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# Long-term measurement on a road embankment reinforced with a high-strength geotextile

K.-H. Blume
*Bundesanstalt für Straßenwesen, Bergisch Gladbach, Germany*

**ABSTRACT: Large-scale experiment on the loadbearing behaviour of textile reinforcement below an embankment base area**

About 2 km of the national road B 211 (Bundesstraße) near Grossenmeer in Northern Germany had to be built in 1986 an embankment on soft subsoil. The embankment height is up to 4,5 m, the base wide up to 40 m. The subsoil layer, consisting of saturated non-consolidated peat and organic clay, has a thickness from 3 m to 5 m and is underlayered by sand.

Under these conditions and from technical, economical and ecological point of view it seemed to be the optimal solution, to reinforce the embankment base with a high-strength low-creep polyester woven geotextile.

The Federal Institution for Roads (BASt) introduced and performed a short- term (1986 - 1990) and additionally a long-term (1990 - 1996) measurement program to verify the used calculation methods and to prove the short-term and long-term stability, deformations and serviceability of the structure.

The short-term measurements were carried out an a trial embankment which was then integrated in the final road embankment due to the positive results of the first measurements, verifying the effect of the high-strength reinforcement and the assumptions made in the design stage.

The strains in the reinforcement, the settlements, the stresses and horizontal soil deformations were measured. During the short-term measurements (1986 - 1990) reinforcement strains between 3 % (edge) and 6 % (center line) were registered, last value corresponding to a stress ratio of about 50 %. During the long-term measurements after completion and consolidation and under traffic (1990 - 1996) no relevant settlements or strain / stress changes due to creep / relaxation of the still tensioned polyester reinforcement were registered. The complete system fulfils to the requirements for short- and long-term stability and serviceability. The next measurement session will be carried out in summer 1996.

The geometry and the mechanical properties of the embankment, the reinforcement and the subsoil will be shortly described as well as the building stages of the trial and final embankments and the computation assumption and analysis. The results of all the measurements over the whole 10-years period (1986 - 1996) will be comprehensively reported and presented in a proper form, allowing conclusions about the long-term behaviour especially of the polyester reinforcing woven geotextile.

## 1. Introduction

In construction of highways on subsoil with a low bearing capacity, increasing use is being made of a construction method in which the embankment is founded directly on the natural soil. This is the case in particular when a partial or complete exchange of subsoil is not possible for ecological, economic or other decisive reasons.

Due to the high compressibility and the generally very low initial shear resistance of the layers having a very low bearing capacity, the embankments can be constructed only with flat slopes and in several stages, construction being interrupted for various lengths of time to permit consolidation. Such a manner of construction is possible only if sufficient time is available for completion of the construction work. If the overfilling or preloading method is applied, adequate stability can often be achieved only by means of additional constructional measures. For increasing stability, geotextiles, for example, are inserted as reinforcement in the embankment base. Fabrics having a high tensile strength at a relatively low strain have proved to be effective for this.

Models describing the action of such fabrics proceed from the idea that the horizontal shear deformations occurring in the embankment base give rise to restraining forces in the fabric. The force transmission from the geotextile to the adjacent soil takes place by friction or adhesion, respectively.

The following report describes a large-scale experiment in which the effectiveness of a high-tensile fabric used as reinforcement below an embankment base under unfavourable conditions was measured. For comparison, the essential results of the measurements accompanying the construction work, which are necessary when the preloading method is applied, are also given.

## 2. Project description

In the period from June 1986 until October 1990, during construction of the B 211 - Großenmeer by-pass - between Oldenburg and Brake, the Federal Highway Research Institute made measurements accompanying the construction work. In addition, now that the federal highway has been completed, its deformation behaviour of under traffic loading is being further observed. Within the framework of this construction work and the measuring programs it entailed, a large-scale special experiment was performed with the agreement of the highway construction authority in Oldenburg-Ost, the aim of which was to observe the behaviour of the high-tensile fabric by means of strain measurements.

