Groundwater Protection at Road Slopes

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ABSTRACT: Several factors change the behaviour of mineral liners, like freeze-thaw cycles, erosion and different chemical actions. This report deals with the requirements set by the Finnish National Road Administration to both mineral and geosynthetic liners used to protect aquifers at road slopes against pollutants released during accidents. The short term requirements connected to accidents, asking for a 12 hours retention period, are superposed by demands for groundwater protection against migration of road salt. Weak points in common construction practice influencing hydraulic performance of slope protection structures are relatively low degrees of compaction and erosion channels, which occured often in connection with rockfill structures, and problems of quality assurance measures. Material parameters for clayey and silty soil liners to achieve acceptable permeability values are given in the report. In most demanding cases and to ensure long-term performance geosynthetic clay liners, geomembranes or bituminized geotextiles are recommended for use in combination with a mineral liner. Testing procedures and test results for the assessment of suitability are presented for such geosynthetic products.

1 INTRODUCTION

On behalf of the National Road Administration and the National Board of Waters and the Environment a code of practice for the protection of groundwater reservoirs in connection with road constructions was elaborated (1991)

A slope protection as a constructive measure shall prevent the migration of pollutants to the groundwater in areas of virgin groundwater formation or in the protective zone of water supply stations in cases like accidents of trucks transporting oil, chemicals or hazardous goods. In such emergency cases a retention period of 12 hours is required, necessary to enable the fire brigade to clean up the site or set further protective actions. Outspreading of road salt during the winter period is another high risk potential for aquifers. Solutions of natrium- and calciumchloride migrate, because of their higher density compared to water, towards depressions in the groundwater stratum. Thus road salt, acting as a pollutant on the long term, is setting another design aspect to slope protection layers.

Some parameters like frost and chemical actions have essential influence on the permeability of mineral liners. Differences occur also between field and laboratory measurements of water permeability values. Each of these factors might cause an increase in the permeability coefficient of up to 1000 times or more.

The design of road dams is guided by demands set to bearing capacity and resistance against frost actions. The guiding design principles for road slopes are maintainance and serviceability. So their inclination is kept as flat as possible, e.g. 1:4 or 1:5.

The design of slope protections has to face several unknowns. In the case of a possible accident involving a truck carrying hazardous liquids the unknowns are the type of the liquid medium, the location of the accident, the climatic and the runoff conditions, only to list a few ones.

2 BEHAVIOUR OF EXISTING LINERS

Until recently the materials used for slope protection were mainly dry crust clay or glacial till. If compacted properly a sufficiently low permeability could be achieved with such materials. Their disadvantages are susceptibility to frost action, erosion and possible shrinkage cracking.

An inventory of existing slope protections constructed of mineral layers showed severe deficiencies. Those were insufficient density, diminished thickness due to surface ero sion or migration of liner material into the roads' substructure. Geotextiles in separation functions had not been applied in those structures. At one site a thin PELD-membrane (0,35 mm) had functioned as a moisture barrier and kept the liner naturally moistened. But during the thaw period also local slides had happened in the layer covering the PE- membrane.

3 REQUIREMENTS TO MINERAL LINERS

The code of practice for the protection of aquifers in connection with road constructions (1991) is giving limit values to the necessary degree of compaction depending on the fines' content (ϕ < 0,074 mm) of the materials suitable for mineral liners. A fines' content > 70 % requires a modified Proctor density > 85 %, a fines' content of < 70 % but > 60 % requires a modified Proctor density > 90 %. The corresponding permeability value at 90 % density and at optimum water content, determined in the laboratory, has to be for water $< 5 \times 10^{-8}$ m/s. To ensure a 12 hours retention potential a mineral liner of 0,7 m thickness has to show in a corresponding field test a water permeability value $k < 5 \times 10^{-6}$ m/s. Such a limit value should count for the effect of shrinkage cracks, of frost-thaw cycles, road salt and different chemicals on the actual permeability.

A set of drawings is giving the necessary structural details for the practical execution. As an alternative other than the described solutions may be accepted by the responsible authority.

The normal solution for a slope protection will be a mineral liner of sufficient quality and thickness. Synthetic liners will either provide an extra safety to the structure or function independently. Geomembranes are considered beeing tight but vulnerable, expensive and difficult to repair. Geosynthetic clay liners (GCL) have compared to geomembranes several advantages but are not perfect either.

