GEOSYNTHETIC CLAY LINERS AS ENVIRONMENTAL PROTECTION IN INFRASTRUCTURE PROJECTS

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ABSTRACT

Geosynthetic Clay Liners (GCLs), are used in many applications as stand-alone barrier to protect the environment. In road infrastructure applications, GCLs are used to protect environmental sensitive areas, such as ground water recharge areas, from any pollution arising from motor vehicles, any materials (deicing salt) used on these particular motorways and/or water-endangering materials in the case of accidents. This paper will present a summary of the German requirement of road infrastructure in groundwater sensitive zones including a summary of a project done here in the province of Quebec.

RÉSUMÉ

Les recouvrements (d'argile) de Géosynthétiques Bentonitiques (d'argile) (G.S.B.), sont employés dans beaucoup d'applications en tant que barrière autonome pour protéger les secteurs sensibles environnementaux, tels que des secteurs de recharge d'eaux souterraines, contre n'importe quelle pollution résultant des véhicules à moteur, tous matériaux (sel de dégivrage) utilisés sur ces autoroutes particulières et/ou eau-mettants en danger des matériaux dans le cas des accidents. Cet article présentera un sommaire de la condition allemande de l'infrastructure de route dans des zones sensibles d'eaux souterraines comprenant un sommaire d'un projet fait ici dans la province du Québec.

1. INTRODUCTION

Groundwater protection is generally required where a road enters a groundwater sensitive area, to avoid damage from winter maintenance with deicing salt, everyday pollution arising from motor vehicles, and to protect the area from accidents with the possible release of polluting substances (chemical/petroleum tankers/transporters). Numerous guidelines are in existence throughout North America, however this paper will only look at the German Guidelines edition 2002 of the RiStWag (guidelines for construction projects in waterways of protected areas) of the Research Society for Road and Traffic. The hope of this paper is to look at European guidelines as a review to ensure our own guidelines are equivalent and/or superior.

Guidelines stipulate various sealing systems that can be installed either near the surface or in deeper layers. This paper will look at Geosynthetic Clay Liners (GCLs) as a stand-alone barrier. Sealing systems with GCLs have successfully been used in various application fields such as road and railway construction, landfill, and hydraulic engineering (dams, canals, ponds, rivers, lakes, waterproofing buildings).

2. GERMAN GUIDELINE, RISTWAG.

The object of the RiStWag guideline is to protect the waters against pollution with the use of geosynthetic materials. Most of the attention is drawn to drinking water protection areas (in general groundwater and drink water barrages) and mineral spring areas (state-approved mineral springs). For both areas, there are three different protection areas:
Zone I: surrounding of groundwater exploitation plants resp. reservoir with embankment area in drinkwater barrages. In both cases, road sore is not allowed. If they cannot be avoided, the exploitation plants are to be given up or alternative water supply must be provided. In the case of drinkwater barrages, special methods are required.

Narrow protection zone (zone II): Here, a sufficient water protection is absolutely necessary, if a road is designed or extended through this zone. In addition, maximum traffic security must be ensured and the construction of filling stations, service areas and parking lots are not acceptable.

Additional protection zone (zone III): The water protection has also to be provided in this area. In addition, the zone can be divided into zone IIIA and zone IIIB. In zone IIIB, less protection measurements are accepted than in zone IIIA. The necessary protection efficiency depends on various elements such as the average daily traffic volume (DTV) and the protection efficiency soil layer over the groundwater (thickness and permeability). The construction of filling stations, service areas and parking lots should possibly be avoided in zone III and IIIA. If it cannot be avoided, sewage and rainwater must be collected and routed out of the water protection area. In all cases, the risk of contamination on surfaces where water-endangering materials are stored and/or filled up is to be avoided.

2.1 Sealing

In areas where infiltration should be prevented, impermeable drainage systems are necessary in order to protect the subsoil and groundwater against contamination. Geosynthetic sealing systems such as geomembranes and geosynthetic clay liners are used for infrastructure projects in the protection zone I and II. Their use in the protection areas III, IIIA resp. IIIB mainly depends on the classification of the drainage system that, on its part, depends on the thickness and permeability of soil layer over the groundwater, on the protection zone as well as on the average daily traffic volume (DTV). The necessary drainage systems in the protection zones III A and III B can be divided into the following levels (more details are described in chapter 6.2.6 of RiStWag):

Level 1: Occurring rain water can run off over the surface and seep away. The thickness of the top soil must be between 20 and 30 cm and sufficiently allow root growth. Manholes and infiltration strands are not allowed.