A length of around 2 km of the embankment of the B 211 - Großenmeer by-pass - was founded directly on the natural subsoil (surface of ground between 0.1 m above and 1.1 m below sea level) and thus on the soil layers of thickness 3 to 5 m, which consist of peat and highly organic coarse silts and have a low bearing capacity. Below these compressible layers is firm pleistocene sand, semi-densel to densely. The applicability of the preloading or overfilling method, which was selected for ecological and economic reasons, was confirmed by a soil-engineering foundation report prepared by the Federal Highway Research Institute, account being taken of certain execution criteria.

The magnitude of the preloading was established for the entire construction section as a sand mass of 4.5 m thickness. Depending on the degree of settlement, the raised gradeline is between 20 and 50%, which means that approx. 0.9 to 2.30 m should be removed after approximately two years.

When the preloading method was being executed, it was necessary that the following conditions be observed during the fill work to ensure a stable embankment foundation:

(1) Insertion of a high-tensile fabric on the embankment base (Stabilenka® having a tensile strength of 200 or 400 kN/m);
(2) Layer-wise placing of the fill material in dry operation with a total of five fill layers up to a sand mass thickness of 4.5 m
(3) Execution of a slope grade of 1:3 after placing of each fill layer;
(4) Observance of a two-month interruption in filling to permit consolidation after a sand mass thickness of 2.6 m had been reached;
(5) Monitoring of the consolidation and settlement behaviour by means of measurements accompanying the construction work

The settlement and consolidation behaviour of the embankment was monitored during and after completion of the construction work by means of measurements accompanying the construction work. Continuous checking of the safety against shear failure, of the degree of consolidation and of the associated overall settlements, and immediate intervention in the construction process in order to avoid shear failure damage and ensure the stability of two high voltage towers were the main aims of these measurements.

## 3. "FABRIC" experimental cross section

### 3.1 Aim of the experimental program

The main aim of the "FABRIC" experimental program consisted in achieving a high stress-ratio in the woven material „Stabilenka" by means of unfavourable ground conditions and specifications for the execution of construction work, and to record this procedure by measurements. It was imperative that possible shear failure damage also be avoided in the experimental cross section.

In addition, the long-term behaviour of the woven under a high tensile stress-ratio was to be studied. This required, however, that the measuring systems applied did not fail prematurely and that the measurements could be performed for as long as possible under traffic loading.

**3.2 Specifications for execution of construction work and description of the construction process**

For the "Fabric" experimental program, an additional experimental cross section with the designation "MQ 2A" was installed over a length of approximately 40 m of the new road section. Because of the approximately 4 m thick peat layer, the subsoil conditions in this area were, in terms of bearing capacity, particularly suitable for the large scale experiment. By means of strain measurements on the woven, which were complemented by pore water pressure, settlement and inclination measurements, the force borne by the fabric under particularly unfavourable stability conditions was to be examined.

The fill procedure was checked by means of measurements, account being taken of the stability recalculations. The construction work was to be interrupted if there were any signs of shear failure-like deformations.

Before the experiment was started, an approximately 1.5 m thick fill layer was placed over the entire construction width. It served as a preliminary embankment and site road so that the construction process on the road section would not be obstructed by the experimental embankment for the "Fabric" measuring program. The experimental embankment was subsequently filled over half the construction width to the specified final height (sand mass thickness: 4.5 m). This was done in only four days and without any interruptions in filling. The slope was constructed with an inclination of 1:2. It was imperative that a possible shear failure be avoided even with these specifications, which were considerably less favourable than those elsewhere on the construction section.

**3.3 Determination of the initial stability $\eta_A$**

The initial stability of the embankment with respect to shear failure was estimated by the slip-circle method (Bishop) in accordance with DIN 4084.

For the initial stability calculations, values of $c_u = 7$ and $9\ kN/m^2$ and $c_u = 20\ kN/m^2$ were used respectively for the undrained shear resistances of the peat and the upper soil layer. These values were determined by vane shear tests in the field.

Because the subsoil consolidates due to load acting upon it, and its shear resistance consequently increases, an initial stability of $\eta_A = 1.2$ at the time of filling was regarded as adequate.

