Drainage and Filters
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Third International Conference on Geotextiles, 1986, Vienna, Austria

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SYPHONING EFFECT OF GEOTEXTILES
HEBERWIRKUNG VON GEOTEXTILIEN
L'EFFET SIPHON DES GEOTEXTILES

It will be shown that geotextiles, in particular nonwovens, bonded by needling, are capable of transporting water in their plane. It will be stressed that these geotextiles are capable of conveying water over an elevated level due to a syphoning effect.

The syphoning effect is demonstrated in laboratory testing and the results are depicted as a function of time; consideration has also be given to external loads.

The results found through laboratory testing could be of great importance for the construction of railroads. The syphoning effect was tested by means of an accurate scale model of a railroad construction. The geotextile was used as a separation layer between a subgrade consisting of fines and the aggregate. The actual loading conditions on a main line were simulated by applying cyclic loadings.

1. Introduction

It is known that certain geotextiles can transport water in their plane. This function is termed drainage and the system in which it occurs is designated a vertical or horizontal drain, depending on the principle orientation of the installed geotextile.

It is not obvious that these same geotextiles can also carry water over a higher level to a lower level than that of the hydrostatic level. This effect is referred to in the following discussion by the simplified term syphoning effect.

The syphoning effect opens up some interesting applicational possibilities especially for needle-punched nonwovens in road and railway construction.

This function is important in the building of all-purpose rural roads and service roads, especially where the road must be built over water-saturated soils of low load-bearing capacity and for which geotextiles are frequently laid directly on the turf without the construction of a subgrade.

However, even where a subgrade is built, the possibility cannot be excluded that during the construction and subsequent compacting of the embankment, hollows will be formed, in which water can collect over time and thereby impair the load-bearing characteristics of the substratum. In such cases geotextiles that can transport water along their plane and also function as a syphon can extract the water from these hollows (Fig. 1).

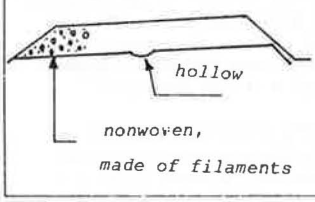

Fig. 1

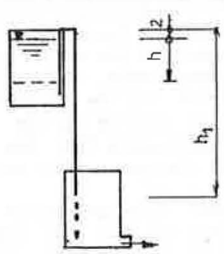

Fig. 2

In this application geotextiles, in addition to the drainage of existing hollows, also by their separating function prevent the migration of part or all of the embankment material into the substratum and, vice versa, the rise of substratum material into the embankment as a result of static and dynamic loading.

Newby (11) reported on long-term observations of track installations in which the ballast had been laid directly on clayey substratum. In addition to the separating effect, drainage in the plane of the geotextiles played a significant role in removing water from the ballast-substratum plane. Although these results cannot be applied directly to road construction because of the high water-permeability of the base course and the difference in dynamic loading, they nevertheless provide qualitative information for this application.

2. Explanation of the syphoning effect

Liquid can be removed from a vessel with the liquid at hydrostatic level through an arched tube (syphon) by passing over a level higher than the water level to a level that is lower than the water level, provided the partial vacuum at the peak height of the syphon tube does not attain the vapour pressure of the boiling liquid or that of the gases contained in the liquid (13). To place a syphon in operation the air must be removed, i.e. the tube must be filled with the liquid. In practical applications water can be raised to a height of about 8 m by this method.

No doubt geotextiles cannot be set equal to closed tubes in the sense described above. In contrast to a closed tube the surface of geotextiles is in contact with the ambient air. The transport of liquid in the plane of the material is effected through capillary spaces between the fibres and is obstructed by crosswise fibres. The shape and size of these spaces depends on the method of manufacture used. The existing drainage cross section is reduced by the obstructions and laminar flow does not occur.