Level 2: Like level 1, but infiltration ponds are allowed if a sedimentation plant is lined up.

Level 3: In principle, rain water has to be collected and routed out of the protection zone or, if this is not possible, routed into the outfall drain after purification. Ditches, trenches and ditches lined with geosynthetic sealings (e.g. GCLs) can also be installed (see fig. 2).

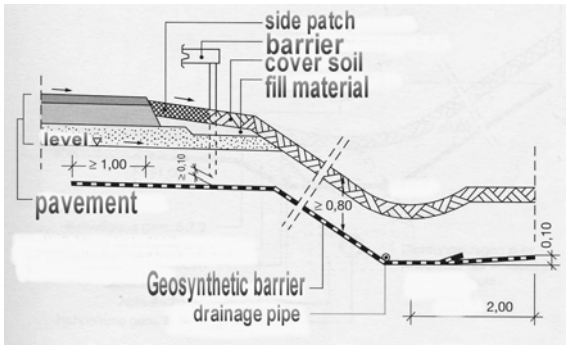

Figure 1. Basic drawing for a road cross-section zone III "drainage over the slope"

Level 4: Like level 3, but the sealings (e.g. geosynthetic sealings) have to cover the whole ditch (> 2 m from the middle of the syncline) resp. on slopes the sealing has to be installed at least 1 m beyond the road edge. In the case of a low protection efficiency of the soil layer over the groundwater the whole road has to be sealed.

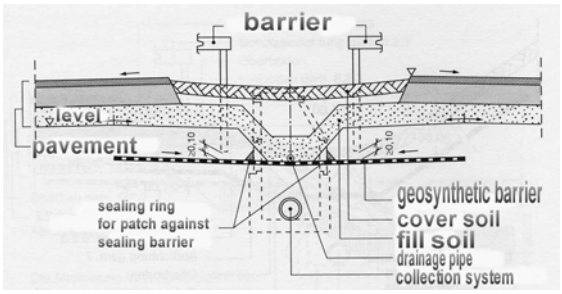

Figure 2. Basic drawing for a road cross-section zone III "central reserve"

2.2 Requirements for Geosynthetic Clay Liners

During the expected service life of the structure, the GCL has to exhibit the necessary permittivity of $\psi \leq 1 \times 10^{-7}$ 1/s corresponding to a permeability coefficient $k_{GCL} \leq 1 \times 10^{-9}$ m/s (polypropylene coated GCL via ASTM E96, a value of less than 5×10^{-13} can be expected) equal to calculated for a commonly 1 cm thick bentonite layer. The test method to determinate the permittivity resp. the permeability coefficient is described in Kaufmann (1997) resp. in the standard DIN 18130. If a GCL is applied, the required permittivity value may also include permittivity against other mediums such as gasoline, heating oil, diesel fuel and saline solutions. However, it is necessary to consider constructive methods such as the required soil cover of 0,80 m. This ensures that the bentonite of the GCL remains moist. In normal conditions, the soil cover is sufficient to protect the GCL against desiccation and freeze effects. All overlaps have to be impregnated with bentonite (powder, granulate or paste) in order to achieve the same permeability as the GCL itself. Pre-fabricated impregnated overlaps (e.g. in the case of Bentofix® B4000 or NSP 4900-1) or GCL-types that are impregnated over the entire surface (e.g. Bentofix® BFG 5000) simplify the installation process on site. In this case overlaps do not additionally have to be bentonite treated thus facilitating considerably the installer's work.

Mechanic impacts during installation and after completion may have negative effects on the function of the sealing system. Strict obedience of the installation guidelines and the appropriate selection of the GCL can prevent them. In principle, the installation guidelines of the manufacturer and the project-specific installation instructions have to be followed as they describe appropriate installation methods.

For RiStWag projects, the following items concerning the selection and installation of GCLs should be considered in order to ensure the safety of the structure:

Installation plan: Before installation, an installation plan should be established. It should not only indicate the position of the GCL but also include a schedule for the installation process.

