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EMBANKMENTS ON SOFT SOIL

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Soft soils have a low bearing capacity and a high compressibility. If the loading process is so slow, that the soil can consolidate under each loading step, the embankment can be constructed in safe conditions. Consolidation means dewatering, what depends on the water permeability of the soil.
Geotextiles as separation layers separate a coarse grained fill from a fine grained subbase, allows the rise of water from the subbase into the fill. Both soils can react unchanged after the laws of soil mechanics. The separator equalises and helps against local subsidence. Geotextiles or geogrids as reinforcement can hinder a slipform failure. The reinforcement of foundations by one or more layers equalises the conditions and allow the foundation of small bridges and culverts as integral part of an embankment. Geosynthetic drains as vertical drains accelerate the dewatering of soft soils and accelerate the consolidation.

1 INTRODUCTION

Soft soils represent a great variety of soils. They have common a low bearing capacity and a high compressibility. On the one end of the scale are pure organic soils with organic debris like peat, on the other end fine grained sediments like clays and silts and in between there is a mixture of these basic elements. The angle of friction is low and also the cohesion, depending on a mostly high watercontent. Under load the pore pressure rises and the internal friction lowers down. But when the water flows out and the overpressure decreases down to a balance with the load, the internal friction of the soil rises up and there can be a safety- stadium as before: in balance between the porewaterpressure and the load. That means: the consolidation under load gives a higher amount of safety. The underground can fail, when the charge of an embankment is so high, that the overpressure of the porewater liquifacts the soil. But if the porewater can ooze out and the soil can consolidate, the safety of the system develops according to the load.

So the reaction of soft soils under load is a question of balance between the velocity of loading and the time, which is necessary for dewatering and consolidation. This can be checked by measuring the porewater pressure and the settlement.

In german technical regulations the basics for the use of geosynthetics for this purpuse are given [1], [2], [3], [4]. In the following chapters few examples of realisation are shown.

2 GEOTEXTILE AS SEPARATION LAYER

On a test embankment in the Horloff valley near Giessen in Hessen/Germany the following points had been checked [5], [6]:

- the amount of consolidation under embankments of 0,5 m / 1,0 m / 1,5 m / 2,0 m / and 3,0 m height
- the influence of the velocity of fill
- the influence of compaction by static and by vibration rollers
- the influence of site traffic with vehicles with axle - loads between 10 t and 45 t
- the influence of consolidation on the bearing capacity of the subsoil
- the influence of a geotextile
- the embankment - height which is needed, to hinder the roadtraffic to stimulate new consolidation - settlements in the subsoil.

The subsoil was a 3 m layer of silty soil with a high amount of organic material and a high water content. The shear strength measured by vane-shear tester was about 10 to 20 kN/m², after stripping of the embankment 5 years later, the shear strength was 30 to 50 kN/m², increased by consolidation. In order to examine the load behaviour of embankment and subgrade, the embankment was loaded by a truck next to the settlement gauges and the deflection under load and the recovery on load removal, were measured by levelling. Figures 1 and 2 shows the results.

FIGURE 1 & 2: It can be seen that at embankment heights of 2.0m and 3.0m no significant deflections are achieved. At heights of 1.5m however, deflections are measurable, and these become very significant at heights of 1.0m and 0.5m. A distinct difference in deflection was registered between bays 2 and 9, the bays with and without geotextile. This was increased by the considerable difference in the depth of the water table in the two bays. The water level was much higher under the area with geotextile. This goes hand in hand with greater sensitivity to load. The load-unload- deflection curve in Figure 1 under a 45 t single axle, but after consolidation shows approximately no difference between the two bays.

