Geomembrane Liners for Groundwater Protection in Roads

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ABSTRACT: In this paper the use of geomembrane liners for groundwater protection in roads in groundwater-pumping areas is described. The requirements for the chemical resistance of geomembrane liners are shown. Furthermore, field tests with regard to mechanical damage of geomembrane liners under cyclic load are introduced and evaluated. Finally, a procedure to verify the stability of cover soil on geomembrane-lined slopes is described.

1 INTRODUCTION

Because of increasing traffic volume and extension of road network, more and more traffic routes have to be built in areas where, due to unfavourable geological conditions, special measures have to be taken to protect the groundwater against pollution (Forschungsgesellschaft für Strassen- und Verkehrswesen, 1982). This can be achieved by a multi-layer system with geomembrane liners (figure 1).

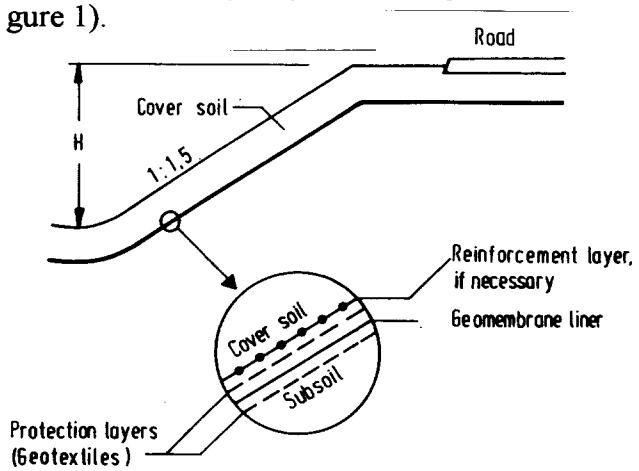

Figure 1: Example of the use of geomembrane liners for groundwater protection. Road on embankment.

In contrast to waste-disposal constructions, for this application of geomembrane liners there are still no requirements. Therefore at the Institute for Foundation Engineering Soil and Rock Mechanics at the Technical University of Munich a research programme with the following subject matters was instigated:

- Requirements for chemical resistance of geomembrane liners
- Investigations into mechanical damage of geomembrane liners under cyclic load
- Stability of cover soil on geomembrane-lined slopes

2. REQUIREMENTS FOR CHEMICAL RESISTANCE OF GEOMEMBRANE LINERS

Geomembrane liners used as described above can be attacked by following pollutants:

- Permanent pollutants which result from the traffic (e.g.abrasion from the tires or small amounts of oil and gasoline)
- Pollutants which result from an accident (e.g. with trucks which transport dangerous liquids.

Pollutants which result from ordinary traffic do not penetrate deeply into the soil beneath the road (Unger, 1991). As geomembrane liners must be covered by a soil layer of at least 80 cm thickness to ensure protection against mechanical damage, the geomembrane liner is attacked by this only to a slight degree.
The most important task of geomembrane liners is to protect the groundwater against pollution after an accident.
The evaluation of accident statistics (Bayerisches Landesamt für Statistik und Datenverarbeitung, 1990) showed that the probability of an accident with liquids other than oil or gasoline leaking out of the tank of a truck is very low. Besides, there is a possibility of an immediate reconstruction after such an accident and the geomembrane liner can be replaced if necessary.
Because of the above-mentioned aspects it generally seems to be sufficient that the geomembrane liner used has good long-term resistance to oil, gasoline and de-icing salt. Opposite other liquids which e.g. are given in Institut

für Bautechnik, 1985 only short-term resistance is required.

3. INVESTIGATIONS INTO MECHANICAL DAMAGE OF GEOMEMBRANE LINERS UNDER CYCLIC LOAD

For waste-disposal constructions many investigations into the protection of geomembrane liners against mechanical damage (e.g. Sehrbrock, 1992, Bundesanstalt für Materialprüfung, 1992) have been made. However, for the use of geomembrane liners in roads other boundary conditions exist. Here the geomembrane liner is placed between coarse grained soil. Furthermore static loads are very low but dynamic loads can be high.
In the research program three different loading conditions were investigated:

a: Permanent static load from the cover soil next to the road.
b: Short-term dynamic load from a truck driving beside the road.
c: Dynamic load from the compaction of the cover soil above the geomembrane liner and from the construction traffic before the installation of the paved road.

