LABORATORY TESTS ON THE EFFECT OF STATIC LOAD TO THE DESICCATION OF GBR-C

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ABSTRACT: Clay geosynthetic barriers (GBR-C) are hydraulic barriers used as single liners or as a part of a composite lining in various applications, such as landfill caps, base seals, canal liners or in environmental protection applications. Their functional efficiency depends essentially on the conditions of the moisture under changing climatic conditions during its estimated service life. Possible desiccation and therefore an increase of permeability is one of the substantial facts which need to be investigated for project designs and which might influence the overall performance. However it is known that the bentonite used in common GBR-C has a self healing performance once it is in contact with water or surrounding soil moisture. The results of examinations in test fields have shown that cracks in GBR-C used as cap seals in landfills once developed, did not close even after a re-wetting cycle under certain circumstances. In the Geotechnical Department of the Institute for Material Research and Testing (MFPA) at the Bauhaus-University Weimar systematic laboratory tests were carried out to investigate the limit state conditions and the crack behaviour of GBR-C under different static loads during and after several periods of drying and rewetting. The new developed test equipment and the test procedure as well as first results are presented and discussed in this paper.

1 INTRODUCTION

Clay geosynthetic barriers are highly flexibly usable sealing elements due to their low thickness, consistent quality due to industrial production and easy handling. Their use in a variety of geotechnical tasks is today “state of the art.”

An authoritative parameter is the tightness of the GBR-C in all applications, expressed by the water permeability or the permittivity. The particular controversy over its long time effectiveness is discussed by experts again and again. Negative examples from the past have shown that irreversible structure changes can appear through too strong drying because of extreme external influences or an unsuitable layer construction of the capping system. On the other hand positive examples also show the effectiveness of GBR-C (HENKEN-MELLIES et al., 2003), that via an effective construction system, going under the moisture minimum limit can be avoided in dry conditions. The moisture limit means this ultimate water content at which the first continuous cracks appear under the predefined boundary conditions and the GBR-C function as a sealing element is not effective any more. For that reason we ask the question, how far the water content limit changes and whether the first continuous crack repeatedly appears in the same place under the same boundary conditions and repeated water dry cycles. To this end, tests were carried out under different boundary conditions in particular under different loads at the MFPA Weimar.

2 MATERIAL AND TEST EQUIPMENT

2.1 *Test material*

The laboratory tests were performed with GBR-C samples of a needle punched GBR-C with sodium bentonite in an equipment developed and continuously improved at the geotechnical department of the Institute for Material Research and Testing.

Round samples were cut out of a standard factory-new GBR-C Bentofix ® NSP 4900-1, Naue Fasertechnik, with a diameter of 23 cm. The tested area was 283.5 cm² at a test thickness of 19 cm. The authoritative properties on this clay geosynthetic barrier are represented in table 1.

Table 1 Properties of the used GBR-C and the Bentonite

Technical data	Unit	Value	Test method (based on)
Mass total per unit area	g/m²	5000	DIN EN 965
Mass bentonite layer	g/m²	4670	DIN EN 965
Thickness, total	mm	6	DIN EN 964-1
Permittivity	1/s	$\leq 5 \cdot 10^{-9}$	DIN EN ISO 18130 ASTM D 5887
Montmorillonite content	%	≈ 90	XRD
Water absorption	%	≥ 600	DIN 18132
Atterberg Limits LL PL	%	 550 48	 ASTM D 4318 DIN 18122
Swell index	ml/2g	≥ 25	ASTM D 5890

2.2 *Test equipment*

The tests were carried out in the test cell developed and further improved by the MFPA Weimar (WITT & SIEGMUND, 2001). The test cell consists of an overhead pressure plate with multi connections for water and air and a bottom-plate with different connections. In the core of the test cell there are two Plexiglas pipes with flanges which are put between the head and foot disk. The test bodies are put in between the two flanges. With that peripheral circulation can be excluded during the test.