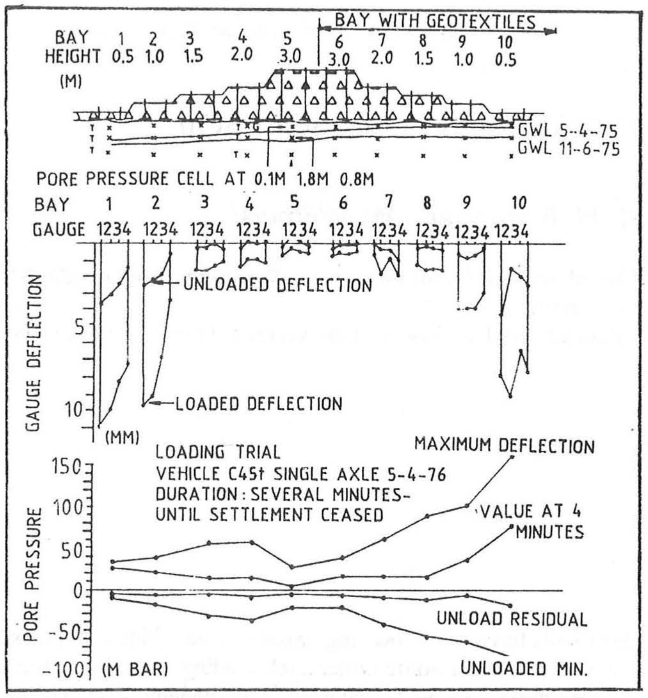

Figure 1: Trial Embankment in Horloff Valley-Plan, Loading Trial.

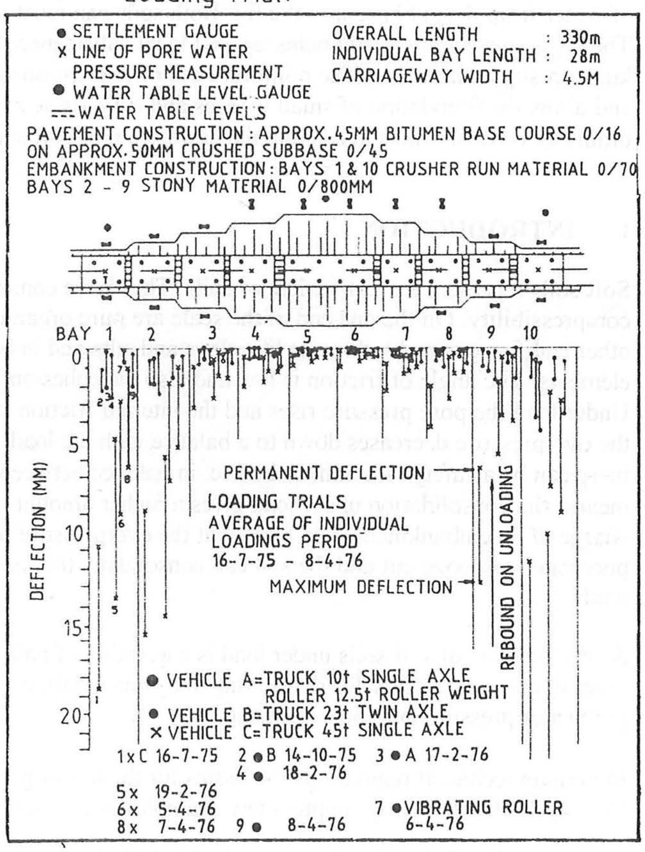

Figure 2: Trial Embankment in Horloff Valley-Layout, Loading Trials.

It is not evident, whether this is the influence of the geotextile or in first the success of consolidation. A study of the settlement readings at different times (figure 2) shows, that the readings vary widely with the axle load and the values of settlement at constant axle load, reduced with time: result of consolidation [5]. The remarkable increase of shear strength shows the strengthening efficiency of consolidation.