The investigations of cases a and b are reported in Fillibeck and Floss, 1994. For case c laboratory and field tests were carried out. The laboratory tests were performed in a 70 x 70 cm² loading device, which had already been used to show the change of geotextile properties under dynamic loading (Floss, Laier, Bräu, 1990). The investigations are also described in Fillibeck and Floss, 1994. The field tests are introduced below.

3.1. Field tests

The field tests were carried out during the construction of highway A 96 near Leutkirch / Germany. The effects of extreme construction traffic on the cover soil over the geomembrane liner before the installation of the paved road were investigated. The period of load was 7 weeks. Two geomembrane liners with a thickness of 2.5 mm made from HDPE and modified HDPE (HDPE mod.) which is softer than HDPE were investigated. Under the geomembrane liner a needlepunched geotextile of 600 g/m² unit weight was used as a protection layer. Above the geomembrane layer two needlepunched geotextiles of 325 g/m² and 600 g/m² were used (figure 3). The grain-size distribution of the adjacent soil, a globular gravel, is given in figure 2.
Before the installation of the multi-layer system the surface of the subsoil was mixed and compacted with sand. The cover soil was placed over the multi-layer system and compacted to a thickness of 80 cm. After loading by the construction traffic, the thickness reduced as shown in figure 3.

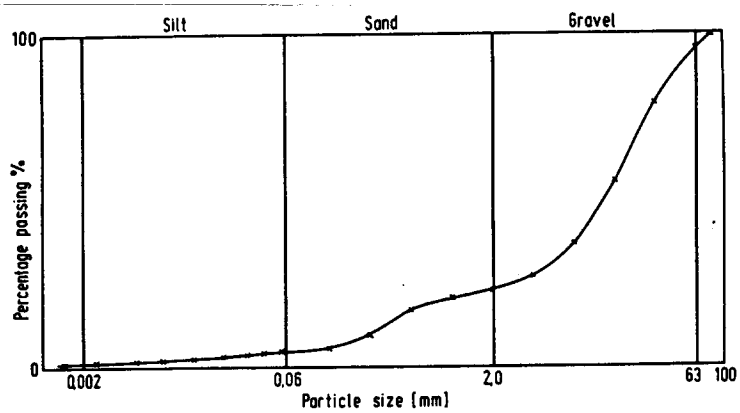

Figure 2: grain-size distribution of the adjacent soil

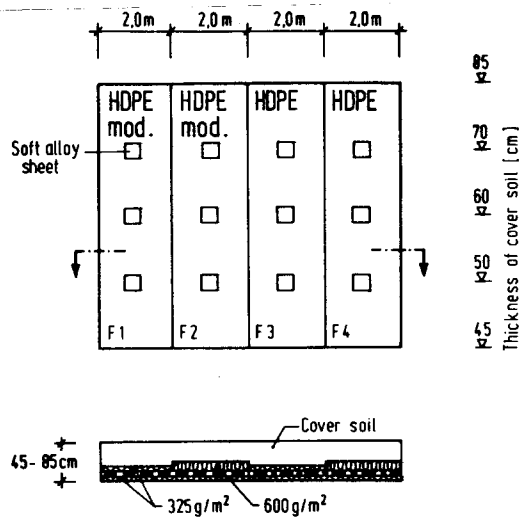

Figure 3: Test field

To evaluate the deformation, the geomembrane liner was examined visually immediately and one month after recovery from the test field. Beneath the geomembrane liner and the lower geotextile a soft alloy sheet was placed to record the maximum deformation of the geomembrane liner during the test. The maximum strain Δl/l of the alloy sheet was analyzed with a computer program. The results are shown in figure 4.