Subgrade: The GCL is installed upon the subgrade that should be prepared such that it is even and compacted

and should hardly exhibit ruts or void spaces. Shortly before installation, the surface should be free of water.
Installation: The GCL should be unrolled under dry weather conditions and be pulled only to be flattened or straightened. In general, anchor trenches are necessary on the top of the slope. It is not allowed to drive over the GCL and walking on it should be limited to a minimum. Tools and other objects should not be placed on the GCL.
Overlaps: Overlaps shall be installed roof to prevent water flow into the overlaps in drainage direction (≥ 30 cm overlaps are recommended) and be free of foreign particles that might affect the permeability.
Placing soil material: The highest static and dynamic impacts on the GCL usually occur when covering the GCL with soil material. It is therefore recommended to place the cover soil directly on the GCL without traffic taking place directly on the GCL. It then should be distributed with the appropriate equipment. In the overlap area, soil placement shall be done in overlapping direction thus preventing the overlaps to be opened and soil material to penetrate into the overlaps. A wide-grained material with possibly low grain size is recommended; round-grained material is to be preferred to instructions crushed material. In principle, it is not allowed to cover a GCL in hydrated condition. As standard value, the water content of bentonite should not exceed 50%. The minimum cover of the first layer (≥ 30 cm) depends on the grain size distribution and the GCL components. A woven component on the top is more susceptible to damages than a nonwoven component. However, a high mass per unit area of a nonwoven component makes the GCL top cover more robust and consequently more resistant against coarse armour soil material. At least 30 cm of soil material is to be placed prior to the end of every working day. Overlap areas that are needed for the next day must be wrapped up with foil over night to avoid free swelling.

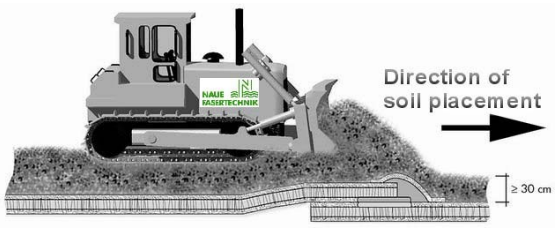

Figure 3. Schematic soil placement over a GCL

Covering process: Continuous site traffic and vehicle passage may cause damage after installation. A minimum cover of 80 cm is required to provide sufficient protection for frequent traffic.
In principle, calculated tensile stresses on the GCL are not allowed. All slope-parallel shear strengths have to be proven either in the contact surface to the GCL (external shear strength) as well as within the GCL (internal shear strength) in hydrated condition. Needle-punched geosynthetic GCLs are particularly suitable as they exhibit a direction-independent shear strength resistance due to a specific manufacturing process.
Detailed information about GCL characteristics cannot be found in the RiStWag guideline so that standard values that have been used up to now have to be considered., e.g. from successful projects, the regional performance catalogue from the Road Construction Agency Baden-Württemberg (amendments to the technical terms of contract in road construction Baden-Württemberg, tender texts for GCLs, edition 1996) or from the EAG-GTD (2002).
If a nonwoven is used, the components of the GCL should be ≥ 200 g/m^2 resp. ≥ 100 g/m^2 when using a woven. However, the selection also depends on the cover soil. Project experiences have shown that in the case of course grained soils the mass per unit area for nonwovens should be ≥ 270 g/m^2 and for wovens ≥ 180 g/m^2. These geotextile characteristics ensure a relatively high robustness against installation stress and an erosion-controlled bentonite encapsulation.
The mass per unit area of the bentonite should be ≥ 4000 g/m^2 (at a bentonite water content of 12%). Natural sodium bentonites with the following characteristics are commonly used (von Maubeuge 2002):

Swelling volume according ASTM D5890: ≥ 25 ml.
Absorptive capacity according DIN 18132: ≥ 600%
Fluid loss according to ASTM D5891: ≥ 18 ml
Permittivity according to DIN 18130: ≥ 5 x 10^{-9} l/s

The use of high swelling natural sodium bentonite for the GCL additionally provides safety in the case of an unmeant and undeterminable damage during installation. The natural sodium bentonite has an exceptional swelling capacity when absorbing water and can self-seal damages up to a dimension of approx. 2 cm. Other bentonites (e.g. calcium bentonite) do not exhibit such properties to that degree.
The characteristics of the GCL are the maximum tensile strength (≥ 8 kN/m according to ISO 10319), a permittivity of ≥ 5 x 10^{-9} l/s according to DIN 18130 as well as project-specific internal and external friction coefficients. In addition, it makes sense to determine the bonding strength of the GCL, especially when using it on slopes and when a correlation to the internal shear strength can be proven, e.g. in the case of a needle-punched GCL (Heerten, 1994 and von Maubeuge, 2000). As standard value 600 N/m according to ASTM D6496 or 60 N/10 cm according to ISO 10319 can be used.

