Effect of ion exchange on GCL used at roads in water catchment areas

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ABSTRACT: The suitability of GCL as a sealing layer at roads in water catchment areas was investigatet. The main focus was on the effect of ion exchange on the ability to swell and close cracks with the consequernce of changing permeabilty. The condition of GCL having been in use for several years and the constitution of the surounding soil have been dokumented using test pits. A Laboratory test accelerating ion exchange combined with wet–dry-tests has been developed. An analysis comparing results of GCL taken in the field and laboratory simulations was made and proposals for the use of GCL as a sealing layer at roads in water catchment areas were made.

1 INTRODUCTION

The German guideline for the sealing of roads in water catchment areas (RiStWag) is revised. In addition to mineral sealing layers made of fine grained soil with low permeabilty, polymer e geomenbranes and geosynthetic clay liners (GCL) shall be taken into account. As standard to value the quality of the new products, the mineral sealing is used. By order of the Ministry of Traffic the suitability of GCL for this purpose was investigated during a research programm at the Institute for Foundation Engineering, Soil Mechanics and Rock Mechanics, Technical University of Munich.

The main purpose was on the durabilty of GCL by investigating the effect of cation-exchange on the quality as a sealing layer. Samples of GCL been in use for several years were taken for laboratory tests. Further tests using new GCL have been developped to simulate the aging by accelerated ion exchange combined with wet-and–dry-tests.

2 GCL AS SEALING AT ROADS

2.1 *Qualities of GCL*

GCL consist of clay dust that swells by addition of water and that is usually fixed between two needlepunched or sewn layers of nonwoven geotextile. As sealing material predominantly natural or artificially (soda) activated sodium bentonite is used. Calcium bentonite with lower ability to swell is unfrequent. GCL customary in trade have a bentonite content of 3000g/m² to 5000g/m².The very high swell property and the low permeability of the bentonite determine the suitability of GCL as sealing layer.

The swell property of sodium bentonite with water using the Enslin –Neff-Test (free swelling of a little cone of clay) covers a margin of approx. w_a=500 % up to w_a=700 %. In comparison the swell property of calcium bentonite reaches from about w_a=200% to w_a=300%. A load of 15kN/m², simulating a soil cover of about 0.8m, reduces the swell property of sodium bentonite with water from w_a=150% to w_a=200%.

The permeabilty of fresh sodium bentonite has a range of about k=1E-11m/s to k=5E-10 m/s. The permeability of calcium bentonite ist approx. factor 10x higher. A clay thickness of 1cm leads to a permitivity ψ [1/s] factor 100x higher.

The supply with calcium ions from seepage water in field conditions effects a transformation from sodium-bentonite to calcium-bentonite during several month to a few years. This ion exchange affects natural sodium bentonite als well as activated bentonite.

When water is added cracks in the bentonite layer caused by desiccation or the influence of frost close fast because of the high swell property. The capability to close cracks and as a consequence the quality as sealing material of sodium bentonite can decrease when ion exchange takes place.

The swell property of bentonites ist reduced when saline solutions are used instead of water. Swelling is very low using water mixed with hydrocarbon (oil, diesel fuel or gasoline). In this cases the ability to close cracks and therefore the effectiveness as sealing decrease.

2.2 *Special tasks as sealing at roads*

2.2.1 *Permittivity*

Using the mineral sealing as standard, GCL must have a durable permittivity of $\psi < 1.0$ E–07 m/s. In case of accidents this liquid tightness must be guarentied versus gasoline, oil and diesel fuel at any time. Saline solutions can occur in huge amount in winter as well. The required permittivity versues these liquids can only be optained if permanent wet and saturated conditions of the bentonite in the GCL are ensured. Changes in structure caused by desiccation or frost have to be avoided. The required permittivity must be assured as well for GCL containing chemically modified sodium bentonites after ion exchange.

2.2.2 *Mechanical properties*

A sealing system must resist the stress of installation, earth works to shape the cover, compaction and traffic at the construction site. Later in use permanent stress results of the cover and possibly dynamic loads are caused by traffic. As extraordinary loading case vehicles deviating the road during accidents must be considered.

2.2.3 *Stability*

Installing sealing systems at slopes requires stability of the embankment itself and stabilty at predetermined shear planes at the bottomside and the surface of the GCL. The shear strength of the water saturated GCL must not be exceeded. No systematic tensile stress on GCL is allowed.

3 FIELD- AND LABORATORY INVESTIGATIONS

3.1 *Test pits*

Seven test pits in Germany were opened to investigate the status of GCL having served as groundwater protection between one and seven years. Five of the GCL had been installed at roads and two at retention basins in water catchment areas. All GCL excavated in the test pits contained of sodim bentonite.