In a study conducted at the Franzius Institute of Hannover University (3) the explanation of the syphon effect of geotextiles by analogy with the operation of a water-filled tube was placed in doubt and explained as follows: "The water in a syphon tube acts in response to gravity and therefor tends to flow out both sides (suction tube and fall tube). If air is admitted at the apex of the tube, the water column quickly narrows and is pinched off. Since the water column at the apex of a closed syphon tube cannot narrow, however, a partial vacuum forms at this point and the water flows through the syphon to emerge at the end of the fall tube. In geotextile syphons narrowing of the water column at the syphon apex is not prevented and hence a partial vacuum is not formed. On the other hand the water column at the apex can narrow to only a certain minimum cross section, because the interaction of adhesive forces (adhesion of water to the textile fibres through molecular forces) and cohesive forces (attraction between water molecules) prevents the water column from pinching off at the syphon apex. The maximum suction height is determined solely by the interaction of gravitational, adhesive and cohesive forces. For this reason it appears conceivable that the maximum suction height h depends on the geotextile raw material and the porosity".

Both explanations of the syphon effect are mentioned here because both are conceivably correct. In structures in which the geotextiles lie between layers of material that are more dense than the textile material, the explanation of the syphon effect on the basis of a water-filled tube is conceivable. In open systems, as in the laboratory studies described below, the explanation based on the interplay of gravitational, adhesive and cohesive forces is probably correct.

3. Laboratory studies of the syphon effect (14)

3.1 Open system without external load (Fig. 2)

One end of a water-saturated strip of geotextile material was placed in the upper vessel, which was filled with water. The vessel was filled only to 2 cm below the rim to prevent the water from overflowing when the end of the strip was submerged in it. The other end of the geotextile strip hung free in the air, but this end had to be below the surface level of the water in the vessel. Owing to the force of gravity water began to flow from the longer, free end of the strip, thereby transporting water out of the upper vessel. With time the water level in the upper vessel fell until the suction head h reached a certain maximum level. In the trials described below 11 different geotextiles were tested in this way (Table 1

In preliminary trials the influence of the width of the test strip on the syphoning effect was investigated. In these trials strips of geotextile No. 3 were used in widths of 2 cm, 10 cm and 20 cm. In all cases the same maximum height h was determined. A width of 10 cm was chosen for subsequent trials.

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Table 1

No.	mass g/m²	thickn. mm	raw material	bonding method	type
1	150	1,7	PES-filament	by needling	nonwoven
2	200	2,2	"	"	made of
3	300	3,1	"	"	filaments
4	360	3,3	"	"	"
5	500	4,3	"	"	"
6	200	2,3	PP-filament	"	"
7	300	1,2	PP-staple + PES reinf.	thermally	nonw. made of staple fiber reinforced
8	140	0,5	PP-filament	"	nonw. made of filaments
9	175	0,8	PP/PE (core/ sheath fil.)	"	"
10	720	2,3	PP-slit-tape	woven	woven slit tape
11	200	0,8	PE-Monofil.	woven	woven

The height h_1 was varied, and from h_1 = 21 cm to h_1 = 71 cm it was increased by 10 cm steps. The results presented in Fig. 3 for test strip Nos. 3 and 6 show that within the range investigated the height h_1 apparently had no effect on the maximum suction head. For the other test strips the same results were obtained but are not presented here.

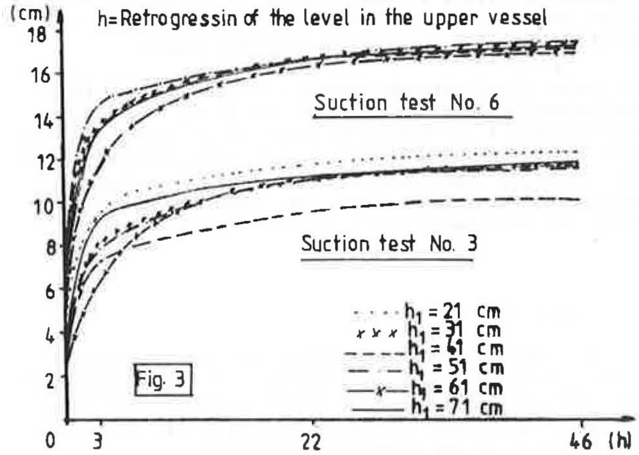

Fig. 3

Fig. 4 shows the maximum suction head h of the 11 test geotextiles for h_1 = 41 cm. From the curves it can be determined that for test strip Nos. 1 - 6 the maximum suction head was achieved after about 46 hours, while for type 7 the final value of 16.3 cm was not reached until 106 hours after the start of the test. The thermally bonded nonwovens Nos. 8 and 9, the polypropylene fabric of split tape No. 10 and the polyethylene monofil woven fabric No. 11 exhibited no syphoning effect.