The static load is applied over the pneumatic pressure gauge and stamp fastened to the top plate. Through this pressure stamp working an independent, constant pressure can always be reached by varying events. Additional the vertical movements of the pressure stamp caused by the swelling and shrinking processes of the Bentonite and thus the consequential changes in thickness of the test bodies can be recorded reliably by measuring instruments.

Perforated and slit Plexiglas disks above and below the test body ensure an uniform load sharing, an uniform moisture content and also the drying of the test body.

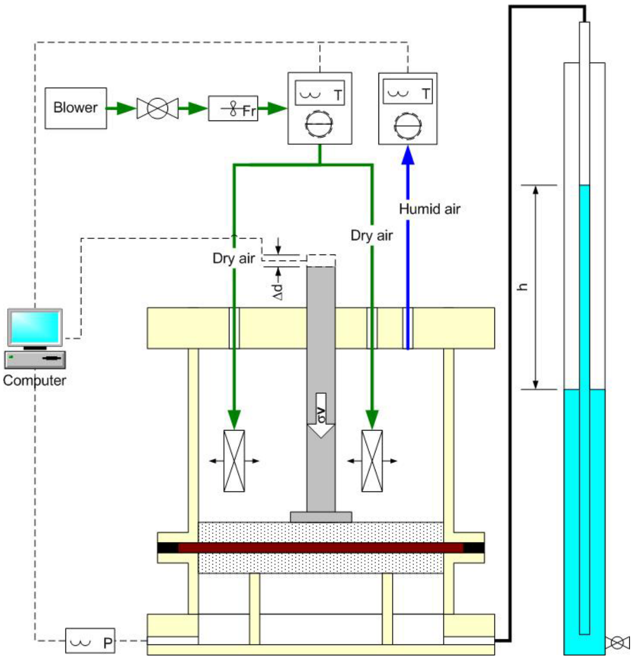

Figure 1 Schematic experimental setup during a drying cycle

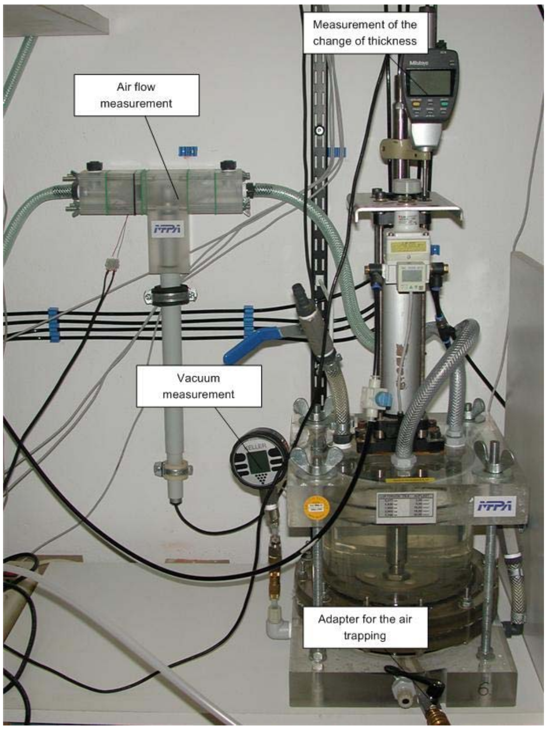

Figure 2 Rigid-wall permeameter

An analysing device is attached to the head plate ventilation plant to control and measure the drying of the GBR-C. With this, the streamed air can be measured and regulated by a control system facility. At this point the temperature and air humidity can be measured. The streamed air becomes spun by a diffuser inside the container so that an uniform drying of the test bodies is reached. The temperature and the humidity can then be measured from the escaping air.

An air trap is attached below at the foot plate of the test cell. This device can exactly regulate a minimal atmospheric pressure during the drying cycles. A principle outline of the experiment construction and a photo is shown in figure 1 and 2.