During excavation the situation and the detailed profile of the covering soil as well as the soil unter the GCL were registrated. Samples of the GCL and the soil were taken for further investigation in the laboratory.

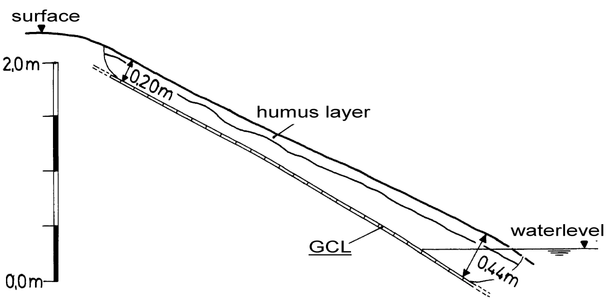

Figure 1: GCL with little cover at a retention basin.

A typical situation of a GCL with little cover at the slope of a retention basin is shown as cross section in figure 1. The typical situation of a GCL installed in an embankment with sealed up ditch is shown in the cross section figure 2.

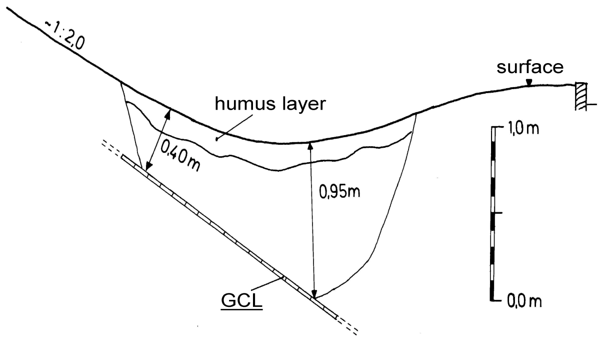

Figure 2: GCL in an embankment with ditch.

The thickness of the *humus layer* did not vary much. It consisted in most cases of sawed grass added by succession with corn and herbs. Even the humus layer above the one year old GCL had a thick network of roots.

Table 1: VEGETATION / HUMUS LAYER IN 7 TEST PITS

INVESTIGATION		QUANTITY OR RESULTS
Plantation	[+ / -]	predominantly (grass, clover)
Succession	[+ / -]	in addition to plantation (grain, herbage, thistles)
Thickness	[m]	0.05 to 0.15
Depth of roots	[+ / -]	full layer

The *cover* of the GCL had a great variety of thickness and composition. It did not only change from one site to another, but the thickness varied even in one pit between 0.40 m at the slope to 0,95 m at the ditch. Fine grained material, coarse material as well as mixtures of both have been detected. With one exception, a cover installed in layers, more or less unique material was used. In three cases a protective layer ore drainage was situated above the GCL.

Table 2 COVER OF GCL IN 7 TEST PITS

INVESTIGATION		QUANTITY OR RESULTS
Thickness without humus layer	[m]	0.10 to 1.60
Mixed with humus soil	[m]	0.00 bis 0.44
Depth of roots	[m]	up to 0.80
Protective layer above GCL	[m]	3 out of 7 pits 0.05 m to 0.20 m
Predominantly finegrained	[x/o]	2 out of 7 pits
Fine- and coarse grained (mixed)	[x/o]	2 out of 7 pits
Predominantly coarse grained	[x/o]	3 out of 7 pits
Humidity - upper part	[+ / -]	different
Humidity - lower part	[+ / -]	mostly higher than upper part

Normally *roots* reached to a depht of about 0.80 m or to the GCL that was mostly situated in minor dephth. Only a site with very deep GCL at 1.10 m to 1.70 m and the site with one year old cover did not show roots reaching down to the GCL.The intensity of roots decreases with increasing cover. Roots in the bentonite layer tend to follow the clay instead of crossing the GCL in right angle. Besides this no systematic could be recognised concerning diameter and intensity oft roots in the top nonwoven geotextile, the bentonite layer or the bottom geotextile.

Cracks caused by desiccation with a size that can be recognised visually have been detected in two pits where the GCL were covered less than 0.5 m. The intensity of cracks decreased with the increase of cover. “Bending” GCL-samples with caution after removing the top geotextile, uncovers further preexisting crack patterns.