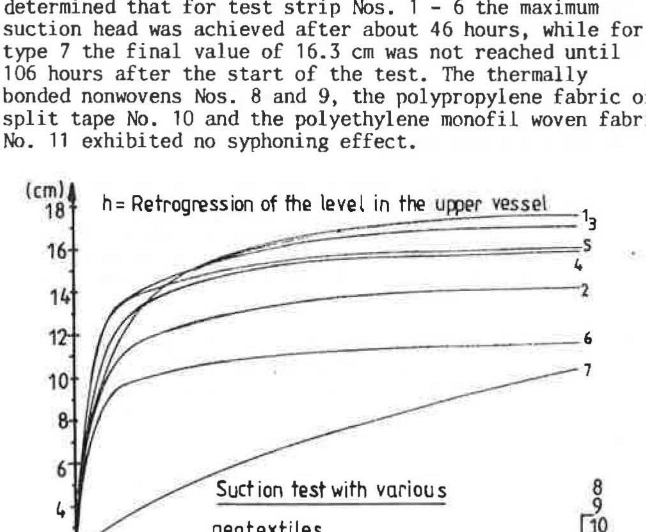

Fig. 4

The higher maximum suction head of specimen No. 2 (nonwoven of polyester filament) in comparison with specimen No. 6 may be influenced by the difference in the fibre surface.

3.2 Open system, variation of supported length and external load

In the laboratory experiments described under 3.1 the horizontal distance between the lower and upper test vessels was unvaried and small. In the possible applications of geotextile syphons for road and railway construction, water must be transported over greater distances while the fabric is subjected to external loads. Studies (3) were conducted at the Franzius Institute of Hannover University to investigate the effects of supported length and external load on the syphoning effect.

The studies were conducted in stages. In the first stage the supported length of a 10-cm-wide geotextile strip lying in a U-profile section was adjusted to 30 cm, 60 cm and 90 cm without an external load being applied.

The experiments showed that the syphoning effect is reduced as the supported length is increased.

Next the dependence of syphon performance on hydraulic gradient was investigated. Flow between 2 points can occur only if there is a hydraulic gradient $i = \Delta h / \Delta L$ between these points. The experiments described above showed that with increasing suction head and supported length (= transport distance) syphon performance declines. This means that in both cases the hydraulic gradient decreases. When the maximum suction head is attained, flow stops; the hydraulic gradient has decreased to zero. Equal hydraulic gradients resulted in equal flow rates. Within the range $\leq h_{max}$ (maximum suction head), a given geotextile of constant width with a defined geotextile strip length ΔL and a given difference in height Δh, will yield the same syphon performance as a strip with $2\Delta L$ and $2\Delta h$. In the range of hydraulic gradients $i > 0.06$, there is a linear relationship between hydraulic gradient and syphon performance; Darcy's law applies. The nonlinearity in the range $i < 0.06$ represents the initial phase of the gradient-flow relationship.

Further experiments were conducted to examine the influence of static loads ranging from 2 kN/m² to 200 kN/m² (corresponding to a load of an approximately 10-m-high embankment) on syphon performance. Additionally the supported length and hydraulic gradient were varied. Here only the results obtained with the ® TREVIRA SPUNBOND type 11, 500 g/m² is presented.

Fig. 5 shows the experimental arrangement. The load is applied by the same method as that used by the Franzius Institute (2) in measuring the coefficient of water permeability in the plane of the geotextiles. For comparison the area under load was also doubled from 165 cm² to 330 cm².