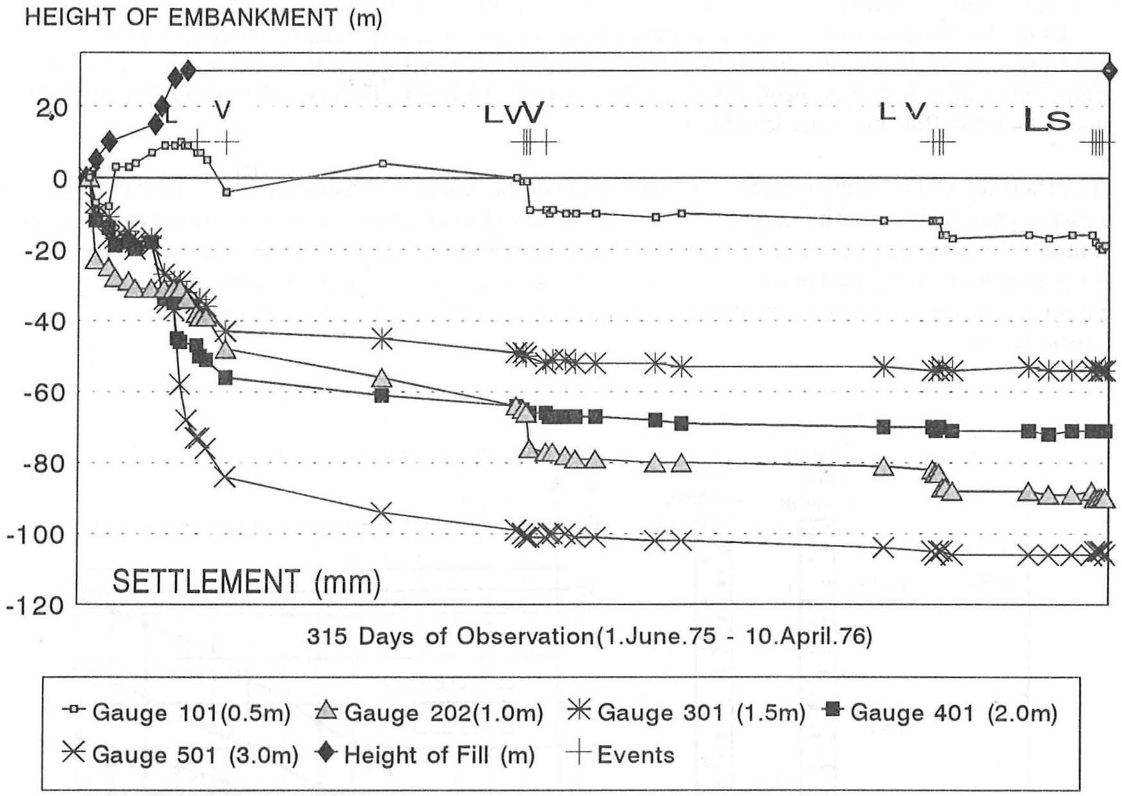

FIGURE 3: Trial embankment in Horloff Valley: settlement with time
heights of embankment bays: 0.5 m / 1.0 m / 1.5 m / 2.0 m / 3.0 m - over 2.5 m organic silt
Trial events:V / L / S: Passes of V = heavy duty vibratory compaction roller / L = lorry 14 t and 25 t / S = heavy lorry 65 t

The main results of the site trial are:

- The settlements takes place very quick after each layer of fill (figure 3)
- the settlements had been accelerated by vibration compaction
- the porewater pressure curve proofed the quick reaction of porewater on load, vibration and impact of the vehicles passing
- the increase of groundwater on both sides of the embankment during fill and compaction demonstrated the groundwater flow to the side and not only vertical
- under the 0,5m - layer local shear failure developed under the wheel-ruts of site traffic
- under the 1,0m layer the subsoil showed irregularities during fill - perhaps by local subsidence, but consolidated after a while
- the 1,5m - layer was after consolidation stable enough for the traffic with axle - loads of 10t to 15t and had only little reaction on the 45t - axle of the heavy lorry
- the geotextile did not influence the amount of settlements but equalised it locally
- the geotextile layer (a thermally bonded nonwoven and a splityarn-woven laid one atop the other) did not reduce the rutting under wheels but protected against a total subsidence
- in all sections the bearing capacity of the subsoil increased with consolidation.
- the proof was found by vane shear testing.

3 ACCELERATION OF SETTLEMENT BY GEOSYNTHETIC VERTICAL DRAINS

Much higher are the problems in regions with several meters of peat or fine grained soils with high content of organic material and very high water content. Large field test showed the efficiency of vertical drains to accelerate the consolidation in these conditions, with low risk of failure, because the overpressure of porewater can slacken by the drains. There are a lot of different types of strip drains, used as vertical drains. They all together use geotextiles as a filter, wrapped around a flat core of synthetic material ore a pipe, which lets flow the water lengthways.

The efficiency can be seen in figure 4 by comparison of the degree of consolidation measured by porewater pressure gauges [7]. The Highway A 27 near Cuxhaven in Lower Saxony/Germany crosses over a length of nearly 3 km an area with alluvial sediments like peat and „Klei", an organic silty clay. Different types of vertical drains were used in comparison with bays without vertical drains. All drains worked well. Especially in soils with low permeability, they accelerate the dewatering and by this mean the consolidation.