A geotextile having the trade name STABILENKA® 400 was used as reinforcement in the embankment base. This high-strength woven geotextile consisting of polyester yarns has a maximum tensile strength of around 400 kN/m at a breaking strain of high tenacity around 10% (manufacturer's specifications). The force-strain curve behaviour of the fabric is approximately linear.

Due to the structure of the calculation program used, it was assumed in calculation of the initial stability $\eta_A$ that, in the event of shear failure-like deformations, the fabric exerts a restraining anchoring force ($A_h$) on the slipping mass. Accordingly, a state of failure was assumed ($\eta_A <$ 1.0 without restraining force) in which the fabric adapts to the slipping surface The restraining forces initially assumed in the calculations must, in practice, be borne by a fabric which has the required tensile or tear strength. The force assumed in the calculations cannot be taken equal to the maximum tensile force, that is to say a safety factor must be applied to the tensile force of the fabric.

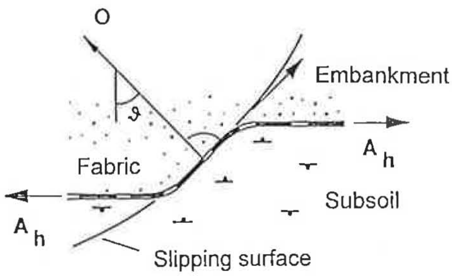


Figure 1: Assumed position and action of the fabric at state of failure

It has proven to be effective to establish the fabric tensile force as a function of the fabric strains to be expected or on the assigned soil deformations respectively, and to assume a fabric strain of $\varepsilon \leq 5\%$. A maximum permissible stress-ratio of approximately 50% of the tensile strength was thus calculated for the fabric to be used.

The results of calculations with no fabric and with fabric strains varying in the range 1% to 6% respectively are represented in Figure 2.

Without fabric, shear failure would have been expected with the second fill layer (2.6 m). In the final phase of filling, stability's in the range $\eta_A$ = 1.2 could be achieved only with fabric strains between 5 and 6%.

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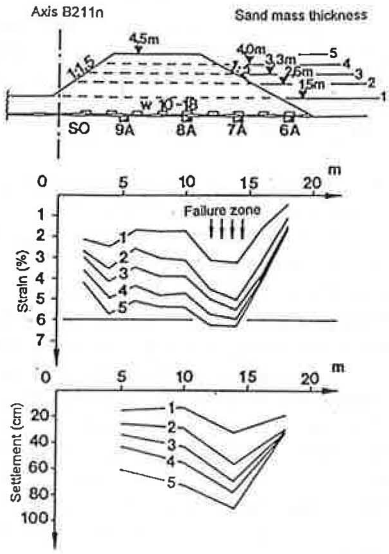


Figure 2: Initial stability's $\eta_A$ with and without fabric

On the basis of these recalculations, a high stress-ratio of the reinforcing woven and relatively large horizontal deformations verging on a state of failure are to be expected.

### 3.4 Investigations in the metrological laboratory of the Federal Highway Research Institute

In the metrological laboratory of the Federal Highway Research Institute, various experiments were performed on sample pieces of the above-mentioned fabric, and the following part tasks completed:

(1) Determination of the relationship between tensile stress and strain;
(2) Establishment of the tensile strain;
(3) Checking of the functionality of the fabric strain measuring device developed in-house.

When the stress/strain behaviour was being examined, the stresses were increased so slowly that temporal effects could be ruled out. The planned publication in the reports series of the Federal Highway Research Institute will contain an explanation of the extensive laboratory experiments and the results obtained.

On the basis of the recalculations, a fabric strain of 5 to 7% was assumed under the intended embankment load. For safety reasons, 10%, as specified by the fabric manufacturer, was assumed as the maximum strain.