The graph (Fig. 6) shows that syphon performance declines as the load is increased. The rate of the loaded to the unloaded area also affects performance. When the loaded area is doubled, syphon performance declines by a certain amount, which is virtually constant at all load levels except zero load. This means that the influence of the loaded area on syphon performance is greater at high than at low loads.

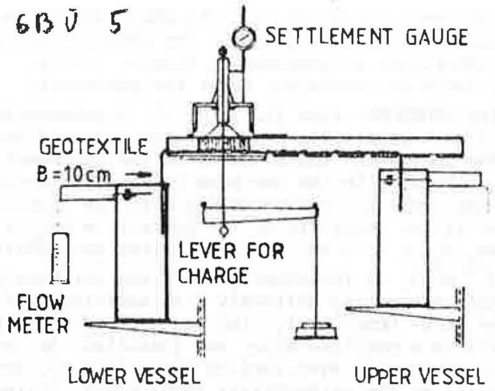

Fig. 5

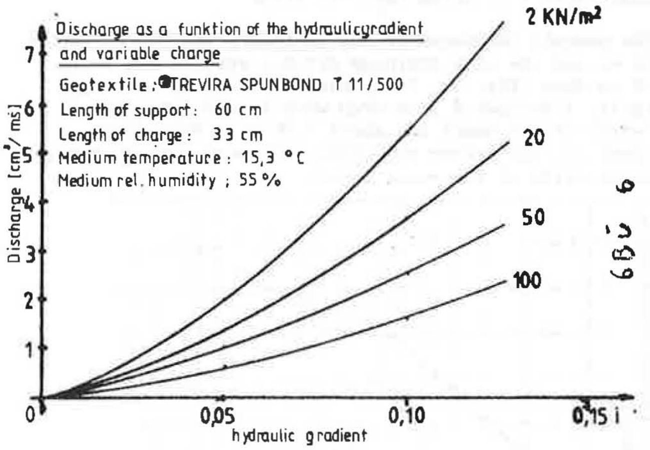

Fig. 6

The syphoning effect of a geotextile in an earth construction is affected by a number of factors which were not taken into account in the laboratory studies described above: soil contact, dynamic load and whether a system is partially or completely closed (total obstruction of the air supply from below and partial obstruction from above).

Since it appeared too expensive to conduct trials with the required instrumentation in the actual working environment, studies were conducted on a 1/3 scale model of a railway substructure cross section at the Institute for Soil and Rock Mechanics at Karlsruhe University (7).

4. Experiments on a 1/3 scale model of the cross section of a railway substructure (Fig. 7)

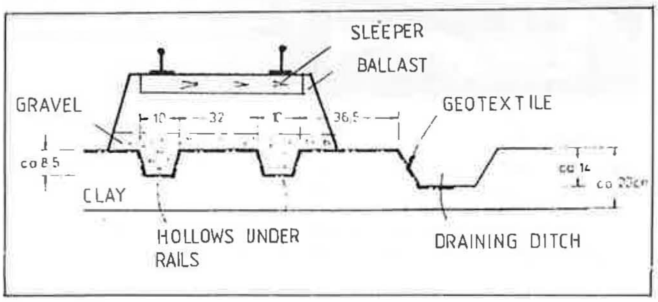

Fig. 7

The trials were conducted in a pit which was filled with sand. With this arrangement the elastic behaviour of the substratum in response to dynamic traffic loading could be simulated. Under the geotextile ® TREVIRA SPUNBOND, type 11, 200 g/m², a geomembrane was laid as a separation layer between the sand and the soil. The choice and installation of the earthwork proved difficult. On the one hand no material could be found that complied simultaneously with the requirements of filter stability of the geotextile ($d_{50} \geq$ 0.015 mm, $d_{90} \geq$ 0.15 mm) and the desired permeability ($k \leq 10^{-8}$ m/s); on the other hand it was not possible to install marly clay uniformly with admixtures of silt, sand and rock. Hence marly clay was uniformly mixed with silt in a positive mixer and installed. As is seen from the grain size distribution curve (Fig 8), the soil satisfies the permeability requirement. Filter stability was ensured by the application of an additional 1-cm-thick layer of silt.