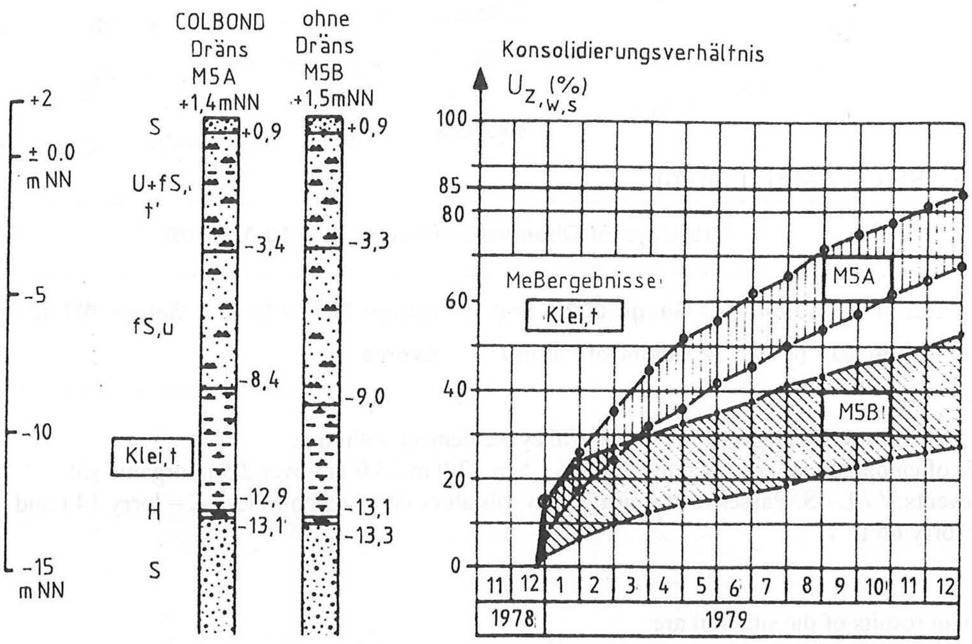

FIGURE 4: Time for consolidation of a Klei (organic silty clay) with vertical drain **(M5A)** and without drain **(M5B)** under the same load (embankment height 6 m). U (%) is the ratio of consolidation, measured by porewaterpressure gauges at different depths.

4 SAFETY AGAINST FAILURE BY GEOSYNTHETICS AS REINFORCEMENT

If the system is not safe against slipform - failure, a reinforcement can help. But a reinforcement cannot hinder or reduce consolidation settlement or the squeeze out of the soft soil under the embankment load in the whole. If the squeeze out is a local event by local overload, a reinforcement can reduce the partial settlement and stop the squeeze out and the beginning subsidence.

After the experience with the observation of several reinforced embankments [7] [8], in 1986 in a part of the B 211 - by-pass Grossenmeer near Oldenburg in Lower Saxony, a test-section was installed [9]. An embankment of 4.5 m height over 4 m to 6 m peat was reinforced by a polyester multifilament woven with a tensile force of 400 kN/m at 10% elongation.

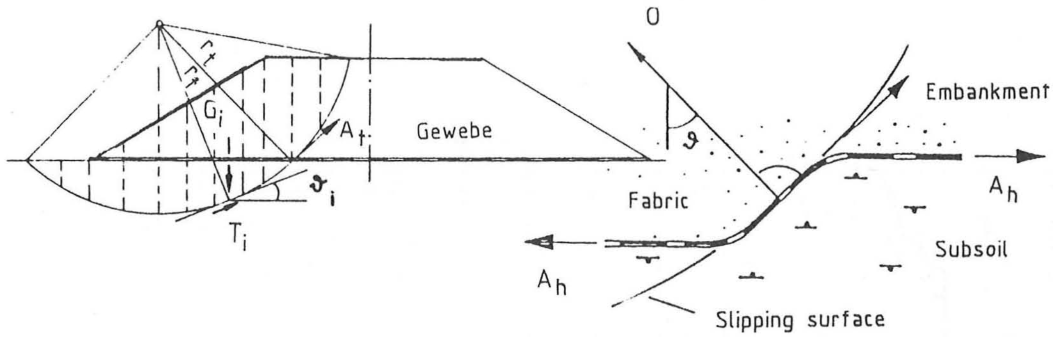

Figure 5: The reinforcement acting as horizontal force in the calculation of a slipform failure [8]