### 4. Aims of the "Fabric" experimental program

The main aim of the experimental program was divided up into the following sub-aims:

(1) Achievement of an extremely high degree of loading (stress-ratio) of the fabric installed
(2) Checking of the assumptions made in calculations relating to the initial stability $\eta_A$
(3) Preparation of criteria for use of the strain gauges developed
(4) Preparation of criteria for application, and specifications for execution, of the preloading method on highly settlement-sensitive subsoil
(5) Metrological monitoring of the long-term behaviour of the woven geotextile and of the measuring devices used
(6) Testing of new measuring instruments and measuring methods for stress and deformation measurements
(7) Comparison of the strain and deformation behaviour in the „Geotextile" experimental cross section (MQ 2A) with the results from the comparative cross section (MQ 2)
(8) Scientific evaluation of the measurement results and findings from, in particular, the long-term observations of the geotextile and of the deformation behaviour of the road under continuous loading.
(9) Documentation and publication of the results of the experimental program
(10) Preparation of recommendations for selection and economical use of high-strength geotextile
(11) Incorporation of the findings in technical standards

### 5. Selection and arrangement of the measuring instruments in the "Geotextile" experimental cross section

For the observation of the peat subsoil,

- settlement measurements in the embankment base area;
- pore water pressure and settlement measurements in the quarter-points of the peat layer;
- slope measurements for determination of the horizontal deformations, and
- ground water measurements were performed.

The strain measurements were performed on two fabric lengths in the experimental cross section (MQ 2A) and on one fabric length in comparative cross section (MQ 2). On each strip, nine inductive strain gauges are installed at intervals of 2 m.

For comparison of the strains of the fabric with the associated vertical deformations of the embankment base area, nine pneumatic settlement gauges (Glötzl measuring system) in the area of two fabric strip lengths equipped with strain gauges were used in the experimental cross section (MQ 2A), and five pneumatic settlement gauges beneath the fabric strip length were used in the comparative cross section (MQ 2).

This measuring system has the advantage, inter alia, over bench marks measurement that the measuring gauges and measuring leads can be laid below the embankment base area long before commencement of embankment construction. Construction work is not obstructed. An essential advantage, however, is the automatic measured-value acquisition, which can be preset and registers each of the required construction phases. Geodetic settlement measurements, which are time-consuming, require many staff, and are weather-dependent, can be dispensed with.

The geotextile was supplied in rolls of 5 m width and was laid, with an overlap of at least 30 cm between adjacent lengths, transversely to the embankment axis on the grass cover, which had previously been mowed.

For cost reasons, the following specifications were to be observed for the laying work:

(1) Reduction of the laying length by 2 m (ends of the fabric lengths in each case 1 m from each toe of the slope).

(2) No turning back of the fabric lengths over the first fill layer.

Installation took place with a special merolling device.

The strain gauges were preadjusted in a frame, clamped on the fabric, subsequently released from the frame, and covered with a piece of fabric. The zero points were determined directly before filling work proceeded.

## 6. Summary representation and assessment of the measurement results

### 6.1 Measurement results during embankment construction and consolidation

Immediately after the preliminary fill of 1.5 m in one of the two measurement profiles of the experimental cross section (MQ 2A), an increase of around 3% in the fabric strain and an associated vertical deformation of 32 cm below what was to be the centre of the slope were determined. In this region, a local zone of weakness of the subsoil was also indicated, which became more pronounced after the second fill layer and led to premature activation of the fabric (Figure 3).

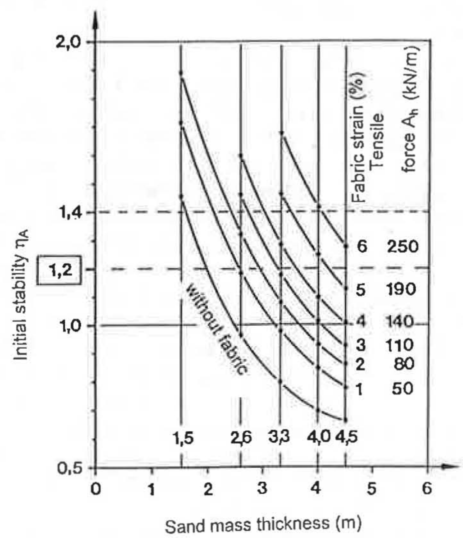


Figure 3: Settlement curves and strain distributions during filling

In due course, the geotextile strain in this zone rose to a maximum value of 6.2%. The settlements were around 90 cm. As a result of the decreasing load, and because of the absence of anchoring of the fabric, the strains in the vicinity of the embankment toe decreased considerably.