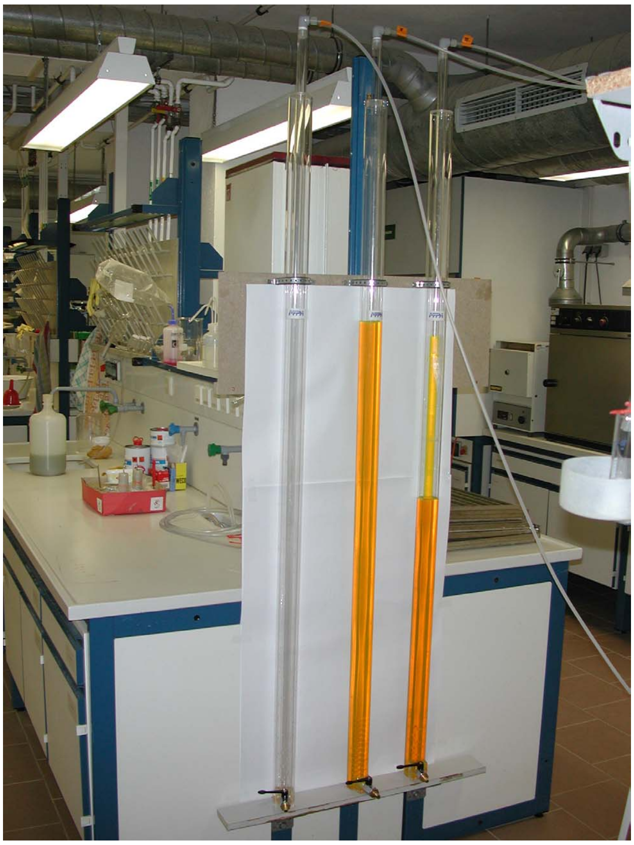

Figure 3 Air trapping (left: empty, middle: filled, right: vacuum)

The air trap consists of an inner and an outer pipe. The outer pipe has a thick lower end and is provided with a ball valve which empties the air trap when filled with water. The inner pipe is provided with a tube and a tube airtight clutch closure which makes it possible to attach the air trap on the bottom plate of the test cell later.

In the first process the air trap tube clutch in the inside pipe is at open and the pipe is filled with water, at this point the water-levels in the two pipes are therefore the same level, since the inner pipe is perforated on the lower 30 cm and a connection passes between the pipes. In the next step the inner pipe gets connected to the bottom plate of the test cell via the tube clutch. The wet and swollen GBR-C close the inner pipe and thus the lower part of the rigid-wall cell is airtight. Water is then drained from the air trap by the tap on the outer pipe. At this the water-level of the outer pipe sinks clearly faster than the water-level of the inner pipe since no pressure balance is possible for the inner pipe because of the airtight closure made by the GBR-C. From a physics view point the working principle of two of vessels connected to each other is valid i.e. there is a pressure balance striven between the two pipes. At this time a lighter atmospheric pressure is produced in the lower part of the cell which can be exactly regulated with help of the water columns.

3 TESTING PROCEDURE

In the context of the tests, the test bodies were subject to a number of water drying cycles under predefined boundary conditions. The highest investigation priority was the determination of the moisture minimum under different pressure loads. The illustrations 4 and 5 show a schematic experiment order of events.

Before the installation of the test bodies into the cells, decisions were made over reference points of the water content and the thickness under the scheduled load and in the exit condition of the test bodies.

After the installation of the test bodies to the experiment facilities the static load was set on the pressure stamp. Loads of 15, 25 and 35 kN/m² were scheduled in the original experimental program. After the first tests it showed that no linear coherence had to be expected between load and minimum water content. Therefore additional static tests were carried out with loads of 20 and 30 kN/m².

At the introduction of the 1st wetting cycle, the test cell was filled with deaired water. A hydraulic gradient wasn't found in this first 10 day swelling phase. The first determination of the Permittivity started with adjusting a hydraulic gradient of 30 cm between high and low water. The by flow was carried out according to the natural conditions of high to low. It was decided that the Permittivity duration was to be limited to a duration of 30 days in the first and subsequent water cycles. The pressure phase of 10 days was required only before the 1st water cycle since the tested bodies weren't dried down to the exit water content in the following cycles any more. Deaired water was used in all cycles for the tests.