In a well-instrumented part of the embankment the load was augmented so quick, that a prefailure deformation developed in the 4 m deep peat in the ground. It was a combination of partial squeeze out, measured by horizontal displacement gauges and a beginning slip circle [10]. There were installations for the observation of settlement, horizontal deformation, porewater pressure and strain in the woven fabric. The observations have shown:

- The deformation of the soft soil activated strain in the woven fabric by elongation of 6% to 7%, which means 60% to 70% of the strain at maximum load.
- The activated force of the fabric stabilised the system.
- The fabric did not creep under the load.
- The strain in the fabric is stable over 10 years of observation, also under traffic load.
- There is no hint of important effect of creep or of hydrolyses for these years.

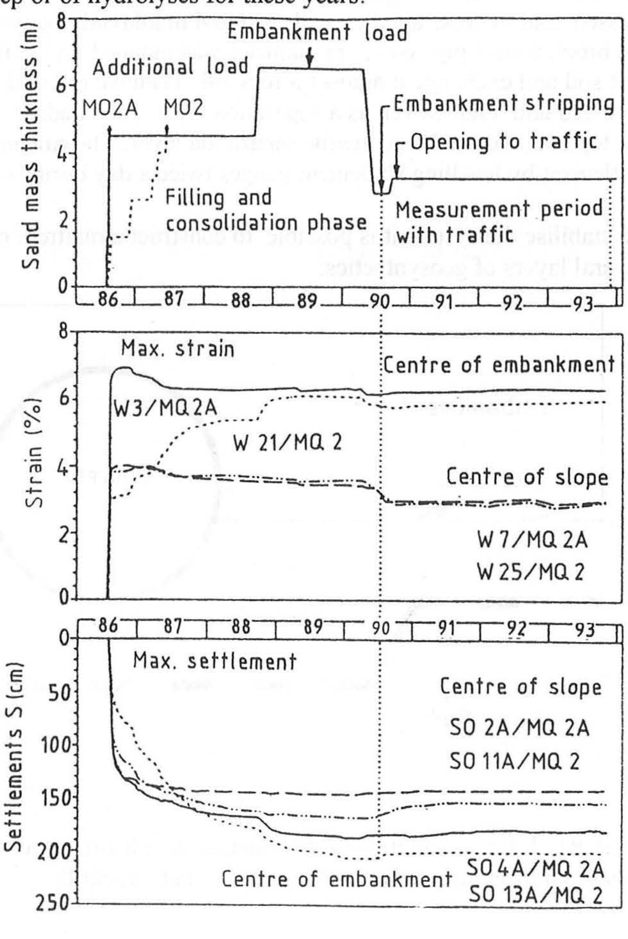

FIGURE 6 [7],[9]:
The history of the embankment for the B211 bypass Großenmeer between 1986 and 1993. The test section MQ 2A with the very quick loading process shows a much higher strain in the reinforcement than the section MQ 2, where the filling process was slower with several consolidation phases. The strain in the reinforcement is in both sections more or less the same after the end of consolidation. The stripping of the overload reduced the strain only in a little amount together with only a small heave by this reduction of load of the embankment.

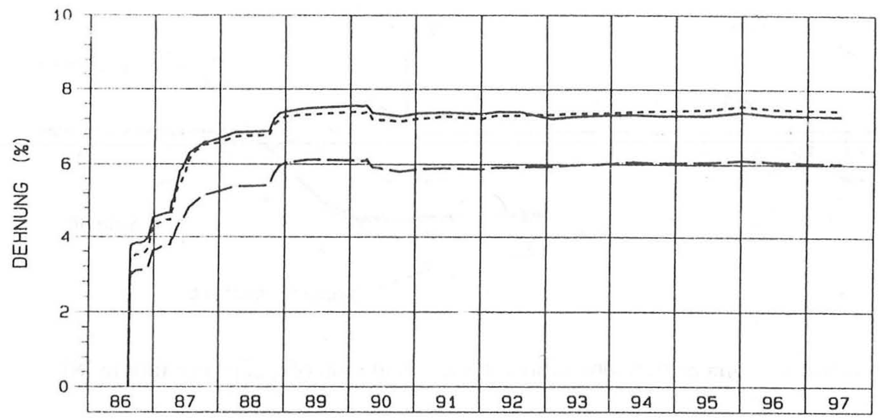

FIGURE 7: Elongation (%) of woven reinforcement layers, same as Figure 6, continued until July 1997. There is no remarkable change with time, after consolidation took place.