3. NEW GEOSYNTHETIC CLAY LINERS / POLYPROPYLENE COATED

New needle-punched, thermally locked, geosynthetic clay liners with polypropylene membranes have been introduced since the start of this decade. New to the geosynthetic industry, these types of GCLs offer engineers and designers with a permeability value of less than 5x10^{-13}cm/sec (ASTM E96). The polypropylene coating is typically applied to the woven portion of the GCL, thus allowing the non-woven fabric to be available for soil-fabric interaction (angle of friction). These GCLs also offer the prevention of root growth should this be a concern on a specific site, which may be the case for road related projects as outlined in this paper.

4. CONSTRUCTION PROJECTS WITH GCLS

The following case studies are representative for the installation of several million square metres of needle-punched Bentofix® GCLs. The European standardization committee CEN TC 198 has been working on the application standard “Sealing in infrastructure projects” for more than a year now. It shows that the use of geosynthetics, especially geomembranes and geosynthetic clay liners, is important at international level.

4.1 B 3 City by-pass Wasser near Freiburg (Germany)

The project had been discussed for more than 40 years before the three-laned road (width 11.50 m) was finally constructed in 2002. The required water protection measurement was performed in four working steps according to the planning of the designing office Misera in Freiburg:

A 10 cm thick sand layer was installed over the prepared subgrade.
A needle-punched GCL-Bentofix® BFG 5000 followed serving as barrier according to RiStWag.
In order to prevent damages on the GCL caused by coarse-grained and sharp-edged cover material, a needle-punched Secutex® R504 nonwoven was installed upon the GCL.
The road superstructure according RstO 86/89, construction class II, line 1 completed the sealing system

At the official demonstration on site that finally took place on 31st August 2002, the GCL was installed and the advantages of needle-punched geosynthetics were described (simple installation, robustness against installation stress, factory-manufactured overlaps). The construction company Gebr. Pontiggia GmbH & Co. KG had invited representatives from the Road Construction Agency Freiburg, from the Building Material and Soil Examination Facility Freiburg and from the local press to attend the installation that was performed by the GCL manufacturer Naue Fasertechnik GmbH & Co. KG and its installation partner Ludwig Kunststoffe OHG.
„This is the first time that a carpet is rolled out when I show up“ was the joking comment of the construction manager. Of course, he meant the GCL as RiStWag sealing system (figure 5) that is located in a protection zone IIIB and II.
In the preliminary stages of the project, it was already known that the installation of the sealing system would have an important influence on the entire project procedure. The excellent cooperation between the installer and the construction company as well as the self-sealing overlap, one of many characteristics of the selected GCL, enabled an installation of almost 10,000 m^2 GCL in only 3 days.

Figure 4. Installation of the needle-punched geosynthetic clay liner serving as RiStWag sealing in the project B 3 Wasser near Freiburg

4.2 B 19 City by-pass Herbrechtingen, Germany

As a result of the new design of the connection road to the B 19 (regular width 8 m), the new pass-by near to Herbrechtingen led through a water protection zone III so that a sealing had to be installed. The responsible Road Construction Agency Ellwangen contracted the company Baur Consult, Hassfurt to make the planning for the design and the company Walter Hebel Baugruppe AG, Sontheim, to perform the project. A needle-punched Bentofix® NSP 4900-1 according to RiStWag was selected for a surface of approx. 20,000 m^2.
After removal of a 2.50 m thick peat layer, a load-bearing gravel layer was provided as base course. Soil replacement as well as the road sub-base where made of removed soil or from excavation material from a tunnel. The needle-punched GCL from Naue Fasertechnik GmbH & Co. KG (installed by Ludwig Kunststoffe OHG) completed the structure according to RstO 86/89, construction class I, table I, line 3.