Thickness of cover soil h_{cs} =50 cm

Geomembrane liner	Upper geotextile m.p.u.w.[g/m²]	Max. strain Δl/l [%]	Average strain Δl/l [%]	Geomembrane liner after recovery
HDPE mod.	325	7,38	0,26	significant abrasion
HDPE mod.	600	6,02	0,2	no abrason
HDPE	325	3,92	0,14	significant abrasion
HDPE	600	0,64	0,03	slight abrasion

Thickness of cover soil h_{cs} =60 cm

Geomembrane liner	Upper geotextile m.p.u.w.[g/m²]	Max. strain Δl/l [%]	Average strain Δl/l [%]	Geomembrane liner after recovery
HDPE mod.	325	4,13	0,21	slight abrasion
HDPE mod.	600	1,79	0,1	no abrasion
HDPE	325	2,41	0,04	slight abrasion
HDPE	600	1,71	0,04	no abrasion

Figure 4: results of the field tests

3.3. Conclusions

The field and laboratory tests of the three cases lead to the following conclusions.

- To avoid mechanical damage to the geomembrane liner the subsoil must be compacted and levelled.
- In the case of short-term, seldom-recurrent loads (case b) the advantage of the HDPE-liner over the HDPE mod. -liner is its greater stiffness. However, under long-term dynamic load (case c) the HDPE-liner tends to show more abrasion damage (figure 4). Under long-term static load (case a) both geomembrane liners show very similar behaviour.
- The mechanical damage of the geomembrane liner depends to a large degree on the present bundary conditions (e.g. grain-size distribution and grain shape of the soil, applied load). Therefore the best way to verify the suitability of the protection layers is to carry out field tests. If this is not possible, the effectiveness of the protection layers can be examined by laboratory tests, e.g. with the 70 x 70 cm² loading device mentioned above.
- The field tests show that the thickness of the cover soil affects the mechanical damage of the geomembrane liner because of the load distribution. At a thickness of 50 cm the upper geotextile with 600 g/m² mass per unit area did not seem to be suitable which was evidenced by abrasion of the geomembrane liners or the high maximum and average strain. However, when covered with 60 cm of soil this geotextile adequately protected the geomembrane liners.
  The results of the investigations of cases a and b showed that for a cover soil of 80 cm thickness a nonwoven needlepunched geotextile with a mass per unit weight of 325 g/m² above and below the geotextile is sufficient to protect the geomembrane liner against inadmissable deformation or damage.

4. STABILITY OF COVER SOIL ON GEOMEMBRANE-LINED SLOPES

For the use of geomembrane liners in slopes the stability of the cover soil has to be investigated.
To improve the stability of the cover soil, a reinforcement layer (e.g. geogrid) can be used (figure 1).
Before verifying the stability, the interface-friction behaviour of the multi-layer system must be analyzed. In the research program a laboratory test was performed to investigate the multi-layer system as a whole, considering the different displacements between the layers (Fillibeck and Floss,1994). Thus, the limit friction angle δ_{ML} of the multi-layer system can be determined.
In the past, several design models have been introduced (e.g. Koerner and Hwu, 1991; Druschel and Underwood, 1993) which refer to the use of multi-layer systems in landfills. However, for groundwater protection in roads in groundwater pumping areas different boundary conditions exist which are taken into consideration here.

4.1. Multi-layer system without reinforcement layer

The sliding-block model to calculate the stability of cover soil is given in figure 5 This model referes to a road on an embankment (figure 1). In Fillibeck and Floss, 1994, two other sliding-block models were investigated.

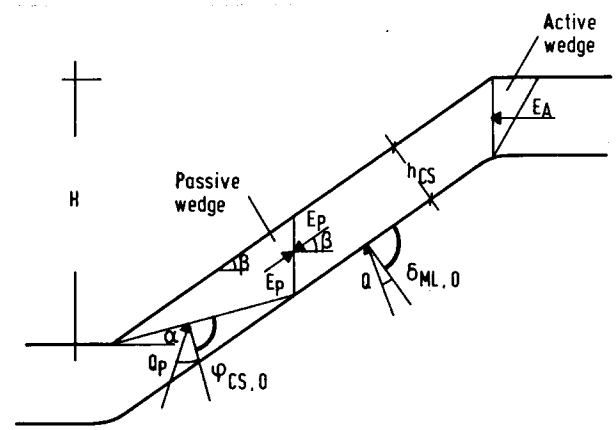

Figure 5: Sliding-block mechanism

The following assumptions were made:

