Two reinforced embankments on soft soils: Experience after more than twenty years

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ABSTRACT: Two projects of embankments on soft soils with high-strength basal woven geotextile reinforcement are described. Started in 1981 and 1986, respectively they belong to the first one's using preloading plus reinforcement for autobahns and highways in Germany. Projects, measurements and evaluation are shortly presented, including long term strain measurements and durability evaluation until 2009 (for 28 resp. 23 years). The present publication is a continuation of the work done for the same embankments in 1995 and published in 1998-1999. To our knowledge such a following up for more than twenty years is quite rare and is believed to be very useful.

1 INTRODUCTION

In Germany for the construction of highways and autobahns on soft soils the so called preloading method in combination with strong basal geosynthetic reinforcement is in the meantime a well established procedure. The development is closely connected to the development of geosynthetics in Germany: their reinforcement function is of critical importance.

Since the 70-ies, the Federal Highway Research Institute (BASt) has been involved in such projects. Measuring programs have been performed on large-scale test embankments focusing also on high-strength geosynthetic reinforcement (BASt, 2005, Blume, 1995 & 1996, Blume & Hillmann, 1996).

For the federal autobahn project BAB A 26, connecting the cities of Hamburg and Stade, a test embankment was built at the town of Rübke in 1981 ("Rübke embankment"), simulating a real autobahn section with high-strength basal reinforcement. The project being followed up until now (28 years) is reported focusing especially on reinforcement durability. Based on the first Rübke experience the entire highway B 211 at the town of Grossenmeer was built in 1986 comprising test sections under similar conditions using an analogous reinforcement but of higher strength ("Grossenmeer embankment"). For the first time strains of the woven were measured as well. The project being followed up until now (22 years) is reported focusing on long-term strains.

In 1995 and in summer 2009, after a 14-, resp. 28-years service period, parts of the high-tenacity polyester woven from underneath the Rübke embankment were exhumed and its durability evaluated. The most important findings are presented.

The present publication is a continuation of Blume & Alexiew (1998) and Alexiew & Blume (1999). More details of any type can be found in those publications. Due to the lack of place herein only the most important information as per 2009 is provided.

2 TEST EMBANKMENT AT RÜBKE (1981)

2.1 *Description of the full-scale test*

The embankment has a standard cross section of a German autobahn (Figure 1). Preloading height was 3.6 m. The stability calculations were performed according to DIN 4084 (Bishop) modified by reinforcement retaining force. Only low short- and long-term strains were allowed (short-term: at least 90 kN/m at 5% strain; long-term: max 1% creep strain in two years for 90 kN/m tensile force; ultimate tensile strength (UTS) of at least 200 kN/m and ultimate total strain < 10 %). A high-strength polyester woven geotextile (Stabilenka® 200) was selected to meet the requirements. The test comprised preloading with a subsequent consolidation, unloading and partial reloading (Figure 2). The woven was installed directly on the grass.

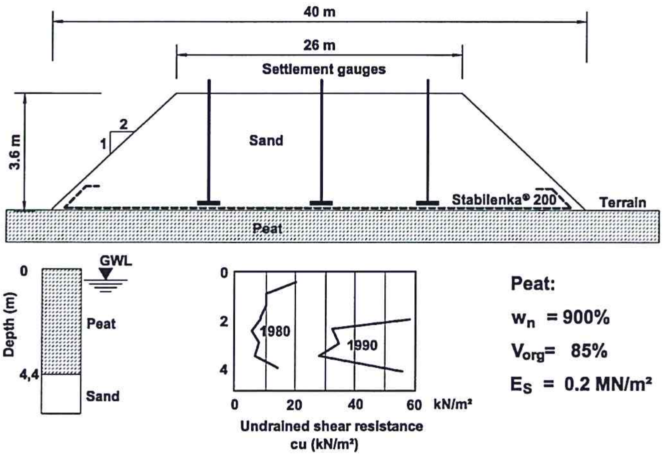

Figure 1. Full-scale test embankment at Rübke (not to scale)

2.2 *Course of the test and measurement results*

The settlement shows a significant drop in the settlement rate (Figure 2). The rate in 1998 was less than 0.5 cm/year with a decreasing tendency, thus the measurements were stopped in 1998.

