Geosynthetics: Applications, Design and Construction, De Groot, Den Hoedt & Termaat (eds)
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Design and construction of sealing systems with geosynthetic clay liners (GCL)

D. Heyer & R. Ascherl
Lehrstuhl und Prüfamt für Grundbau, Bodenmechanik und Felsmechanik, Technische Universität München, Germany

ABSTRACT: The meanwhile wide applications of GCL's for groundwater protection in traffic areas, as landfill liners or in hydraulic engineering, showed that on the one hand they are economic and easy to handle, but on the other hand high demands on design and construction have to be satisfied.
First, the technical demands and the required qualification tests for the various applications are presented. Particularly, specifications for laying, testified in special drawings, are important for construction control and to prove laying performance. The importance of test grounds is shown by an example. Finally, quality control during construction is a further point of main effort. With respect of this, instructions for the storage of GCL's, the quality of the surface of support, proving the laying performance, placing the surcharge and the creation of joinings are given. Furthermore the kind and the expense of required control tests is proposed.

1 INTRODUCTION

During the last years the distribution of Geosynthetic Clay Liners (GCL) significantly increased. Among the wide applications the following are essential:

- Groundwater protection in traffic areas [1,7]
- Sealing elements in hydraulic engineering [4,5]
- Landfill-cover-liners [2]
- Sealing elements for artificial ponds in parks in parks or golf-courses

The main advantage of GCL's is their easy handling, that facilitates a fast and flexible laying so that they fit better to the constructing process than other sealing elements.

Though GCL's are a relatively new geotechnical product, so that no uniform standard could be developed for the following criteria:

- definition of technical demands on the industrial production
- development of suitable examination methods
- the kind and expense of qualification and control tests for the required properties

Furthermore only few consulting engineers and building firms are experienced in the application of the sealing element GCL.

At present recommendations and instructions for minimum technical demands for the product and the construction of sealing systems are worked out.

Geosynthetic Clay Liners are uniform industrially produced, so that high quality standards can be reached. To ensure the required technical demands, an adequate internal monitoring and additional external monitoring of the production in the factory is necessary.

As the main element of a sealing system, the GCL always operates in connection with the surface of support and the fill - the other components of the sealing system. Consequently the quality standard of the production is only part of the quality of the sealing system.

Therefore proving the appropriate laying of the GCL and mounting of the adjoining layers is of great importance.

As the external controller needs detailed knowledge of the laying of GCL's, it is advisable to include him already during design - especially the selection and the arrangement of the components of the sealing system and the conception of the quality control system. Therefore the responsibilities of the external controller are wider than the execution of the control tests.

2 BASIC EXAMINATIONS ON THE TECHNICAL DEMANDS FOR THE VARIOUS APPLICATIONS

The main technical demands have to be defined already during the design of the sealing measure. With respect of those technical demands, qualification tests have to be carried out. The varied GCL-products can only be compared with regard on their composition of different layers.

Relating to the various applications, the suitability examinations [3] may include the following criteria:

- permeability characteristics
- effect of wet/dry cycles
- effect of freece/thaw cycles
- influence of loading
- influence of hydraulic gradient
- influence of saline defrosting solutions and hydrocarbons
- selection of soil material below and above the GCL
- effect of root-perforations
- internal shear strength (short- and long-term)
- shear strength between GCL/geomembrane and between GCL/other adjoining components of the sealing system
- permeability of overlapping
- self healing after perforation

The essential test-procedures to examine the questions mentioned above, are described in [3].

Often the quality of the surface of support and the selection of fill-materials are of main interest. In this context, it is important, whether there are dynamic loads (construction traffic), or cyclic loads (water-level variations), so that the soil material and the design elements, as the elevation of fill above the GCL, should be adapted to the actual surrounding conditions.

If there are conflicts between the properties of the particular components of the sealing system, as for example on the one hand a sufficient drainage capacity of the fill and on the other hand the protection of the saturated bentonite layer against single large grains, an optimising will be necessary. Such aspects can be examined in the laboratory or better on site by test grounds.