- Geomembrane liners for groundwater protection in roads are only applied for coarse-grained soils. Therefore no cohesion of the cover soil is taken into account. Also no potential adhesion of the multi-layer system was taken into account.
- The thickness of the cover soil h_{CS} is 0.8m to ensure protection against mechanical damage.
- For road construction the angle of the slope is typically β=33.7° (h/b=1/1.5).
- The safety factor refers to the friction angle of the cover soil ϕ_{CS} and the governing interface friction angle δ_{ML} of the multi- layer system. Using equations 1 and 2, the reduced friction angles which are required for stability $\phi_{CS,0}$ and $\delta_{ML,0}$ can be calculated.

$$FS = \frac{\tan\phi_{CS}}{\tan\phi_{CS,0}} \qquad (1)$$

$$FS = \frac{\tan\delta_{ML}}{\tan\delta_{ML,0}} \qquad (2)$$

- To achieve overall stabilitity, the friction angle of the cover soil must be at least $\phi_{CS,0}$.
- For high slope inclinations (e.g. h/b=1/1,5), the sliding angle of the passive wedge α cannot be assumed to be horizontal. α depends on the friction angles $\phi_{CS,=}$,$\delta_{ML,0}$ and the total height H of the slope.Since there is no closed solution, α must be fixed by optimization. For the governing angle α the height of the slope H is minimum.
- The earth pressure from the active wedge E_A can be calculated by Rankine.

Taking equilibrium of forces and varying α in the above mentioned manner, the maximum height of the slope H_{MAX} can be calculated according to FS, ϕ_{CS} and δ_{ML}.

In figure 6 the results of the calculation are shown graphically for FS=1.2.

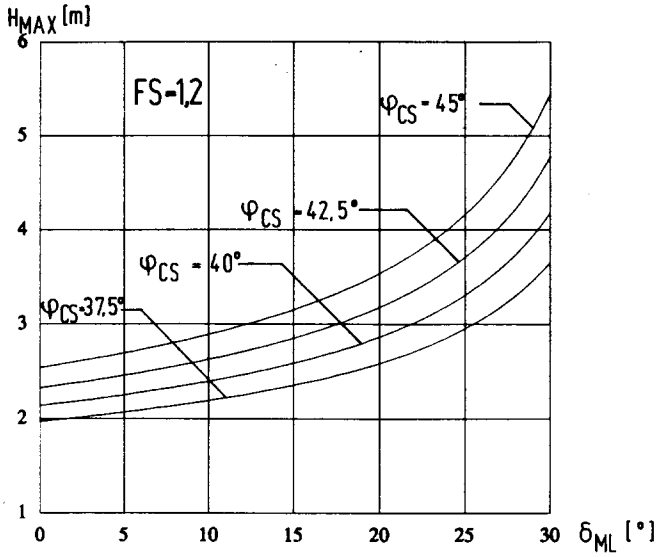

Figure 6: Maximum height of the slope H_{MAX} in dependence of ϕ_{CS} and δ_{ML} (FS=1.2; h/b=1/1,5; h_{CS}=0,8 m).

4.2. Multi-layer system with reinforcement layer

With figure 6, the maximum height of the slope H_{MAX} can be determined. If slopes with height $H > H_{MAX}$ have to be built, a reinforcement layer can be used (figure 1) to bear the surplus force.
The required tensile strength of the reinforcement F_{REQ} can be calculated with equation 3.

$$F_{REQ} = \frac{\gamma \times h_{CS} \times (H - H_{MAX})}{\sin\beta \times \left(\sin\beta + \left(\frac{\cos\beta}{\tan(\beta - \delta_{ML,0})}\right)\right)} \qquad (3)$$

Because of the strain of the reinforcement layer, the surface structures of the geomembrane liner have to be chosen in such a way that the critical sliding surface develops above the geomembrane liner. Furthermore it must be ensured that relative displacement of the reinforcement layer at the base of the slope is not too high.

5. SUMMARY

In the construction of roads in groundwater-pumping areas the groundwater has to be protected against pollution. This can be done by using a multi-layer system with geomembrane liners. In this paper the requirements for the multi-layer system are summarized. These differ considerably from those for waste-disposal constructions. If these requirements are taken into consideration, a high level of safety can be achieved.

6. ACKNOWLEDGEMENTS

The research reported in this paper was funded by the German Federal Ministry of Traffic. The authors express their appreciation for this support. Thanks are also due to R. Schmidt from the Local Autobahn Office Heidenheim, who permitted the field tests on the A 96 Leutkirch.

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