4.3 B 82n City by-pass Langelsheim, Germany

When constructing or extending new roads, the responsible designers and contractors are increasingly faced by the task to prevent soil contamination. Therefore, measurements for the protection of the groundwater are necessary. The corresponding requirements and specifications for such measurements are regulated in the German guideline for constructional measurements in roads in water protection areas (RiStWag, edition 2002). Even at the European Standardization level CEN TC 189 such a guideline for infrastructures is in preparation.
The design of the new by-pass road B 82n from Goslar, Germany to the highway A7 also required a groundwater protection measurement. In the area of the village Astfeld, area Herzog Julius Hütte, Germany, the planned road leads across a 250 m long and 500 years old waste deposit. The bottom soil layers consist of smelter slag and were considered as contaminated. The official plan approval for the road B 82n stipulated a sealing in order to

prevent surface water to penetrate the waste body and wash out contaminants into the groundwater.

Considering various solutions, the regulators finally decided to install a GCL (geosynthetic clay liner) as the single sealing barrier. According to the calculations of the designing office BBU in Braunschweig and the Geosynthetic Consultant BBG, Lemförde, Germany, the application of a geosynthetic drainage system above the GCL was recommended thus preventing backwater and weakening the soil strength. Additionally, a geogrid with high strength junctions was placed in several slope areas allowing a steeper and low-cost construction.
As a result of detailed tests, the GCL Bentofix® BFG 5000, the geosynthetic drainage system Secudrän® R 201 W D 601 R 201 and the geogrid Secugrid® 200/40 R 6 as well as 300/40 R 6 from Naue Fasertechnik GmbH & Co. KG were chosen as geosynthetic products.
The result is convincing: The regulators have been highly satisfied about the design and the performance of the project as well as about the quality of the applied materials. On behalf of the city council, another project simultaneously started according to the regulations of RiStWag and using the products of Naue Fasertechnik: the sealing of a boundary dam in the border area of the road B 82n was sealed.

Figure 5. Installation of geosynthetics in the infrastructure sealing application by-pass road B 82n Langelsheim, Germany

4.4 Autoroute 73, Stoneham, Quebec

The existing highway (Route 175) connecting the Lac Saint-Jean area with the Provincial Capital is undergoing lane expansions. One of the problems faced by Transport Quebec was the possible contamination of residential wells in the Stoneham area. To resolve this situation, Transport Quebec lined the existing highway in the Stoneham area with a geosynthetic clay liner in 1993. During the fall of 2003 and the spring of 2004 the new highway lanes through this sensitive area of Stoneham was connected with the previously installed GCL from 1993. The GCL used in this project was supplied as per Transport Quebec's guidelines with a scrim reinforced GCL, which included a thicker than normal non-woven fabric on both sides of the GCL to obtain a high strength resistance as well as the addition of an enhanced polymer for the protection against road salt.

Figure 6. Deployment of the GCL for the future Autoroute73/existing Route 175 in Stoneham, Quebec.

Figure 7. Cover soil placement of the GCL seams. Technique used to prevent the movement of the membrane and the seams during the soil placement operations by Bulldozers as shown in Figure 3.

Altogether, the highway was properly lined with a GCL for a total length of one (1) kilometre for a total of 40,000 square metres.

5. SUMMARY

The first edition of the German "Guidelines for construction projects in waterways of protected areas" of 1982 has been replaced in 2002 by a new edition describing among other things geosynthetic sealing systems such as geomembranes and geosynthetic clay liners (bentonite mats).

Covered with at least 80 cm of soil, geosynthetic clay liners (GCL) are equated with the previous standard solution, a clay liner. However, GCLs exhibit various advantages compared to other RiStWag sealing systems:
The GCL is a homogenous sealing layer that can be tested for its quality prior to installation.
The use of natural sodium bentonite provides a self-healing effect of the GCL, especially during installation.
A needle-punched GCL exhibits a direction-independent shear resistance over the entire surface. Correctly designed, it can be installed in steep slope areas.
GCL products that are impregnated with bentonite over the entire surface can be installed on site. Since the field application of bentonite paste to the overlaps is not required, a quicker and saver installation can be ensured.
GCL products can easily be delivered to the site (approx. 4,500 m2 per load) and easily be installed with light equipment. Therefore, GCL products are economic and ecological solutions.
Large experiences with needle-punched geosynthetic clay liners have shown that a GCL comply with the new RiStWag requirements. It is not only a product of high quality and high future potential for the road construction but also easy to handle and quick to install during constructions in process. GCLs are cost-saving sealing products and preserve our natural environment.

6. REFERENCES

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