Referring to the actual surrounding conditions, the demands on the selected materials and components of the sealing system should include statements on the properties of the GCL-product, as permittivity, mass per area, thickness, mechanical demands, furthermore on the soil material for the surface of support and the fill, as the distribution of grain sizes, minimum sand content and demands on compacting.

3 LAYING PLAN AND DOCUMENTATION

Laying plans are an important element of quality management, so that they should be required in the announcement of the construction project. The laying plan should be prepared by the executing firm in advance of the construction process and should be controlled and approved by the orderer and/or the external controller. During the installation of the GCL's, the laying plan is used for documentation on the location of the particular GCL and the laying performance.

The importance of the laying plan is, that the executing firm and all participants have to examine the aspects of an appropriate handling and laying of the GCL's. In this context, test grounds to instruct the executing firm in laying of GCL's are advisable.

The laying plan should prepared with regard on the following criteria:

- laying in direction of drainage (overlapping like roof shingles)
- laying downwards
- binding ditches in the top of the slope
- no four-time overlapping ('cross-joinings')
- avoidance of overlaps in the top or the bottom of slopes
- observance of required gradients

Special details, as joining to buildings, perforation of pipes or difficult geometric conditions (ditches) should be designed appropriately in advance of the construction process.

With regard on warranty, the laying plan gets additional significance, as it is the basis and the documentation of the quality control. The following data should be included:

- constitution of the surface of support
- date of installation
- place of installation
- roll-no. of the GCL
- location of samples
- weather conditions during installation

This documentation of the laying performance should be carried out daily.

4 EXAMPLE FOR A TEST GROUND

For every large-scale sealing measure it is advisable to arrange test sites referring to the following aims:

- evidence of appropriate and sufficient laying performance and devices by the executing firm
- examination on the suitability of the particular elements of the sealing system
- examination on special problems

As an example, the test ground in course of constructing the A 96 motorway near Leutkirch in Allgäu/Germany will be presented (see fig. 1).

Fig. 1: Installation of the test ground

With regard on the motorway construction process, the traffic of the earthwork operations crossed areas, in which the GCL's were already installed. Regarding this, it was unclear, whether and with which amount the resulting dynamic loads could affect the effectiveness of the GCL. As there was not enough experience to simulate such dynamic loads in the laboratory, a test ground was laid out to examine the following questions:

- effects of various fill materials
- influence of the elevation of fill
- effect of protective geotextile layers

Test procedure

The test ground was located in a cutting of the A 96-line with a length of approx. 26,5 m and a width of approx. 10 m.

As shown in fig. 2, the GCL's were installed with three different soil fill materials, whereby a protective polypropylene geotextile with a surface mass of 600 g/m² was additionally laid on the GCL to half of the extent in each of the three areas. The elevation of fill in all areas evenly decreased from approx. 85 cm to approx. 40 cm, so that the influence of the elevation of fill could be examined (see fig. 2).

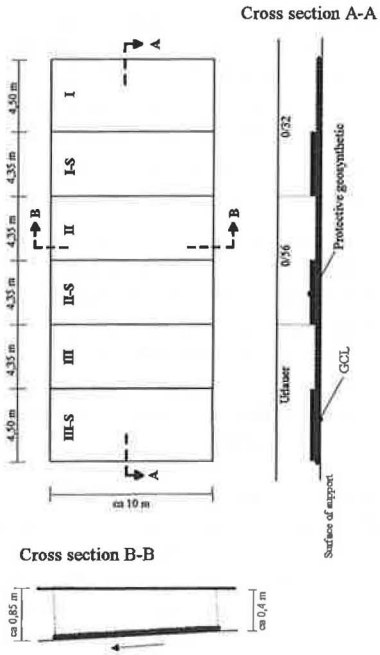

Fig. 2: Construction of the test ground

As fill materials, filter gravel 0/32 and 0/56 and a local sandy gravel, called "Urlauer", were used (grain size curves see Fig. 3).