The drying of the test bodies was effected through continuously circulating air via 3 connections in the test cell head plate. The stream of air produced by a blast can be measured and adjusted by a simple handicapping device. The air stream was spun by a diffuser and passed through a distributor positioned at approx. 5 cm above the test bodies. The damp air was extracted through a wider opening in the head plate. The temperature and humidity of the inward and outward air stream is measured by sensors.

The start of the drying process began with a reduction in air pressure of through the air trap connection in the bottom plate of 0.05 - 0.06 bar. Additionally, the negative air pressure was monitored by observing the height difference between the two water columns with manometers. The test bodies were dried for as long as it took until the first continuous crack appeared resulting from the diminishing water content and the shrinking behaviour of the bentonite in the GBR-C. A clear indication of the arrival of the first continuous crack was a very fast equilibrium of the pressure standard in the air trap between the upper and the lower part of the cell and with that the bringing into line of the water-level heights in the air trap. As soon as the crack appeared, the drying was stopped, the test body rebuilt and the water content determined. The definitive water content represents the water content limit for the test body under the number of predefined boundary conditions (of the cycles carried out and the static load).

To be able to make statements about the cracking behaviour of the GBR-C, X-ray pictures of the test bodies were made. So that crack assessment could be made possible under repeated X-rays, readable markings were attached to the mat which would be easily recognisable in subsequent X-rays. For the continuation of the tests the test bodies were rebuilt into the cell again and the next wetting and drying cycle started. The air pressure, the temperature and the changes in thickness of the GBR-C were measured during all phases of the tests.