The overall thickness of the earthwork was set at about 20 cm and the side drainage ditches were chosen to be 14 cm deep (Fig. 9). To simulate subsidence under the rails, 2 hollows 8.5 cm deep were formed. The overall length of the model was about 1.90 m. A Plexiglass sheet was set across one cross-sectional face to permit observation of the water level.

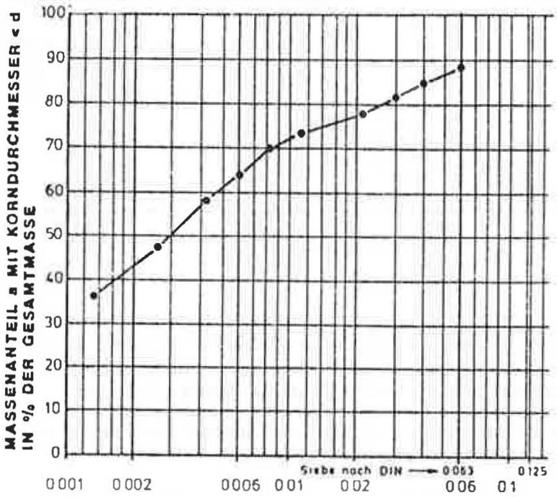

Fig. 8

Fig. 9 Fig. 10

On the substratum prepared in the manner described the geotextile was then laid (Fig. 10).

A total of 11 different trials (Table 2) were run on 3 different systems (Fig. 11). In trial Nos. 1 to 5 the hollows under the rails were filled with water and syphon performance was determined. The influence of the water level in the drainage ditches on the syphoning effect was also examined. In trial Nos. 6 to 8 the hollows were filled with gravel and the geotextile was covered with an about 2-cm-thick layer of gravel. In trial Nos. 9 to 11 with the 1/3 scale ballast structure the passage of trains was simulated by 4 hydraulic presses (Fig. 12). The load amplitude was adjusted to correspond to a 20 ton axel load moving at 120 km/h.

As preliminary trials had shown, the effects of seepage and evaporation were negligibly small. In all trials thorough wetting of the geotextile over its entire surface was of great importance.

The experimental results are shown in the graphs (Figs. 13 to 15). The fall in water level in the hollows is plotted as a function of time. For trials in which the drainage ditches were emptied some additional curves for the amount of water Q a function of time are shown.

Table 2

Nr.	Type of test	Remarks
1	without draining the ditch	wetting of geotextile not optimal
2	as No 1	-
3	the ditch being drained	-
4	as No 1	-
5	as No 3	-
6	the ditch being drained	wetting of geotextile in some places not optimal
7	as No 6	-
8	as No 6	-
9	the ditch being drained train load is applied	-
10	as No 9	-
11	as No 9, load released after 1/2 h.	