During a period of seven weeks, the test ground was subjected to the traffic earthwork operations so that the GCL's were stressed by the resulting static and dynamic loads. At the end of the test period, the test ground was exposed in sections and large-scale samples were taken.

In areas with low elevation of fill, bigger grains of the fill were pressed into the GCL. Furthermore it was observed, that partially single grains pressed the

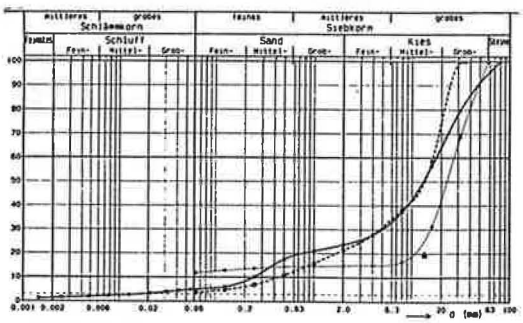

Fig. 3: Grain size curves of the three fill materials examined

bentonite away, so that there was no more bentonite present between the two layers. Those spots, where the two geotextile layers came into direct contact, were defined as 'defectives'. In scattered areas, bentonite permeated the covering geotextile.

Referring to those phenomena, the tests were evaluated as follows:

- opening the GCL (disconnection of the two geotextiles) to identify defectives
- determining the area of defectives
- determination of potential loss of bentonite (mass per area in g/m²) by drying cleaned samples
- permeability tests with variable hydraulic head - viz. DIN 18130-TX-ST-DE-UO [3]

Up to approx. 60 cm elevation of fill, in all tests defectives were observed (see fig. 4). The area of those defectives mainly depended from the maximum grain size of the fill material, so that the 'Urlauer-soil' caused the most defectives. Referring to defectives, there were no recognizable differences between tests with or without protective geotextiles.

In the tests without protective geotextile, a harmonious loss of maximum 35 % bentonite (dry bentonite) up to approx. 60 cm elevation of fill was determined. There was no recognizable difference between the fill materials. The additional protective geotextiles (tests I-S, II-S and III-S) caused significantly higher losses of bentonite up maximum approx. 50 % (dry bentonite). This disadvantageous effect of the protective geotextile is explained by the open pore-structure of the used non-woven geotextiles. In sections with greater depths of fill (approx. 60 - 85 cm), the loss of bentonite decreased in the sequence of 'Urlauer-soil', 0/56, 0/32.

In all sections with defectives, the permeability tests showed permittivities ($\psi = k/d$) up to 8 $\cdot 10^{-7}$ 1/s , that were in comparison to undisturbed samples with permittivities from 1 to 3 $\cdot 10^{-9}$ 1/s significantly heightened. The only loss of bentonite (no defectives) had no recognizable influence on the permittivity.

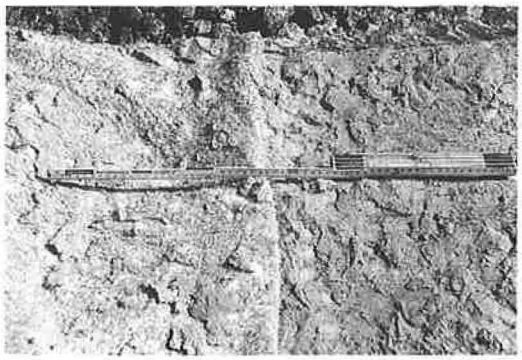

Fig. 4: Disconnected GCL with 'defectives'

Consequently, the sealing effect of the GCL is only affected in sections with defetives. Though the sealing effect was not affected by an only loss of bentonite, this phenomena must be seen critically, because a longer duration of dynamic loads could yet cause defectives and a potential affection of drainage pipes by sedimentation of lost bentonite.