Table 3 GCL IN 7 TEST PITS

INVESTIGATION		QUANTITY OR RESULTS
Depth unter surface	[m]	0,10 to 1,70
Mass per unit area (dry)	[g/m²]	4800
Cover fleece wet	[x/o]	5 (7) out of 7 pits, 2 x only depression
Cracks caused by desiccation in GCL	[x/o]	2 out of 7 pits, predominantly high level
Watercontent bent. upper layer (overlapping)	[%]	33 to 171 (91 samples)
Watercontent bent. high level of embankment	[%]	33 to 55 (27 samples)
Watercontent bent. foot of embankment	[%]	60 to 129 (29 samples)
Watercontent bent. if cover < 0,50 m	[%]	33 to 77

Watercontent bent. if cover > 0,50 m	[%]	76 to 171 (30 samples)
Watercontent bent. Bottom layer (overlapping)	[%]	73 to 161 (11 samples)
Roots in cover geotextile	[+ / -]	4 out of 7 pits, predominantly high level
Roots in bentonite	[+ / -]	3 out of 7 pits, predominantly high level
Roots in bottom geotextile	[+ / -]	4 out of 7 pits, predominantly high level
Diameter of roots	[mm]	0.2 to 2.2
Enslin / Neff (after 24h): all tests	[%]	210 to 535
Enslin / Neff (after 4h): all tests	[%]	144 to 424
Enslin / Neff (after 24h): average per test pit	[%]	260 to 439
Enslin / Neff (after 4h): average per test pit	[%]	180 to 344
Enslin / Neff (after 4h): after CaCl2-treatment	[%]	199 to 263
Permittivity: (start of test)	[1/s]	3.0E-09 to 7.5E-05
Permittivity: (end of test)	[1/s]	8.2E-10 to 2.8E-05
Permittivity: (end of test): average per test pit	[1/s]	1.5E-08 to 5.4E-06
Permittivity: (end of test): total average	[1/s]	9.6E-07

The *soil under the GCL* was fine grained, coarse grained or it was a mixture of both. In more than half of the sites, it resembled the cover material. Dry soil unter the GCL in two pits is an advice for low permeability of the sealing. Only at two sites roots reached into this layer.

Table 4 SOIL UNDERNEATH THE GCL IN 7 TEST PITS

INVESTIGATION		QUANTITY OR RESULTS
Fine grained	[x/o]	2 of 7 pits
Fine- and coarse grained (mixed)	[x/o]	3 of 7 pits
Coarse grained	[x/o]	2 of 7 pits
Dry	[x/o]	2 of 7 pits
Wet	[x/o]	2 of 7 pits
Roots	[x/o]	2 of 7 pits

3.2 *Laboratory tests of field samples*

The overall aprox. 100 *water contents* of the bentonite layer have a huge range between 33 % and 171 %. GCL with little cover of 0.2 m to 0.5 m show the lowest water contents. A significant increase was detectet with rising cover thickness. Covers of more than 0.5 m leads to water contents of the bentonite that are generally higher than 76 %. Sections with overlapping GCL in the different pits show no significant variation of the watercontent depending on the layer.

Using the Enslin-Neff-test bentonites from four out of seven sites showed only 1/3 to 1/2 oft the *swell proper*ty known from fresch sodium bentonite. Bentonite from three pits had more than 1 /2 of the original swell property. The ability to swell decreases in correlation with the time in use. Correlations to the thickness of cover are unclear. Declining swell property can be seen as evidence for starting up to total transformation from sodium bentonite to calcium bentonite as consequence of ion exchange. Comparing these reduced swell properties with the swell property of samples from the field after having been treated with $CaCL_2$–solution (ion exchange), enables to estimate the status of transformation.

The *permittivity* of the field samples varied in a wide range of prox. $\psi = 8E{-}10$ m/s to $\psi = 3E{-}05$ m/s. Regarding the median of each pit, the permittivities are at least factor 100x higher compared to new GCL with sodium bentonte. The highest permittivities have been determined at GCL with little cover thickness, longest time of use and lowest swell property.

3.3 *Additional laboratory tests*

One further objective of the research programm was to develop a workable test to accelerate ion exchange and to analyse effects on the ability to close cracks caused by desiccation and the effect on the permeability in general. Different GCL with sodium bentonite, one with calcium bentonite and bentonite-powders were used. Further tests that are not regarded here, were performed with different clays.

Tests to investigate the influence of wet-and-dry-tests with and without ion exchange were performed in the testing set described in fig.3. The main pattern of cracks was documented after every drying-cycle by taking pictures of the sample illumitnated from the botomside. Using a solution of 20g $CaCl_2$ in 1 liter water, ion exchange was completed after two to six wet-and-dry-tests. A disadvantage of this test is the modification of the bentonite structure and that the effect of ion exchange cannot be determined isolate.