In the second measurement profile of the experimental cross section, approximately equal maximum strains of around 6% and deformations of 84 cm were measured. These, however, occurred below the embankment crest from the beginning of embankment construction onwards and decreased uniformly in the directions of the two slopes.

After completion of embankment construction in the experimental cross section (MQ 2A), the strain increased less rapidly and came almost to a standstill at all measuring points after two months. In the subsequent consolidation phase of approximately 25 months, the measurement curves tend asymptotically towards a maximum final strain of around 6.7 to 6.8% below the slope and 5.7 to 5.9% below the centre of the embankment.

The results make clear that the high degree of loading effected only a very low creep of the high strength polyester. Also, the continued development of the settlement curve does not indicate any substantial increase in strain in the fabric.

The large initial settlements in the filling phase indicate that the mobilisation of the fabric can be attributed almost exclusively to lateral movement of the sand fill. The magnitude of the lateral movement of the subsoil is included as an instantaneous settlement component in the vertical settlement of the embankment base area. In addition, the initial settlements already include first primary settlements due to consolidation of the subsoil, which can be derived approximately from the pore water pressure measurements.

The strain measurements thus confirm indirectly that, after completion of embankment construction, the lateral movement of the embankment has also come to a standstill.

It can be seen from the measurement curves of the pore water pressure gauges, which are situated in the centre of the peat layer, below the centre of the embankment and below the slope, that there was a considerable decrease in excess pore water pressure during the interruptions in filling, which can be attributed to the initially good permeability properties of the peat.

The instantaneous settlements during the filling phase, which were calculated approximately from the pore water pressure and settlement measurements, are confirmed by the results of the inclination measurements. The measurement profile of the four inclinometers was situated immediately adjacent to the strain measurement profile in which the greatest strains and vertical deformations in the slope region were measured.

The subsoil deformations there were already so great after the 1.5 m thick preliminary fill had been placed, that the inclination measuring probe could no longer pass through the inclinometers N 3 and N 4, which are located 2 m and 6 m respectively inside the slope. A check with the device for determining the ground water level revealed that the measuring tubes had not actually been sheared off but were very severely bent as a result of the lateral movements. It was likewise not possible to measure the inclinometer N2, which was arranged 3 m behind the embankment toe, once the second fill layer (2.6 m) had been placed.

In accordance with the strains in the fabric and the vertical deformations of the embankment base area, the greatest increase in deformation occurs when the first fill layer is placed. The changes in horizontal movement then decrease and are, for every fill layer, approximately equal at between 5 and 7 cm. On the surface, the displacement reaches a maximum value of around 37 cm. The check measurement made five days after completion of filling shows that the changes in deformation occur only at the time of load increase, then rapidly decrease and come to a standstill.

The inclination measurements document the mutual dependence of the horizontal movement of the subsoil and the increase in strain in the fabric. As a result of the very poor bearing capacity of the peat, the embankment/subsoil system soon reaches the limit state of failure. This limiting state is indicated here less by formation of classical shear failure, but rather by the inception of a displacement failure or bearing-capacity failure of the subsoil respectively, in which the peat is pressed out laterally and the embankment body sinks into the subsoil. This failure behaviour is additionally promoted in the large-scale experiment by the relatively low thickness of the compressible layer.

The lateral displacement of the subsoil of approximately 40 cm gives rise to restraining tensile forces in the reinforcing woven geotextile, which lead to stabilisation of the system and thus to stagnation of the displacement process. The fabric can, however, develop its stability-increasing effect fully only if considerable displacements are accepted and the shear resistance limits of the subsoil have been reached or exceeded.