Conclusions:

Dynamic loads on installed and already saturated GCL's, caused by construction site traffic in sections without a hard surface should be principally avoided on principle - for example by sealing those sections after finishing earthwork operations. If this is not possible, a well compacted fill and/or a protective sand layer (with low pore-volume) with a designated minimum elevation of fill, additionally an early installation of the hard road-surface should be arranged. Protective geotextiles should be avoided because of the disadvantageous effect of their open-pore-structure. The effectiveness of such protection measures should be proved in advance by test grounds with the selected components and construction of the sealing system.

5 QUALITY CONTROL IN COURSE OF CONSTRUCTION

5.1 Introduction

Monitoring quality in course of the construction process is of great importance because an insufficient installation may affect the sealing effect of the slim and sensible structure of GCL's. Consequently a permanent monitoring of the laying on site is advisable. In this context, the external monitoring includes quality control of the installed materials and the particular sections of the laid GCL's before filling.

5.2 Storage of the GCL's

The storage of the GCL's in construction sites has to be done in a way, so that any injury to the quality of the industrial product will be avoided. Partially wetted and saturated GCL's don't meet the demands on installation-quality. Thus the storage of GCL's should be carried out dry, clean and plain. The GCL must be protected against any precipitation. Injuries of the packing have to be covered/repaired. During loading operations the GCL may not be bended.

5.3 Quality of the surface of support

The surface of support for the GCL's should be sufficiently compacted, plain and able to support load. Irregularities of the planum can be repaired with sand. No single stones or gravel-grains may project. The needs an adequate drainage capacity, because the GCL may not be installed in wetted sections.

5.4 Monitoring the laying performance

As the executing firms often have no sufficient experience in handling GCL's, monitoring of the construction process is very important. Regarding this, the laying instructions have to be observed strictly. Fundamentally, only dry and unsaturated GCL's may be installed.

Because of the high weight of the GCL-rolls, adequate laying devices have to be used for an appropriate installation. Laid, but not yet surcharged GCL's may not be passed over by construction traffic, because of potential injuring of the GCL's.

The GCL has to be installed without folds or distortions. Installed GCL's may not be stressed by tensile loads - for example on steep slopes or in narrow ditches - because the GCL is not qualified for tensile stress.

To ensure the effectiveness of the sealing system, a minimum width of the overlapping is - with regard on the construction process - of significant importance, because the overlapping can be a weak point of the sealing system. Impurities inside of the overlapping must be avoided, because they might result in sections with heightened permeabilities. The worst result would be erosion-channels, so that the sealing system would loose effectivity in the affected sections.

Too big overlaps or more than one GCL one upon the other are also not advisable, because from experience a lowered shear strength is developed inside the surface of contact, so that the application of GCL's in slopes would be significantly limited.

A premature saturating and swelling of the GCL without load from the fill is not admissible. Saturated GCL's (criterion e.g. $w \geq 50\ \%$) must be removed. Consequently, the following demands on the laying operations must be observed:

- the fill should be installed daily - at least before any precipitation
- on condition of dryness, laying may also be done during frost

As laying of GCL's - even in great sections - can be done quickly, the laying performance must be adapted to the capacity of the following earthwork operations to avoid bigger sections without fill upon the GCL.

In descended sections, that cannot be covered continuously by GCL's in one day, laying must start on top of the descent, to avoid a waterflow downwards to sections that have already been partially sealed by GCL's.

Before installation of the fill, the laid GCL's have to be controlled by the external monitor and documented with the particular roll-no. in the laying plan by the executing firm.

5.5 Installation of the fill

The fill must be installed in a way, so that any damage or displacement of the laid GCL will be avoided:

- Building machines may not pass over the GCL's.
- The fill should be installed by forward operating excavators or caterpillars (no passing over GCL's). If caterpillars are used, not too much soil material may be moved simultaneously, because of the resulting high mechanical stress to the GCL. Pushing of soil (by caterpillars) may only be done in the direction of overlaps - not against the overlapping-joint - to avoid displacement or buckling of the GCL's.
- Rough turning of building machines upon the fill can also damage GCL's.
- Heightened static or dynamic loads (from construction traffic) can be reduced by a raised elevation of the fill or by building-roads outside laying sections.
- Local/punctate high loads must be avoided, because they result in displacements of the saturated bentonite.
- For protection against dynamic loads, a special protective layer (e.g. sand) upon the GCL might be suggestive.