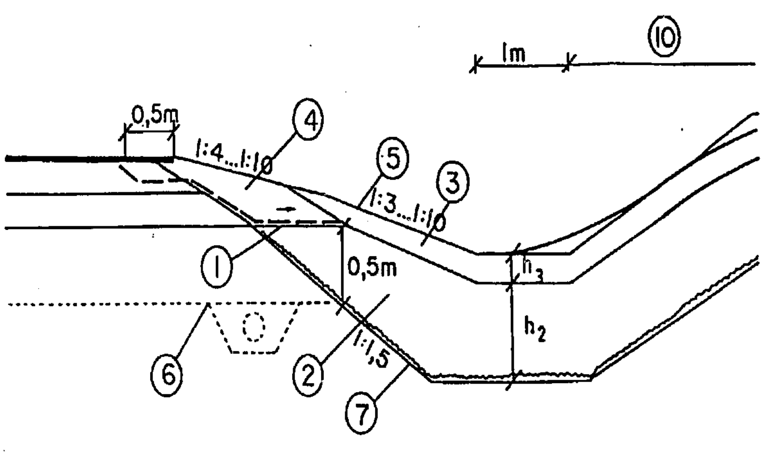

Fig. 1 Road embankment on soil stratum. Guideline for slope protection.*)

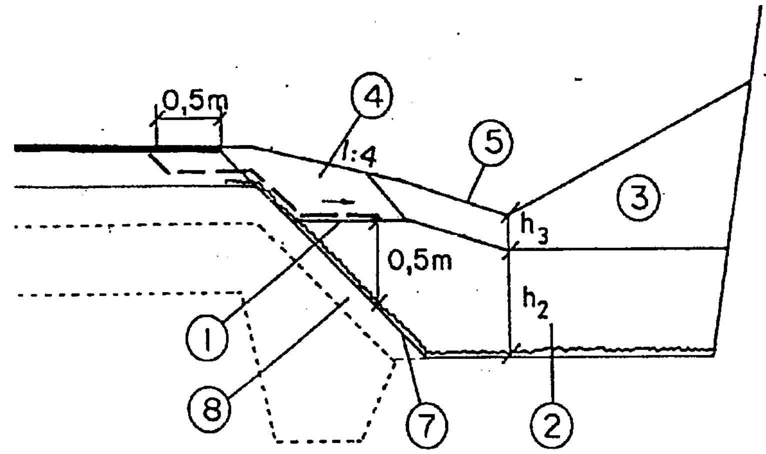

Fig. 2 Road structure in rock cut. Guideline for slope protection.*)

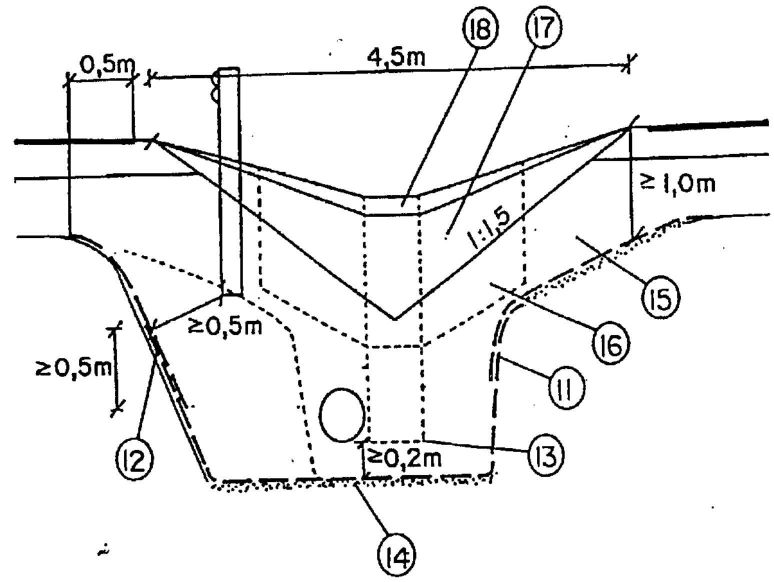

Fig. 3 Central drainage ditch of highways. Guideline for slope protection.*)