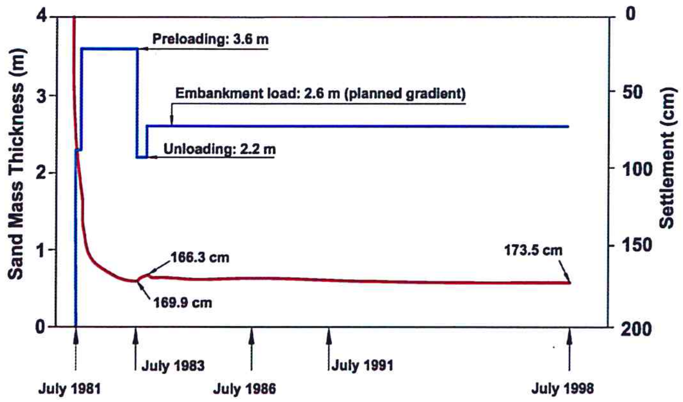

Figure 2. Load and settlement at Rübke from July 1981 until July 1998

The primary settlements after a quick consolidation amounted to ca. 1.1 m, the total ones to ca. 1.7 m. The horizontal displacements at the toe of embankment were max 18 cm in some depth and 12 cm on the surface. The increase of undrained shear strength c_U is shown in Figure 1. The average strain in the reinforcement derived from the settlement profile (no direct strain measurements at Rübke) is ca. 3 to 4%. For more details see Blume & Alexiew (1998) and Alexiew & Blume (1999).

2.3 *Assessment of the measurement results 1981-1985-1998*

The measurements confirmed the feasibility of the concept and construction procedure used. No failure occurred in the embankment and/or in the foundation soil. The high-modulus low-creep woven controlled also the lateral spreading/squeezing successfully. The experience was adequate to recommend in 1985 the solution for the entire new autobahn route BAB A 26 (Blume et al, 2006).

2.4 *Dynamic load tests*

Dynamic loading tests were performed in laboratory and in situ to investigate the influence of traffic loads on the settlements. No additional settlement is to be expected under traffic loads after primary consolidation. For details see Alexiew & Blume (1999) and Blume & Hillmann (1996).

3 HIGHWAY EMBANKMENT AT GROSSENMEER: TEST AND REFERENCE SECTIONS (1986)

3.1 *Description of the project*

Based on the positive results from Rübke the BASt recommended in 1986 the concept for the new federal highway B 211 at the town of Grossenmeer. The BASt performed measurements on two sections: the so called "test" (TS) and "reference" (RS) sections. The TS was a crash test (4.5 m of sand in 4 days with steep 1V:2H slopes). The RS was a standard one with 1V:3H slopes built up slowly over one year. For the first time direct strain measurements of the high-strength basal reinforcement by strain gauges were foreseen. Both TS and RS were integrated later on into the final structure. The weak subsoil consists of layers of peat and organic silts of 3 to 5 m. Stability calculations were performed according to DIN 4084 (Bishop), for details see Blume (1995 & 1996), BASt (2005) and Alexiew & Blume (1999). To achieve the preloading height of 4.5 m and the required FOS = 1.2 (global stability, temporary stage), a reinforcement tensile force of about 200 kN/m was required (Blume 1995 & 1996). For reasons of deformation compatibility with the compacted sand and to restrain lateral "spreading", max 5 % strain in the short-term and max 6% total strain (short-term plus creep) for several years for 200 kN/m were allowed. Based on the isochrones a high-tenacity polyester woven with an UTS = 400 kN/m and 10 % ultimate strain was selected (Stabilenka® 400). The highway (incl. of TS and RS) was opened to traffic in October 1990. The strain measurements continue until now (see below).

3.2 *Description of the tests*

The main aim of both the TS and RS was to provoke a "worst case" stress in the woven, selecting sections having particularly unfavourable subsoil conditions. Under the TS (crash test) extremely high reinforcement stress had to be generated. Nevertheless, failure had to be avoided because of the later integration in the standard highway embankment.

3.3 *Measurement results and assessment*

The most important results for the TS (crash test) are depicted in Figure 3 after a construction period of only four days. After that the strain rate decreased and after 2 months came almost to a halt.