### 6.2 Measurement results of the long-term measurements

After conclusion of the consolidation and lying time of the preloading embankment of around 25 months in the experimental cross-section (MQ 2A) and around 15 months in the comparative cross section (MQ 2) for a sand mass thickness of $h_S$ = 4.5 m, and of a further lying time of the two measurement cross sections of around 20 months for a sand mass thickness of $h_S$ = 6.5 m (additional loading), stripping of the preloading embankment was begun in these areas in May 1990. The construction work up to completion took around 6 months. The federal highway was opened to traffic in October 1990. The subsequent long-term measurements were performed in both measurement cross sections for around three years until November 1993. At this time, it was necessary to remove the measuring containers housing the automatic measuring and recording installations, and the measuring cabinets for the strain measuring points in the experimental cross section (MQ 2A). It was possible to keep a measuring cabinet in the comparative cross section (MQ 2) operational. It was thus ensured that it was possible to continue measuring the strain behaviour of the fabric and the deformation behaviour of the carriageway in this measuring section.

A comparison of the strain and settlement behaviour as a function of the load for the measuring period from 1986 to 1993 is represented in Figure 4.

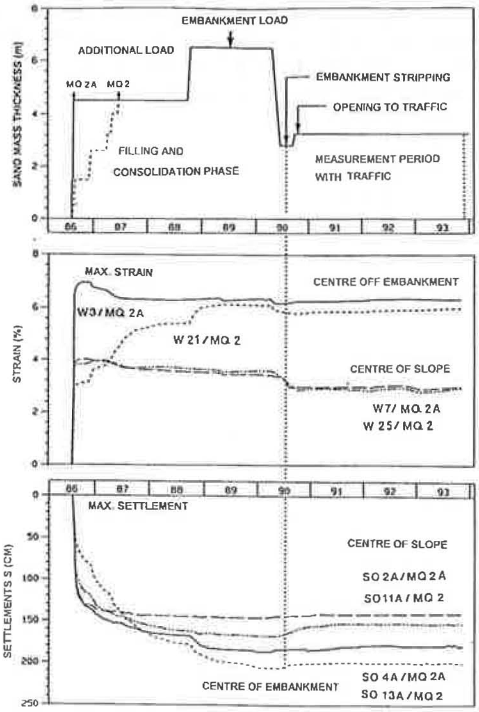


Figure 4: Comparison of the strain and settlement behaviour as a function of the load (1986 to 1993)

The maximum strain measured in the experimental cross section (MQ 2A) below the centre of the embankment (W 3/MQ 2A) in October 1986 of around 7% decreases to around 6.2%, that is to say by only 0.8%, at the time of stripping in May 1990. In the first year after stripping, the strain increases on average by around 0.1% to around 6.3% and remains almost constant in 1992 and 1993.

The measuring instruments below the centre of the embankment in the comparative cross section also exhibit the same strain behaviour. As a result of the substantially longer loading phases, the maximum strain of around 6.1%, which is approximately 0.9% less than that in the experimental cross section (MQ 2A), is not reached until May 1989, and decreases by around 0.3% to round 5.8% due to stripping of the embankment in May 1990. From this point onwards, the instruments in both measuring sections show almost identical behaviour and reach a measured final value of around 6%. In contrast to the experimental cross section (MQ A2), the additional load in October 1988 was registered by the measuring gauge W 21/MQ 2.

Below the centre of the slope of the embankment, the strain behaviours of the two comparable strain gauges W 7 (MQ 2A) and W 25 (MQ 2) are identical. The measured maximum strain decreases from around 4% in September 1986 by around 0.6% to around 3.4% in June 1990. In contrast to a slight **strain increase** below the centre of the embankment, a slight **strain decrease** of around 0.3% to around 3.1% is registered below the centre of the slope until November 1993.

If the strain behaviour in the two measurement cross sections is compared over the whole experimental period of around 7.5 years, the relative percentage decrease in strain, with respect to the measured maximum value after the final load is reached, is around 9% below the centre of the embankment in experimental cross section (MQ 2A), and approximately 2% in the comparative cross section (MQ 2). A substantially higher relative strain decrease of approximately 26% was, however, determined below the centre of the slope in both measuring cross sections.