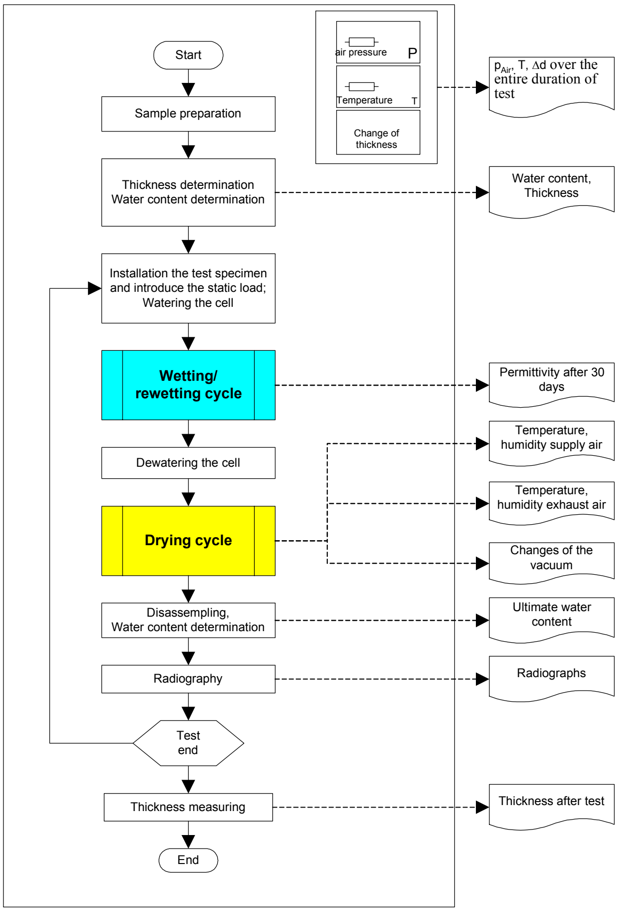

Figure 4 Mainstream of the test procedure

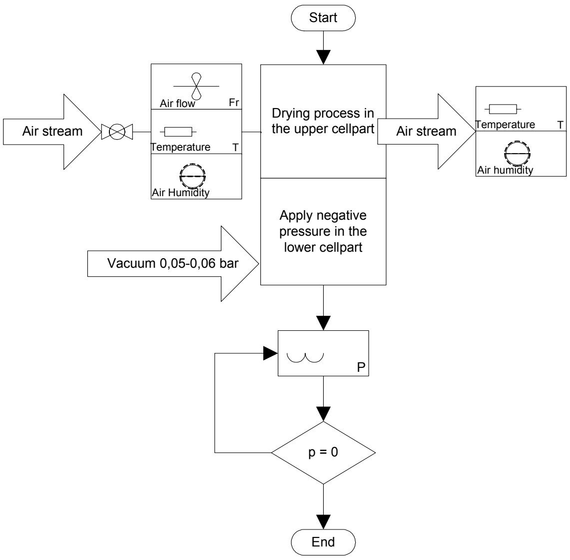

Figure 5 Schematic procedure of a drying cycle

4 TEST RESULTS

4.1 *Ultimate water content*

The main criterion of a clay geosynthetic barrier for its use in land fill covers and other sealings is its permeability. The long term reliability is dependent on a variety of boundary conditions. The risk of desiccation under various climatic conditions is to consider in the design of the capping system and therefore a proper design needs the knowledge of the ultimate water content. From a variety of examinations it is already known that shrinking cracks can lead to lasting structure damages in the GBR-C. Therefore a lining system which prevents drying out the bentonite to or less than a critical water content even in dry phases should be designed in the planning phase. This ultimate water content indicates the condition up to which the GBR-C may dry out without loss of serviceability that is without any continuous crack appearing.

In order to investigate this ultimate water content under different conditions of normal stress, a run of tests were carried out at the MFPA Weimar in co-operation with Naue Fasertechnik GmbH & Co. KG. To indicate the beginning of a crack a low air pressure was created in the lower part of the cell whilst the upper part was continuously dried by air circulation. During the drying there was a steady rising of the negative air pressure in the lower part of the cell. The greatest values of the negative air pressure were registered in the first drying cycle. In any case, after reaching the ultimate water content a pressure balance between the upper and the lower cell part was quickly reached. The GBR-C function was impaired at this time but a renewal was possible after creating a new pressure drop after a further water cycle. The course of the pressure over the experiment duration is shown in figure 6 exemplarily. It can also be seen in that plot that there is a tendency that the process desiccation of the samples under the highest load lasts longer than under low loads under the same impact.

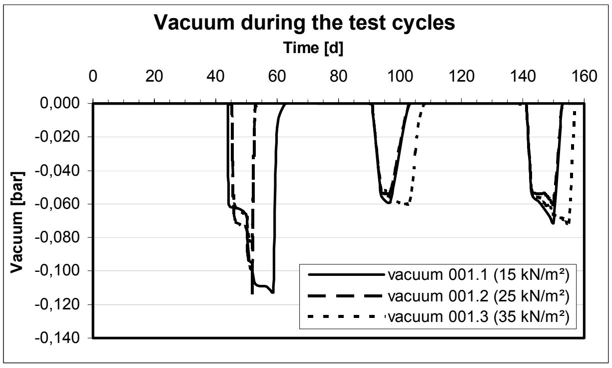

Figure 6 Vacuum during the test cycles

The first tests have shown that first continuous cracks can already appear at water contents of more than 130% at low loads (table 2), far above the plastic limit. This is in good accordance with previous tests with sodium and calcium bentonite (WITT & SIEGMUND, 2001). With increasing loads, the water contents leading to the formation of a continuous crack decreases and with that the risk of desiccation. This covers the importance of a sufficient ground covering depth of the GBR-C not even to reduce the impact of changing climatic conditions but to strengthen the GBR-C against desiccation.

The results of the experiments and the trend lines are represented in figure 7 under different loads for 3 drying cycles in terms of the ultimate water content. In any case the limit where cracks occur lies far above the plastic limit. There is a decrease of the ultimate water content with an increase of the overburden pressure, but a subsequent approximation by means of a linear function has proved un-useable. A polynomial 2nd degree was used which delivered sufficiently good results to give the calculation of the trend line. Additional tests improved the precision by giving with load steps of 20 and 30 kN/m². Until this, a trend of the movement of the ultimate water content in repeating dry-wet-cycles couldn't be established. Obviously reactivating of healed cracks depends on the history end severity of desiccation.