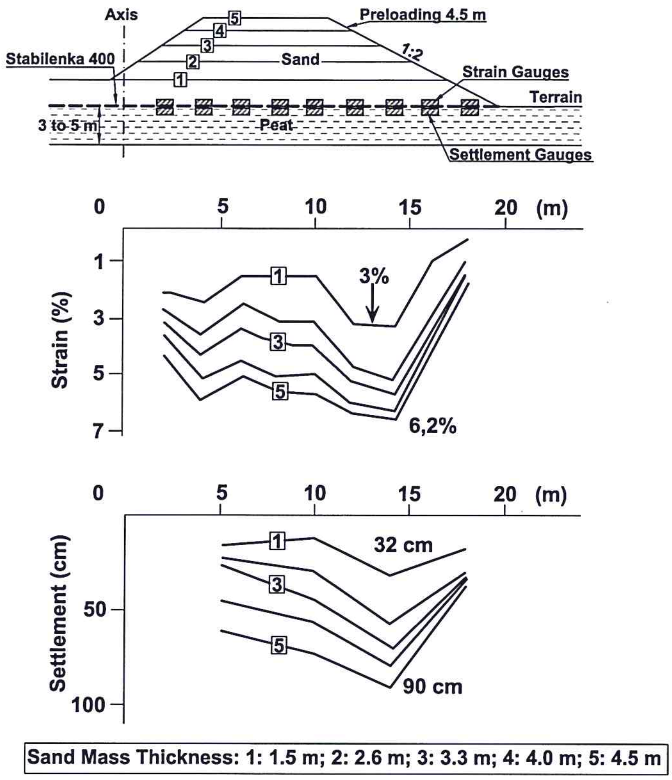

Figure 3. Grossenmeer "test section" (TS): construction stages, settlements and strains during the first 4 days in 1986

Note the unexpected "weaker spot" in the subsoil to the right provoking quickly a high local strain not foreseen in design. Slope failure was not observed for both TS and RS, but the lateral horizontal displacement at the toes became up to 40 cm for the TS approaching "squeezing". .The strains exceeded at some locations the 5 % (short-term) and 6 % (long-term) assumed in design. The stress ratio (tensile force/UTS) exceeded 50 % clearly. Such "surprises" have definitely to be considered by performing a more conservative design (see Alexiew & Blume, 1999).

For the RS the measurements continued after its integration into the final highway (at least once a year until 2001, then in 2004 and 2009, say over 23 years). Figure 4 shows typical results. The strains remain practically unchanged (ca. 7.3 %) from opening the highway to traffic until 2009 indicating that the woven is still under tension 23 years after construction. A precise evaluation is difficult; based on the short- and long-term (isochrones) stress-strain behaviour of the woven used (Stabilenka® 400), the short-term stress ratio amounts to ca. 70% for the first days decreasing to ca. 60% later on until now. Furthermore installation/compaction damage and environmental effects could have reduced the really available mobilized tensile force. For evaluation of environmental effects the best way is to exhume and analyze the same geotextile being under similar conditions for a long time. For this purpose the Rübke embankment offered a good possibility.

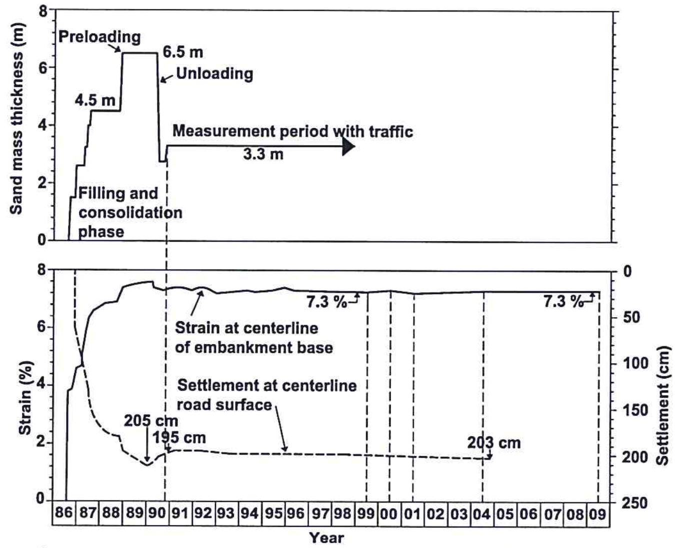

Figure 4. Grossenmeer "reference section" (RS): load, settlement and reinforcement strain over 23 years (1986-2009)

4 INVESTIGATION OF A HIGH-STRENGTH POLYESTER WOVEN AFTER 14 AND 28 YEARS EMBEDMENT IN SOIL (RÜBKE)

4.1 *Description of exhumation and tests*

Year 1995 (14 years in soil): In 1995 the BASt initiated the investigation of exhumed woven from Rübke because it is not possible to take samples from Grossenmeer.