5 GEOSYNTHETIC - REINFORCED FOUNDATION FOR BRIDGES AND CULVERTS

Small bridges like culverts, in some cases can be constructed as integrated part of an embankment. To reduce deformations arriving from settlement-differences, the reinforcement of the foundation by one ore more layers of geofabrics can be a good solution [4]. Good experience we have made with flexible constructions like corrugated steel pipes. The road K 446 Allendorf - Hasselbach near Weilburg in Hessen, had to cross a valley with 3 m to 4 m alluvial organic silts by an embankment of 6 m height. For the brook a steel pipe of 2.5 m diameter was planned. In the first step it was planned, to excavate all the soft soil and exchange it against a rock fill. Than we reduced the excavation to a total of 1.0 m below the pipe and laid a nonwoven as a separation layer. Also under the embankment, which was constructed over the top soil, we used a geotextile separation layer. The embankment were constructed under control of settlement by levelling settlement gauges twice a day during construction and later on in longer distances.

To stabilise the system it is possible, to construct a mattress out of a soil with high friction, reinforced with several layers of geosynthetics.

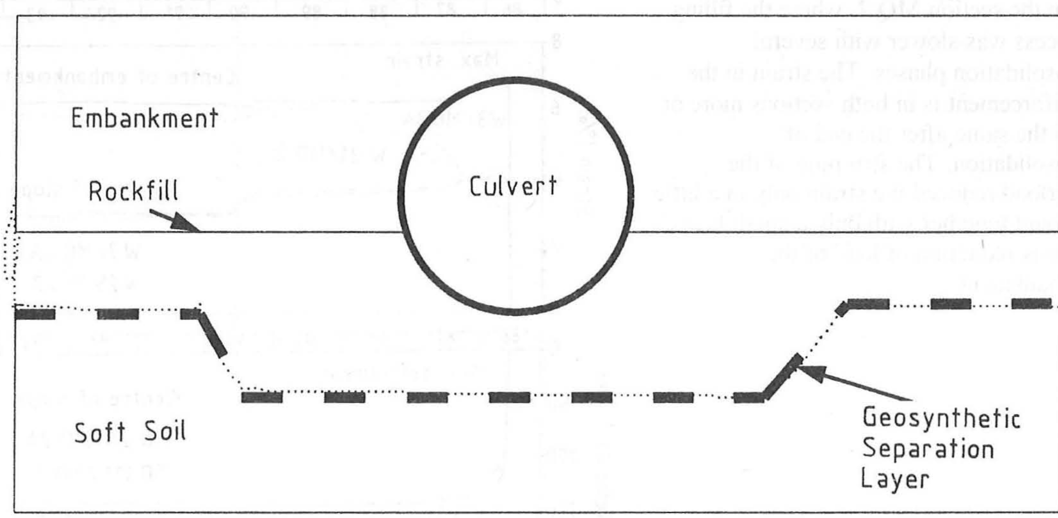

FIGURE 8: Cross - section of the foundation of a culvert as part of an embankment on soft soil: Geotextile as a separation layer between the soft soil and a rockfill

