproof, inductive strain gauges based on the long-term experience with other similar projects with the same materials (although for lower embankment heights and geosynthetic strengths) (Alexiew & Blume 1999). The measurement is triggered automatically. The strain gauges are positioned at regular intervals across the embankment base.

5 SOME TYPICAL RESULTS OF MEASUREMENTS PERFORMED

Before and after every embankment fill layer was heaped, the measurement results were evaluated and displayed graphically. These results formed the basis for further actions in compliance with the observation method according to DIN 1054. The example herein presents typical results for the zone of the high ramp (Fig. 1).

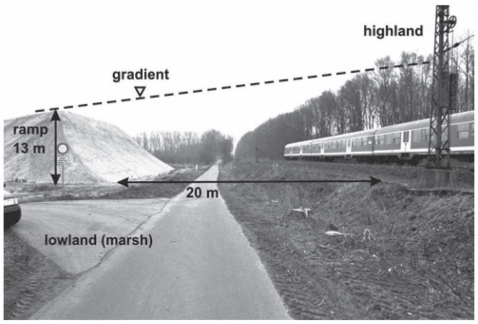

Figure 1. Embankment ramp, leading up from marsh to highland, and railroad.

The maximum settlement value so far was determined with 3.05 m. The maximum pore water overpressure in the soft layers below the strip-drains zone was 168 kN/m^2 before the end of the heaping.

In September 2005 this pore water overpressure decreased to 78 kN/m^2. That means a consolidation of app. 70% was reached compared to a consolidation of app. 85% in the soft layers above which are drained.

Figure 2 displays the strains in the two layers of geotextile reinforcement at a typical point near the centerline of embankment together with the embankment hight over time until a total thickness of embankment of 16 m (3 m settlement + 13 m above the terrain).

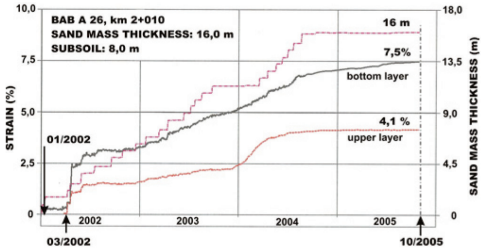

Figure 2. Total height of embankment and strains in the geosynthetic layers vs. time.

As expected (see section 3) the strains ε (say the mobilized corresponding forces) and thus the efficiency of the two layers are significantly different. For the bottom layer max ε = 7.5%, for the upper one 0.5 m above ε = 4.1%. The average amounts to ε = 5.8%, but not the average is the point: the bottom layer tends to be overstressed because of the "under-stressing" (not full mobilization) of the upper one. The corresponding stress-ratio (= mobilized tensile force/UTS) is about 60% for the bottom layer (a quite high value) and about only 30% for the upper layer. The stress-ratio is obtained from the product-specific isochrones (relation strain/time/stress-ratio (HUESKER, Blume et al. 2004)) of the Stabilenka® used. Clearly, it should have been better to use one layer of reinforcement with an UTS of 1100 kN/m (in accordance with the design stability calculations and as recommended, see section 3) instead of two layers with an UTS of each 600 kN/m each installed by the contractor. Despite the huge settlement of embankment, the vertical and horizontal deformations in the critical zone adjacent to the railroad remained in the range of some millimeters over the whole construction period and after more than a year of final consolidation until September 2005. At any time, there was no need to reduce the standard speed of trains of 120 km/h. Although the double-layer reinforcement solution is definitely not optimal (see above), the lateral constraint of embankment and soft soil seems to be sufficient with the geosynthetics used. Note that all construction stages and consolidation waiting times were controlled by the regularly evaluation of deformations, excess pore-water pressure and geosynthetic strains. All measurements will continue until 2008. In the authors opinion and based on comparative FEM-calculations not cited herein, a "stronger" single layer solution instead of the "weaker" double-layer solution should allow even quicker pre-loading and shorter waiting times with at least similar or even lower (lateral) deformations.

6 SUMMARY

The experience gained during the construction of the 11 km long first section of the Highway A26 on very soft saturated marsh soils including a very high ramp adjacent to a railroad results in following more important conclusions:

1. One time more, it is confirmed that construction of high embankments on soft soils using strong basal geosynthetic reinforcement is a successful technique.
2. It seems to be economically more efficient to use higher pre-loads and stronger basal reinforcement instead of EPS.
3. The solution with two "weaker" basal geosynthetic layers is less efficient and even to some extend risky in comparison with one single "stronger" layer, because in the two-layer solution the bottom layer is "overstressed" and the upper layer "understressed" (not sufficiently mobilized) at all construction stages.
4. The use of appropriate measurement devices and program including the strains in the geosynthetics allow to control the construction process in an optimal way and to gain useful information about the systems behavior to be used for next similar projects.

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