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*) Explanation of some essential structural details:

1, 11, 12	Geosynthetic liner
7	Geotextile in separation function
2	Soil liner
3	Surface cover resistant to erosion
4	Crushed gravel at shoulder

4 APPLICATION OF GEOSYNTHETICS

4.1 Functions

Geosynthetic materials may be used for several functions at road slopes: a) as separator between mineral liners and the subsoil or the subbase, especially if constructed of rockfill. b) as a tight barrier at the upper edge of the slope forming the connection to the pavement. c) as moisture barrier in mineral liners to prohibit shrinkage cracks and d) as a carrier for grass roots to prohibit surface erosion.

4.2 Geosynthetic liners

Geomembranes of > 1 mm thickness are considered suitable liners in groundwater protection but require a well prepared supporting layer (Rathmayer and Juvankoski, 1993). In addition a protection by a suitable geotextile of > 1000 g/m2 weight or by a protective sand layer with a maximum grain size of 5 mm is requested. PEHD (or a PE-copolymer) is the recommended raw-material because of its superb chemical resistance.

Geosynthetic clay liners are recommended for use at the upper edge of the slope in close connection to the pavement. There a tight structure of sufficient thickness cannot be formed out of a mineral liner alone. They may be used beneath a mineral liner to ensure long term tightness at most demanding conditions or in combination with a protective layer of insufficient performance.

Plastic coated geotextiles may be used to ensure the long term performance of acceptable mineral liners. Thin products shall be protected against damage by a suitable geotextile.

Bituminized geotextiles may be formed on site by spraying bitumen emulsion (1,5...2,5 kg/m2) or hot bitumen on a carrrier geotextile suitable for separation function at the place of installation. Unless the technology has developed further this solution is acceptable only to prohibit evaporation of mineral liners.

Thin PEHD- or PELD-membranes (0,3...0,5 mm) are suitable only to prohibit evaporation of mineral liners.

4.3 Permeability requirements

Geosynthetic liners have to fulfil the 12 hours retention requirement against an 0,3 m hydraulic gradient at the place installed. Damage during installation, frost-thaw periods, point loads or different chemicals including road salt shall not effect their performance. A 1 mm thick geomembrane shall have a (water) permeability coefficient $k < 7,7 \times 10^{-11}$ m/s, a 10 mm thick geosynthetic clay liner a value of $k > 7,5 \times 10^{-9}$ m/s. For equivalent performance an intact mineral liner having a permeability coefficient of $k < 5 \times 10^{-6}$ m/s would need a thickness of 0,39 m.

It would be wrong to judge equivalence of functioning in terms of water quantities really penetrating the liner. A mineral liner ($k < 5 \times 10^{-6}$ m/s, 0,7 m thick) will permit a flow through quantity of 308 liters water in a period of 12 hours after the 12 hours retention time. At equivalent k values geosynthetic liners prohibit a flow through for a restricted period depending on the effective thickness. Seams and joints have to meet the same requirement for the 12 hours retention period.

5 PROPERTIES OF GEOSYNTHETIC LINERS

5.1 Testing procedures

For the assessment of suitability 5 different geosynthetic liner materials, four GCL types and one thin geotextile composite, were tested according to a testing programme consisting of 12 procedures (Rathmayer and Juvankoski, 1993). Besides the usual index tests other testing procedures especially relevant to geosynthetic clay liners were applied, such as:
- thickness after swelling of the bentonite core
- permeability in 3D -stretched condition
- permeability after drying-wetting cycles
- permeability after treatment with salt solution
- permeability after installation test
- permeability at footprint area (point loading test)
- friction between liner and relevant soil materials
- resistance against erosion
- tightness of seam structure.

A description of the geosynthetic liner types tested according to these procedures is given in table 5-1.

Table 5-1. Geosynthetic liner materials tested

LINER TYPE	Mass g/m^2	Description
GCL 1	5034	Woven carrier geotextiles, linear stitching
GCL 2	5060	Woven/non woven carrier geotextiles
GCL 3	4051	Non woven carrier geotextiles, needle punched
GCL 4	4430	Non woven carrier geotextiles, needle punched
COMP	169	PE membrane calendered on heat bonded non woven geotextile

5.2 Test results

The swelling capacity of geosynthetic clay liners and their possible change in thickness due to drying-wetting cycles is a burning question, if the material is installed beneath the edge of the pavement. Reflective cracking alongside the edge of the pavement shall not occur, because the pavement has to function as the first tight barrier against polluting liquids. The total increase in thickness varied from 3 to 13 mm and lasted 3...8 weeks after initial wetting. This behaviour has to be observed in the timing of pavement works.