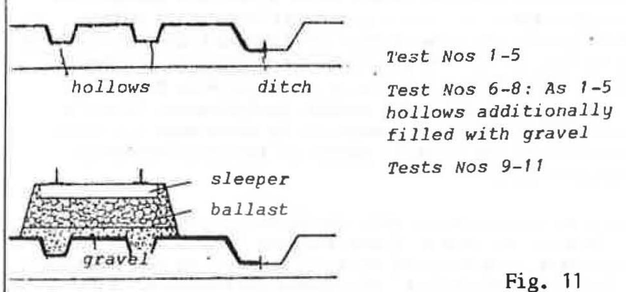

Fig. 11

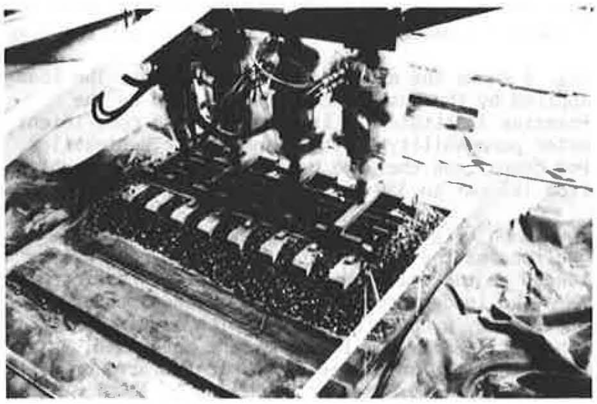

Fig. 12

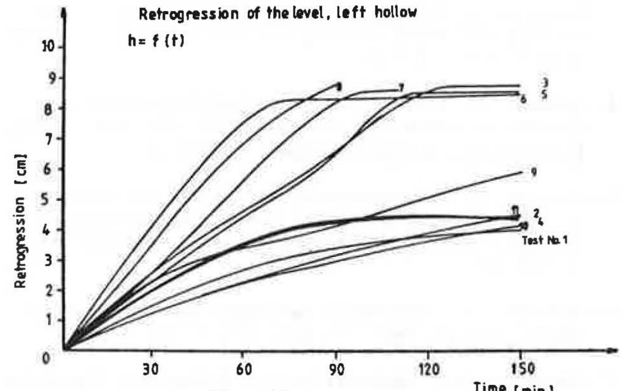

Fig. 13

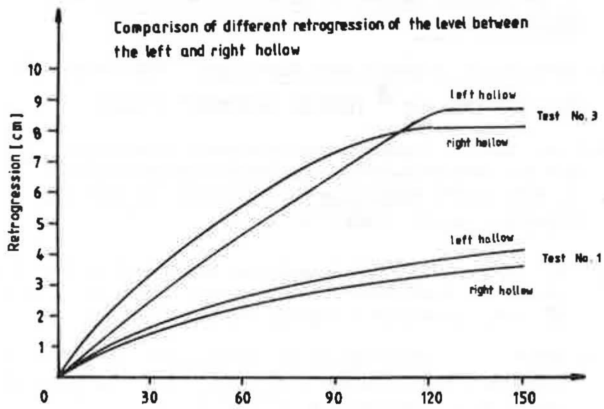

Fig. 14

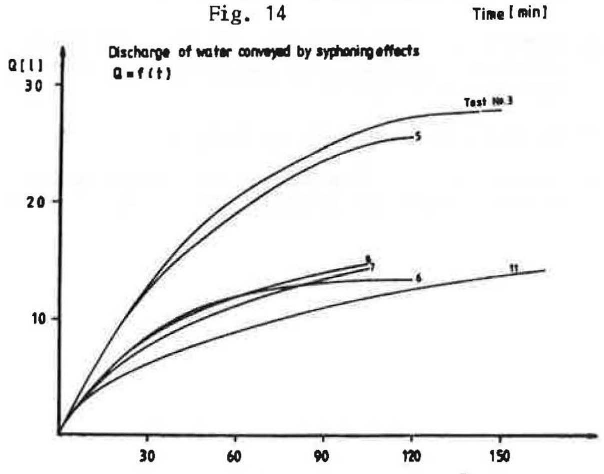

Fig. 15

Some of the results will be discussed here:

- In trial Nos. 2 - 8 (without external load) the hollows are emptied or their water level falls to that of the drainage ditches in 1 1/2 to 2 hours. The added gravel fill has no measurable effect on this result.

- If the geotextile is not thoroughly wetted, syphon performance is correspondingly reduced.

- No change in the syphoning effect was observed during trial Nos. 1 - 8.

- An external load (trial Nos. 9 and 10) reduces syphon performance. Removal of the load (trial No. 11 does not cause performance to improve again.

- Syphon performance was not observed to be linearly related to the hydraulic gradient, but performance did increase with increasing hydraulic gradient.

5. Long-term action of geotextile filters

The studies described here are based on a number of simplifying assumptions that do not apply when a geotextile is used as a blanket drain and syphon in situ. Apart from the geometrical discrepancies, it is necessary to examine more closely especially the question of the long-term stability of the raw material used in the geotextile and the changes in the hydraulic properties caused by soil infiltration.