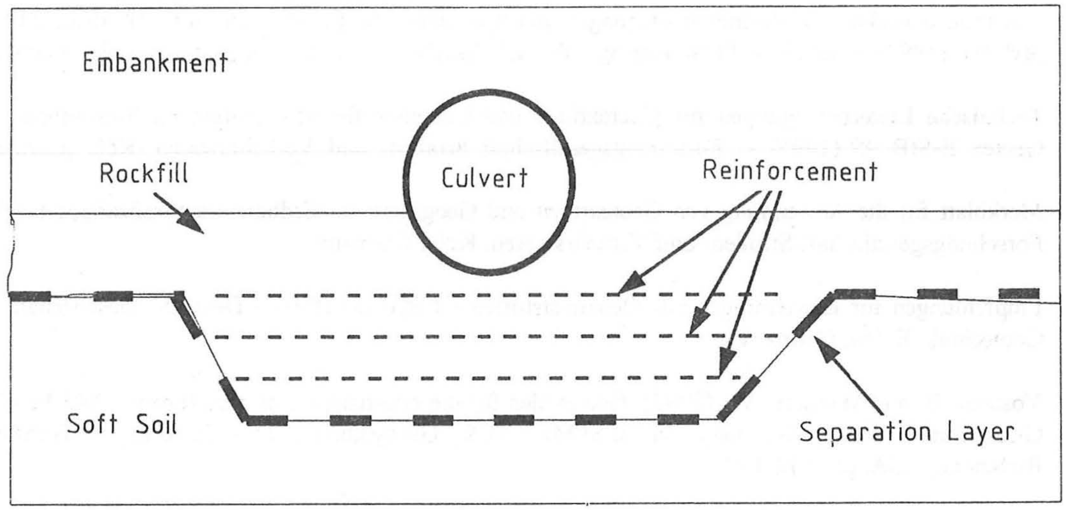

FIGURE 9: Foundation of a culvert as part of an embankment on soft soil: strengthened by geosynthetics as reinforcement layers in a cushion foundation [4]

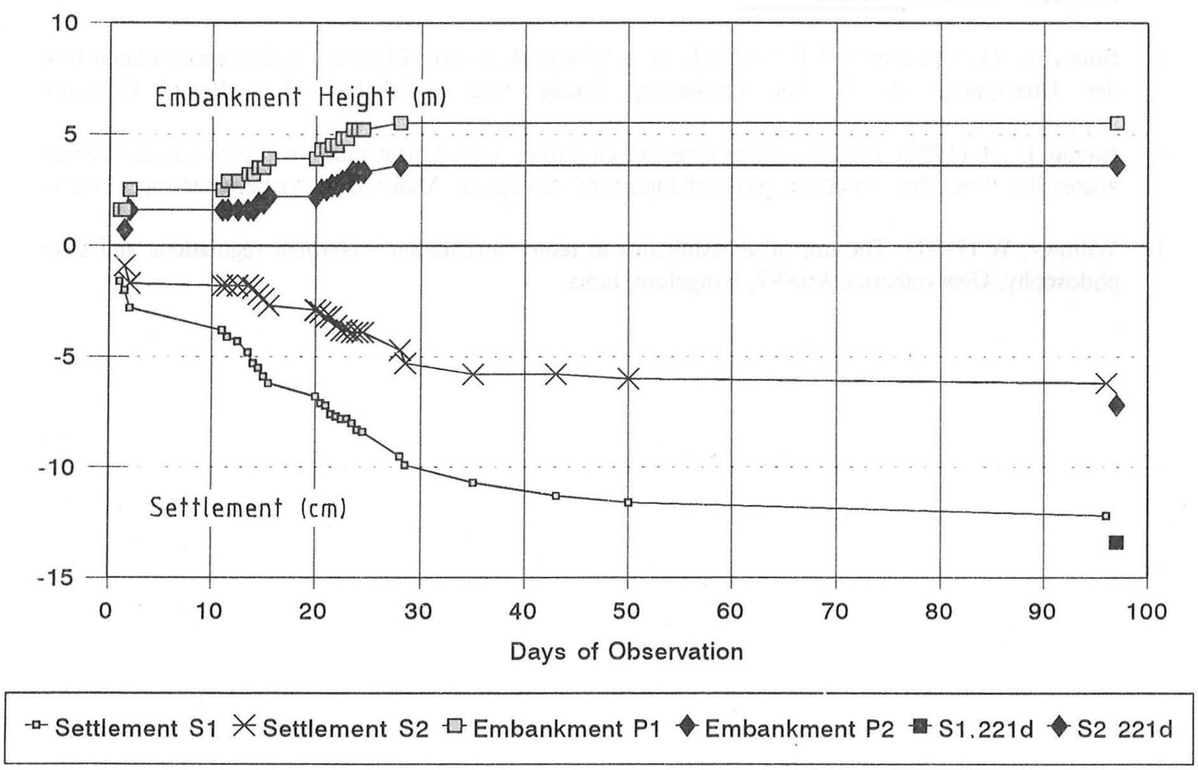

FIGURE 10: K 446 Allendorf: embankment with an integrated culvert: settlement during construction of the embankment and afterwards. There was no deformation of the culvert, critical for ist function. The settlement was a rather quick reaction on each step of embankment fill.

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