5.6 Construction of overlapping and joining

On principle, overlapping is arranged in direction of drainage (as roof-shingles). A (water-) streaming against the overlapping-joint must be avoided, because a potential erosion of bentonite out of the overlapping might result.

If geotextiles (fleece and/or woven fabrics) lay one upon the other without sealing bentonite,

bentonite-paste or -powder is used to avoid zones of heightened permeability in the sealing system.

In slopes, the overlapping should be able to transmit the resulting shear stresses, so that special connections of overlapping should be arranged, to avoid displacement of the overlapping-joints.

Joining between new and old sections of the sealing systems can be arranged by standard overlapping, if the GCL's of the old section swelled/saturated after fill (supposed to the resulting static load). The construction of those parts of the sealing system demands exact monitoring. On principle, GCL's, saturated without fill/load must be removed. Consequently border-sections must be sealed by geomembranes till joining (to avoid swelling) or a strip of the already installed GCL (approx. 1 m) must be removed when the joining is arranged. Regarding this, the exposure of installed GCL's must be done carefully by hand, because building-machines would damage the GCL's.

Beside overlaps, joining to buildings or construction-elements are critical parts of the sealing system, so that they should be avoided, because the permeability may not increase in such areas to ensure the effectiveness of the sealing system. For joining to buildings or pipes, usually special constructive measures, as joining-sleeves combined with a filling of recesses by bentonite-paste, are available.

6 KIND AND EXPENSE OF CONTROL TESTS

The control tests on the installed components of the sealing system are usually carried out in the laboratory. Though, for special questions, test grounds might be necessary. Monitoring includes testing of the following materials,

- soil materials of the surface of support
- GCL's
- soil materials for fill and protective covering

whose suitability and compatibility as components of a sealing system have to be examined and proved. The required control-screen should be adapted to the importance of the sealing system. The tests are subdivided as follows:

- identification tests
- control tests
- special tests (e.g. excavations)

An internal monitoring of the GCL's on site during construction is not necessary because of internal and external monitoring of the industrial production viz. DIN 18200.

Monitoring of the materials should include at least the following examinations:

<u>Soil material for the surface of support</u>

- grain size curve
- compacting properties (proctor test)
- monitoring compacting and load capacity
- control-screen according to technical demands

<u>GCL's</u>

- permittivity (permeability characteristics)
- water content
- mass per unit of area
- internal shear-strength according to technical demands
- tests each 2000 m² - might be reduced, if results are continuously positive

<u>Soil-material of fill</u>

- grain size curve
- homogeneity of the material
- compacting properties (proctor test)
- monitoring compacting and load capacity
- control-screen according to technical demands

Field examinations to prove the permeability of the GCL's are not suitable because of the difficult conditions of permeability tests.

7 SUMMARY

Examinations carried out in recent years confirm the basic suitability of Geosynthetic Clay Liners (GCL's) for various applications. The main advantage of GCL's is their easy handling, that facilitates a fast and flexible laying so that they fit better to the constructing process than other sealing elements. GCL's are uniform industrially produced, so that high quality standards can be reached by adequate monitoring. As the GCL always operates in connection with the surface of support, the fill and other components of the sealing system, the effectiveness and the compatibility of all components must be examined and approved to ensure the required quality standard. Regarding this, the selection of the material and the structure of the other components gets significant meaning. Monitoring laying and installation in course of construction, turned out as the essential quality-ensuring criterion for the

effectiveness of the GCL and the whole sealing system. Various applications demonstrate the GCL as an effective and economic sealing element, provided that design, installation and monitoring were arranged carefully.

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