Table 2 Ultimate water content under different static loads

Sample	Static load [kN/m²]	Water content after 1st drying period [%]	Water content after 2nd drying period [%]	Water content after 3rd drying period [%]
1	15	137,15	117,97	134,71
2	25	116,88	96,6	126,81
3	35	107,76	88,14	121,62
4	15	135,32	-	-
5	25	107,12	-	-
6	35	103,47	-	-
7	20	121,68	-	-
8	30	108,95	-	-

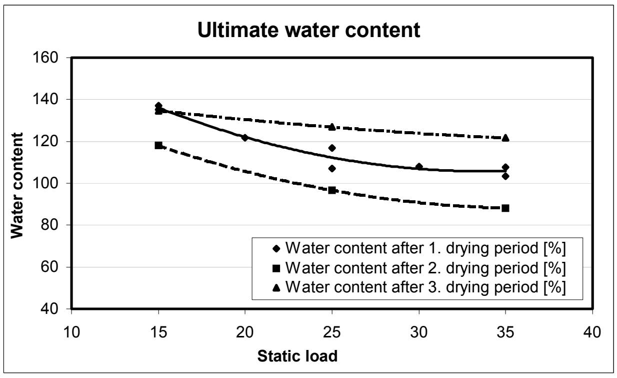

Figure 7 Ultimate water under different overburden pressure

4.2 *Thickness of the GBR-C*

To be able to make statements about the changes in thickness of the test bodies during the experiment cycles, reference pieces of the thickness' of the GBR-C were tested under the planned loads before the first testing began. After the first addition of water in the first wetting phase all test bodies clearly increased in thickness. The largest as expected, was in the test bodies with the lowest load. After an initial swelling phase, no more thickness changes could be detected up to the beginning of the subsequent drying phases. An exception appeared in test 2, which showed a greater thickness during the completed first wet cycles.

With the beginning of the drying, the shrinking of the bentonite became apparent by a slight reductions in the thickness' of the samples. Initially, the thickness decreased very slowly but as desiccation of the GBR-C progressed, the speed of the vertical compression was increased. The bentonite follows the common curve of normal volume shrinkage, with a very steep thinning of the test body thickness shortly before the appearance of the first crack. This state can be called residual shrinkage in terms of soil physics. The constant thickness during cracking stage is clearly above the value under the initial dry conditions. All the phenomena of swelling and shrinking are in good accordance with the well known effects described in soil physics (LI & BENSON, 2000). As expected, the swelling potential decreases with increasing overburden pressure and with the severity of the previous desiccation.

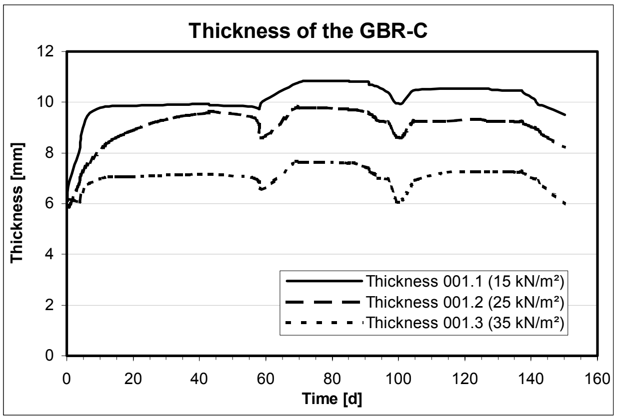

Figure 8 Thickness of the GBR-C

4.3 *Self-healing effects*

In the literature GBR-C are frequently reported to be self healing (BABU et al., 2001) and in engineering practice we trust to this effect. Self healing is the property of the GBR-C, cracks at rewetting phase get smaller and are able to close totally. This very useful quality has also been demonstrated in the tests carried out. With the first water application after the drying cycle the swelling process of the benonite was so fast that an additional wetting phase was not needed before adjusting a hydraulic gradient. After a short phase with a higher inflow, the cracks in the bentonite were sealed up to the initial permeability. The first water flow started up again some days after rewetting. A clear statement with regard to the influence of the load on the self healing properties cannot be made yet with the tests carried out up until now. But nevertheless a higher load doesn’t reduce the self healing capacity.