In September 1995 (14 years after construction) parts of the high-strength woven were exhumed from the embankment base. The entire geotextile was lying below the terrain in the peat below the groundwater-level due to settlements. For more details about the exhumation see Alexiew & Blume (1999). Note, that abrasion and damage of the fabric could not be fully avoided. It was observed during uncovering that the woven was still under tension. This observation corresponds to the still available strain (tension) under the Grossenmeer reference section (Figure 4). In some places, grains of sand had penetrated the woven. Mechanical and chemical tests were performed and the main results published (Alexiew & Blume, 1999) demonstrating a high durability of the woven (average loss of strength: 1.5% in 14 years, say ca. 1 % per 10 years).

Year 2009 (28 years in soil): In 2009 the authors went back to Rübke for a new exhumation 28 years after construction. The same procedure and techniques were applied and more than 60 m² of material exhumed. All circumstances were the same as in 1995, and the same mechanical and chemical tests were performed.

4.2 *Evaluation of the results*

1995: It was found in 1995 that the loss of strength in the woven used was ca. 1.5 % in 14 years under tension in saturated soils (Alexiew & Blume, 1999).

2009: Yarn tensile tests are among others a good criterion for evaluation of strength loss due to environmental effects (Alexiew & Blume, 1999). In Figure 5 the stress-strain behaviour of the exhumed yarns from 1995 and 2009 (45 tests from three different areas) compared to the "virgin" material is depicted. The most significant fact in comparison to the data from 1995 is that no additional reduction of strength or tensile stiffness can be registered during 14 years more (1995-2009).

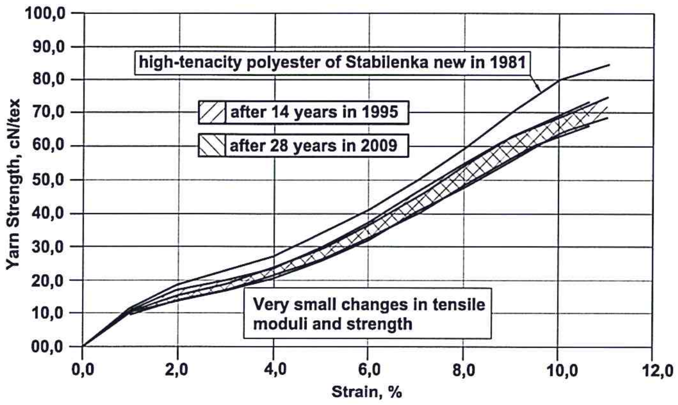

Figure 5. "Rübke"; specific yarn strength after 14 and 28 years in soil below groundwater level

The recent chemical and microscopic analyses confirm so far the same facts. Analyses of all factors influencing the tested yarn strength (for much more details see Alexiew & Blume, 1999) result into two possible hypotheses:

No 1. After some loss of strength the process has practically stopped after 1995.

No 2. The influence of scattering in the measured loss of strength due to environmental impact is comparable to the strength loss measured. Thus, the average strength reduction of ca. 1.5 % until 2009 similar to 1995 has occurred in fact over the entire period of 28 years (1981-2009).

In any case: the average loss of strength for the woven used - being still under some stress - due to environmental factors (embedment in soils below ground water level) amounts to ca. 0.5 % per 10 years. This seems to be one of the most important results from the Rübke test embankment until now.

FINAL REMARKS

Two projects of embankments on soft subsoil with high-strength woven basal reinforcement have been started in Germany: "Rübke" in 1981 and "Grossenmeer" in 1986. "Rübke" is a pure test embankment. "Grossenmeer" is an integral part of the federal highway B 211. High-modulus polyester woven is used with 200 kN/m and 400 kN/m UTS, respectively and < 10 % ultimate strain. Long term strength (durability) at "Rübke" and long term strains at "Grossenmeer" are being registered until now for 28 and 23 years, respectively. Summarizing some focal points:

Stability calculations according to DIN 4084 (Bishop) are correct enough, at least when high tensile force at low short- and long-term strain is mobilized to restrain deformations. The woven used proved to resist unforeseen overstressing. The reinforcement is still under tension after 23 years. Local weaker subsoil zones can easily result in reinforcement overstressing and/or failure tendency; it should be kept in mind when selecting safety factors. The reduction of strength and tensile moduli due to aging (environmental effects) is ca. 1.5 % in 28 years for the high tenacity polyester woven used, i.e. ca. 0.5 % per 10 years.

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