Depending on the type of product the permeability at 3D-stretched liners was found to differ compared to the unstretched product. Due to some squeezing out of the bentonite pasta through the carrier geotextiles of the tested GCL types permeability values increased up to 4 times the initial values, but to the same degree the permeability increased also for the stretched geotextile composite.

The influence of drying-wetting cycles on the water permeablity values showed to be in the same range of order but essentially higher for the GCL type 1 containing lines of stitches (30-times). Drying wetting cycles had negligible effect on the performance of the geotextile composite.

Freeze-thaw cycles showed to increase the water permeability values of geosynthetic clay liners 2...10 times, but had no influence on the permeability values of the geotextile composite.

Treatment with salt solution (0,4 g NaCl / 1 litre water) showed to increase the permeability values up to 20 times for the GCL type 2 and had no effect on the geotextile composite.

The installation test simulated actual performance in the field. The geosynthetic liner was placed on a EPS layer (density 40 kg/m^3, thickness 20 mm) and covered with 0,15 m crushed gravel. The gravel layer was compacted with a vibrating plate to a modified Proctor density of 90 % using 6 passes. The liner material was then recovered and its water permeability was tested. 16 to 18 times higher permeability values were measured for the GCL types 1 & 2, 2 to 3 times higher ones for the GCL types 3 & 4, but for the geotextile composite nearly 1000 times due to more severe damage during installation.

The footprint tests simulated the effect of a point load acting on the uncovered, but expanded and swelled GCL. Depending on the structure of the GCL an irrecoverable damage of the bentonite clay core may occure. A load of 80 kg was placed on the unprotected liner surface using a metal piece 52 x 39 x 20 mm in size. Permeability values increased for the unconfined GCL structure (type 2) up to 10 times, for the GCL type 1 to nearly 4 times the initally measured value.

Water flow arranged in a test set-up alongside the GCL surface caused no essential erosion of bentonite particles through the geotextile cover.

Jointing is normally done by overlapping, 0,15 to 0,3 m wide, and for certain GCL types additional bentonite (powder or paste) is placed between the contacting geotextile surfaces. The recommended jointing solutions showed to function properly for the requested retention time of 12 hours.

6 WIDTH OF SLOPE PROTECTION

Research data from traffic accidents gave clear evidence, that 1/3 of the vehicles, which came off the lane, continued its way to the slope or area beyond the road ditch. For normal road structures the design width of the slope protection may be obtained from principles lined out in Fig. 4. The crosspoint between soil surface and a slope inclined at 1 : 1 placed at a distance of 10 metres from the edge of the pavement determines the extension of the protective structure.

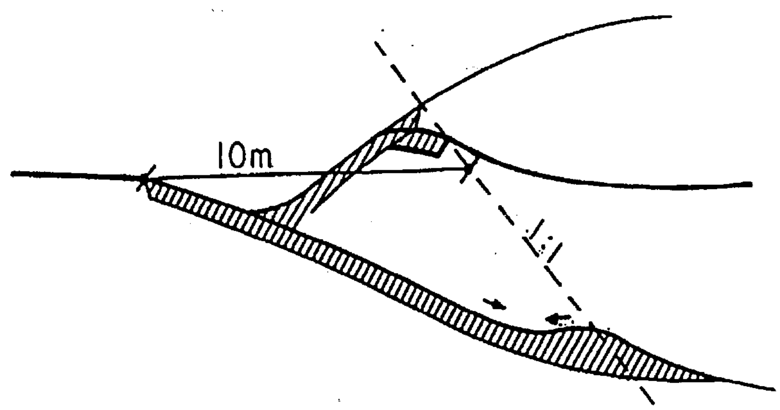

Fig. 4 Width of slope protection. Design principles.

In the case of space restrictions or for environmental reasons, like preservation of nature or structures, the width of the slope protection may be reduced to ≥ 6 m.

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