The measured strain is almost constant after unloading in spring 1990 and from opening to traffic in October 1990.

## 7. Summary

The complex force-strain behaviour of the high-strength woven has been examined many times, account being taken of laboratory parameters. Until now, it has been possible to make only rough estimations of the behaviour under continuous loading and under practical conditions. In determination of allowable force assumptions, the new "Information sheet for application of geotextiles and geogrids in earthwork in highway construction" (1994 edition) makes do with assuming reduction factors which yield a "design strength". In this way, in stability analyses, the different safety requirements can be verified. The economic aspects must wait for the time being. The investigations on the B 211 - Großenmeer by-pass - were intended to help fill these gaps.

The force-strain behaviour was examined not only during the consolidation phase of the compressible soil but far beyond it, during the stripping phase, during construction of the pavement, and into the operational phase which commenced four years ago. At the same time, the soil parameters were continuously documented, with the consequence that the respective interrelationships can be recognised at any time. The measuring systems used in the process functioned faultlessly over the entire measuring periods of 7.5 and 8.5 years respectively. Consequently, it was an still is possible for the long-term behaviour of the fabric under high loading to be measured.

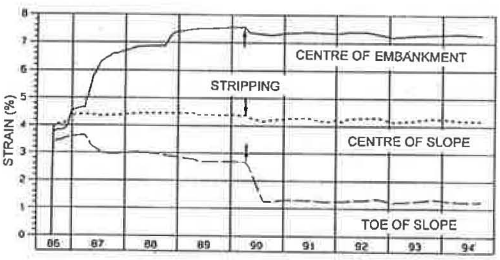


Figure 5: Development of strain from 1986 to 1994 in the comparative cross section (MQ 2)

The strain measurements on the fabric have contributed substantially to the assessment of the bearing behaviour of the combined system of embankment body and high-strength woven geotextile. This also applies for the assessment of the final long-term stability. Thus it is possible that the forces borne by the reinforcement can be taken into account in future designs for permanent structures, possibly using a reducing safety facto.

Maximum strains of between 6.8 and 7.6%, and maximum settlements of the subsoil, which has a low bearing capacity, of 190 to 205 cm were measured. Relative to the maximum tensile strain of the fabric examined, which is given as 10% by the manufacturer, the degree of maximum loading of the fabric in November 1993, thus after around 7.5 years, is still approximately 65%.

From approximately 1991, the measuring instruments exhibited almost constant strains. These results were confirmed by further measurements made in the comparative cross section (MQ 2) until September 1994 (Figure 6). The results can be interpreted to the effect that at this degree of loading of the fabric, neither creep nor a strength reduction, as for example due to hydrolysis, has taken place. The further planned long-term measurements and the intended tests on pieces of fabric dug up should certainly be able to help clarify these questions additionally.

The large-scale experiment for determination of the load-bearing behaviour of a geotextile reinforcement below an embankment base area using the measurements accompanying construction work has contributed decisively to the federal highway B 211 near Großenmeer being able to be constructed in a cost-effective manner with the preloading method on subsoil having a low bearing capacity. The performance

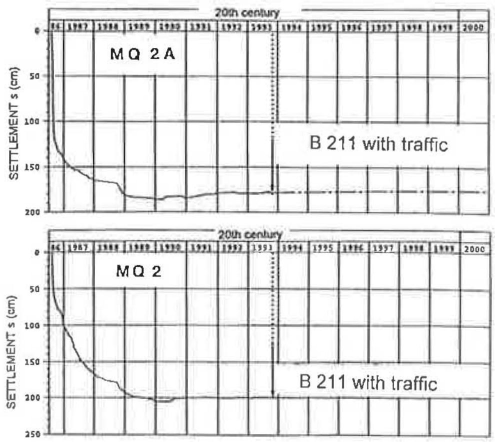


Figure 6: Results of the measured and forecast settlements up to the year 2000 (ten years after opening to traffic).

conditions was applied for the first time in Germany. The previously available settlement measurement results and a settlement forecast in Figure 6 show that no long-term deformations worthy of mention will result, and thus confirm the successful application of the method.