Clear differences in the crack picture at the ultimate water content under different loads weren't ascertainable in the X-ray pictures. The crack structure and the crack breadths were very similar despite the various water contents at the time of the X-ray which has to be put down to the influence of the load. Earlier tests (SIEGMUND et al.,2001) has let himself be seen to announce that the crack distances and the numbers of cracks have increased clearly at the same boundary conditions and a reduction of the water content around approx. 10%. In the tests described here no significant differences could be established between the tests with low loads and higher ultimate water content and the tests with higher loads and lower limits.

Figure 9 Radiographs after the 1st (left) and. 3rd (right) cycle

The appearance of shrinking cracks represents a lasting damage to the structure of the needled bentonite, these have been pointed out in previous X-ray pictures of the dry cycles. Figure 9 shows the X-rays of a test sample after the first and the third drying cycle. The visual impression of the cracks is that they appear to be very fine, unlike the cross-section in the X-ray pictures of the GBR-C where their greater visible width results from a non-perpendicular angle of the cracks. With the marking, it can very simply be proved that shrinking cracks having once developed, appear again after repeated wet-dry cycles in the same place and in the same amount. In this respect the "memory" of the GBR-C can be disposed. The cracks do not actually “heal” to the initial structure during rewetting but become smoothed over by the horizontal swelling process. But as an important result, the tests show, that this capacity is not reduced under higher vertical load.

5 CONCLUSIONS

Clay geosynthetic barriers used in landfill caps are considered as an established alternative sealing system to reduce thickness or to replace compacted clay liners. Despite a lot of knowledge from laboratory and field tests as well as practical experiences, it is never the less difficult to fix an optimal system construction in design. An important point for the specification of the system is the requirement that the GBR-C must fulfil their function as a seal during a life cycle even in very dry periods. The impact running from the change of the climatic conditions can be calculated by numerical simulations such as HELP (ZEH & WITT, 2001). But in a proper design we need the ultimate resistance of GBR-C with concern to desiccation, that is the ultimate water content when continuous cracks might occur. In the tests this borderline has been determined for a needle punched sodium GBR-C. On this several wet - dry cycles were administered in 5 tests under different loads.

The test results show the influence of the load on the desiccation of GBR-C. A dry period leads to a faster desiccation and an earlier crack formation and the consequential loss of the sealing function more on low loaded samples than on highly loaded ones. The self-healing effect of the sodium GBR-C tested appeared clearly in the tests described here. Even after several periods of desiccation the initial permittivity was obtained after rewetting. A stronger load does not reduce this mitigating behaviour. However, with help of the X-ray pictures it was demonstrated that an actual healing of big cracks doesn't take place. Cracks represent a structural weakening of the GBR-C which isn't reversible having once occurred. The cracks always reappeared in the same place during successive cycles of desiccation. Nevertheless a proper design of a landfill capping system will prevent cracking within the GBR-C, protecting with help of certain overlaying layers of adequate soils with an adequate thickness.

Knowing the ultimate water content at different loads the planner can design the system of the cap that a drying out of the sealing can be prevented. Such a design means compose the overburden layers specifically with numerical water balance simulation so that the ultimate water content will not be reached within the expected life cycle. Therefore we have to consider the local climatic conditions and the physical parameters of the available materials. In any case we need a certain thickness of the protecting soils of about 0.8 to 1.5 m in Europe (BLÜMEL et al., 2003; BRÜCKLMEIER et al., 2003). An additional measure is the installation of a capillary protecting layer in contact with the geosynthetic clay liner, as reported in HENKEN-MELLIES et al. 2003 and analysed in ZEH & WITT, 2003.

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