Martinek (10) reported finding changes in the hydraulic properties of nonwovens which have been used for 8 - 10 years as a separation layer between the ballast and the subgrade formation. Because of the high dynamic loading and the presence of water the weight of the nonwoven had increased five- to twelve-fold through the permeation of soil fines into the pores. In needle-punched fabric the water permeability coefficients kv (perpendicular to the plane of the geotextile) and kh (in the plane of the geotextile) had declined in all cases by one power of ten.

List (9) investigated the long-term stability of fabric materials and the filtering efficiency of geotextiles of synthetic fibres and filament that had been installed in protective structures on littoral embankments of coastal and inland waters. The long-term stability of the polymers used, PA, PE, PES and PP, was clearly demonstrated. The water permeability perpendicular to the plane of the material of soil-filled filter samples was in all cases distinctly (5 to 12 times) greater than that of the adjacent soils. The amount of soil that had accumulated in the nonwoven fabric in the course of the years considerably exceeded the mass per unit area of the reference samples, but nevertheless, the remaining open porosity still amounted to 80 % of the total filter volume, which explains the high-residual water permeability.

Huhnholz (7) examined PES and PP nonwovens which had been installed as a separation layer between an embankment and a substratum of low bearing capacity on the west coast of Schleswig-Holstein. This study confirmed that the hydraulic filtering properties of these fabrics had changed over time. The original water permeability perpendicular to the plane of the layer was reduced by a factor of at least one but usually two powers of ten as a result of the infiltration of soil fines into the pores of the nonwoven fabric. Nevertheless, all geotextiles remained more water permeable than the existing substratum consisting of silty clay.

Heerten (5) reported on long-term experience with 16 different geotextiles which had been installed in embankment protection structures on the North German coasts and on canals and rivers, some of them since 1970. Owing to the dynamic action of wave motion all the nonwovens had been permeated with many soil particles, whose cumulative weight exceeded the weight of the fabric itself, in some cases by a factor of ten. One remarkable result of this high level of soil infiltration was that the thickness of the geotextiles had not been reduced by the weight of the overlying protective structure as one might have expected. Additionally in all the nonwovens examined the remaining open pore volume was so great that the water permeability perpendicular to the plane of the fabric was still 5 to 12 times greater than that of the existing soil. These findings obtained with nonwovens cannot, however, be applied to soil-filled woven fabrics, which were also examined. In some cases the latter fabrics exhibited water permeability levels lower than that of the soil to be retained by the filtering action.

In studies of the syphoning effect of retrieved samples of 500 g/m² ® TREVIRA SPUNBOND, which had been installed as a separation layer between track ballast and a fine-grained substratum, our own observations yielded results that at first seemed odd: the syphoning effect had been increased by soil infiltration! The soil fines cause a reduction in the water permeability of the geotextile layer but an increase in capillary action. Consequently, soil-impregnated nonwovens can transport water over a higher intermediate level than nonwovens whose pores are filled only with water. But the amount of water transported Q (t) is reduced because of the altered permeability. There are no quantitative data available relating to this observation.

The results presented above on the behaviour of nonwovens after several years of service in protective structures for littoral embankments and under roadway embankments have all shown that water permeability is reduced by soil infiltration, but it remains greater, and in part very considerably greater, than that of the soil material to be retained by the filtering action of the geotextile. Heerten's report (5) also showed that under the load conditions prevailing under earthworks it is impossible for a nonwoven to become fully clogged. For the function of a geotextile as a filter, blanket drain and hence as a syphon, these findings are of great importance.

6. Conclusion

The syphoning effect of geotextiles has been demonstrated in laboratory studies. Nonwovens that are mechanically bonded by needle punching are especially suited to transport water over a barrier which lies higher than the hydrostatic level. Thermally bonded nonwovens and woven fabrics showed no syphoning effect. The maximum suction heights lay between 10 and 20 cm.

Syphon performance is directly proportional to the hydraulic gradient and inversely proportional to the external load.

The syphoning effect of a mechanically bonded nonwoven of polyester was demonstrated on a 1/3 scale model of the cross section of a railway embankment under conditions resembling the actual working environment.

The experimental results lead to the assumption that the syphoning effect can also be utilized under the conditions existing in the actual working environment.

7. References

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