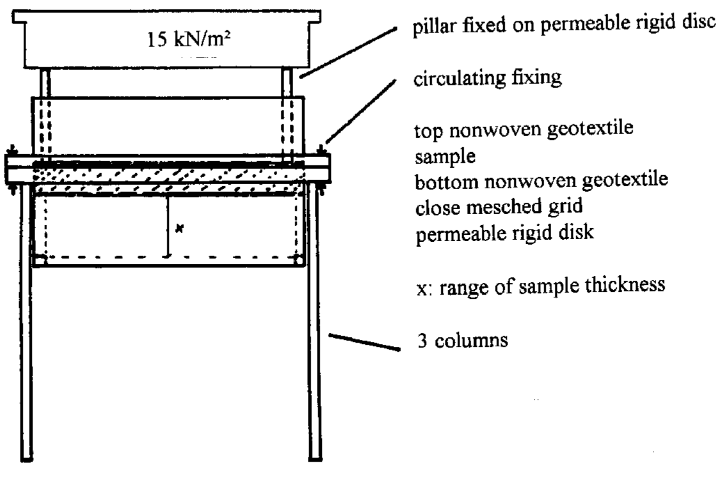

Figure 3: Testing set ϕ 15cm for dry-and-wet–tests with GCL or clay dust.

Different laboratory tests finally led to a simple method to accelerate ion-exchange without distruction of the sample. The initial swelling and storage of a new GCL in a basin filled with a solution of 20g $CaCl_2$ in 1 liter water leads to an extensive ion exchange in less than two weeks. The tests were performed with samples up to 0.40 m x 0.40 m and a constant load of 15 kN/m². The proceeding cation exchange was measured with swelling tests.

Finally a test (fig. 4) was generated that simulates the situation in the field and accelerates the ion exchange. The test is performed with two samples of one kind. The initial swelling is performed with water, the following wet-and-dry-tests are performed with water for one sample and with saline-solution for the other sample. The experimental setup allows a semi-quantitative determination of permeability during the wet-and-dry cycles. Finally permeability tests in separate test-devices are possible.

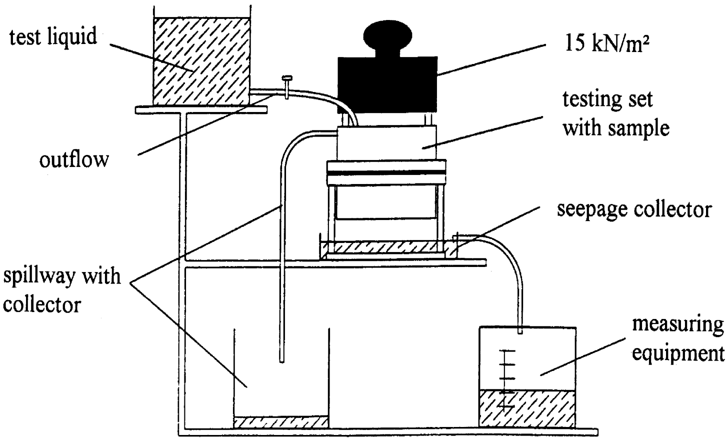

Figure 4: Scheme of the total experimental setup

Ion exchange in bentonites alone did not cause permittivities higher than the benchmark of $\psi = 1{,}0E{-}07$ m/s. A sequence of wet-and-dry-tests alone did not cause a permittivity higher than the benchmark as well. Regarding four tested sodium bentonites, the combination of accelerated ion exchange with wet-and-dry-tests caused permittivities two to five times higher than $\psi = 1{,}0E{-}07$ m/s in three cases. One bentonite remained below the benchmark.

4 RESULTS – SUITABILITY

The general suitability of GCL as sealing layer at roads in water catchment areas is verified. A reasonable use of GCL predominantly demands to prevent desiccation and as a consequence the formation of cracks in the bentonite.

A cover of at least approx. 0.8 m helps to avoid immoderate desiccation and therefore reduces macroscopic cracks. From experience the load of the cover has a positive effect on closing cracks during swelling. Desiccation and variations of the structure caused by frost are efficiently reduced when the GCL is installed deeper. The influence of roots cannot be eliminated totally even in depht below 0.8 m, but it will be reduced. Sufficient depth in addition provides a better protection against mechanical damage.

In field use, the decrease of swell property as consequence of the transformation of sodium bentonite into calcium bentonite due to ion exchange cannot be prevented. This chemical alteration alone leads to permittivities approx. factor 10x higher. In each application of GCL it should be proofed up to what extend the extraordinary low permittivity of new sodium bentonite is required at all.

A higher content of bentonite per unit area, modifications in the set of layers in the GCL, upgraded clays and the material used for the cover are starting points for the adaption to different demands.