Durability of sand bentonite liners in surface cappings of waste deposite sites

D. Boels
R. Wiebing

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ABSTRACT

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At a test site for top liners, laid out in 1982 at a waste deposite site of VAM at Wijster, the quality has been evaluated of a sand bentonite liner. Soil structure formation, if any, may be an indication of highly variable moisture conditions, and of animal or plant life in the liner. The thickness of the liner and the thickness of the material have been determined at three slope locations. The content of Wyoming bentonite has been determined according to the sedimentation method. At various points in time over a period of approximately 3 months, the hydraulic permeability has been measured on the basis of undisturbed samples with a diameter of 0.30 m and a height of 0.09 m, using the method of falling head. In addition, at three slope locations, the loss of percolation has been measured by an infiltrometer ring sealed at the top. More than seven years after construction, the sand bentonite liners have lower permeabilities than was originally intended. Besides, by the current design criteria, they meet the present standards with respect to the maximum loss of percolation.

Keywords: top liner, infiltrometer, Wyoming bentonite

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The WINAND STARING CENTRE for Integrated Land, Soil and Water Research,
Postbus 125, 6700 AC Wageningen (The Netherlands).
Phone: +318370-74200; fax: +318370-24812; telex: 75230 VISI-NL

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PREFACE

The research carried out into the durability of sand bentonite liners in surface cappings of waste deposite sites was commissioned by Cebo-Holland BV at Heemstede. Research was done at a test site of VAM at Wijster. The liners at the test site were made from a mixture of sand and bentonite supplied by Cebo. We are grateful to VAM for its readiness to allow research at its site and to a number of staff members for their loyal cooperation.

SUMMARY AND CONCLUSIONS

It is evident from laboratory and test site research that mixtures of sand and bentonite can be used to make liners in surface cappings of waste deposite sites which are virtually impermeable for liquids. There was no certainty about whether or not this low hydraulic permeability would be preserved also in the long term. Therefore, at the request of Cebo-Holland BV at Heemstede, research has been done into the quality of sand bentonite liners, a considerable time after their construction.

At a test site of VAM at Wijster, sand bentonite liners, which were constructed in 1982, have been examined for the occurrence of soil structure formation, plant roots and animal activity. The hydraulic permeability, density and bentonite content have been determined on the basis of samples taken from the liner. The infiltration from the ring-infiltrometers in the liner has been measured in practice as well.

The thickness of the liner at the top location of the slope proved to be less than the 0.20 m planned in the design. The thickness at the other locations was a few centimetres more than was designed. The dry bulk density at the upper and centre location of the slope is approximately 1750 kg.m^3 and at the bottom approximately 1650 kg.m^3. As the density was not measured directly after the construction of the test site, we cannot determine whether the lower density at the bottom of the slope is the result of subsidence in the dump.

Under the liner landfill gas could clearly be detected. The liner did not show any traces of soil structure formation. This layer is hardly subject to an alternate process of drying out and rewetting, and it has a virtually constant moisture content (saturated). In the liner traces of animal acitivity or plant life were not found either. Populations of rainworms just above the liner indicate that the liner is gasproof.

The sedimentation test showed a bentonite content of an average 7.9%. This content is in accordance with the percentage aimed at during the construction of the test site. The spreading in the content is relatively small.

The hydraulic permeability of the liner, classified, on the basis of the samples, in the gradient class 4 to 6 inclusive, is approximately $2x10^{10}$ m.s^{-1}. The design-percolation loss involved (approx. 17mm in 200 days) is far below the 50 mm in 200 days aimed at initially. Apparently, it is possible to realize in practice an hydraulic permeability as has been measured on the basis of laboratory mixtures. Furthermore, the hydraulic permeability is still very insignificant, even after a number of years.

The percolation loss through the liner has been measured *in situ* from an infiltrometer ring sealed at the top. With an hydraulic head of approx. 0.50 m of water column at the top of the liner, the loss is less than 20 mm per 200 days. In the process only the surface area of the infiltrometer ring has been taken into account; the so-called lateral divergence of the flow paths has been left outside consideration. Based on the hydraulic permeability measured from samples, this divergence is approx. 25 to 35%. However, if this is taken into account, the percolation loss, in the case of a permanent hydraulic head of 0.50 m above the liner, will be 5 to 10 mm per 200 days.

In conclusion: more than seven years after their construction, the sand bentonite liners have lower permeabilities than was planned in the design, and they more than meet the present standard of maximum design-percolation losses.

1 INTRODUCTION

In 1985 the Directive " Waste Regulation" was effectuated in order to implement the soil conservation policy. It is now mandatory that, after the completion of dumping activities, a surface capping containing a liquidproof layer has to be spread over the dump. It was thought initially that geomembranes could provide the desired liner. These membranes, however, have proved to be defective in the long term, possibly due to irregular subsidence; therefore, mineral liners may offer more security. Mineral liners are, however, not absolutely liquidproof. Leakage, though negligible, will always occur. In 1982 field tests with liners made from sand-bentonite mixtures have been carried out by order of the Ministry of VROM (Housing, Regional Development and Environment), and in cooperation with VAM at Wijster. At the test sites outflow measurements were made from 1983 to the spring of 1987 (Hoeks et al., 1987). It was concluded that the percolation loss was very small and within the objective formulated at the time: less than 50 mm in 200 days. By order of the Ministry of VROM, the Winand Staring Centre, in cooperation with Heidemij Consultancy BV, has drawn up directives with respect to the design, dimensioning and choice of material of the surface capping and liner (Hoeks et al., 1990), including a diagram for dimensioning the liner. An acceptable percolation loss is employed which has been determined by the licensing authority on the basis of the present level of science and technology. In this respect, the Commission for Reporting on Environmental Effects (1990) decided that "....for the construction of liners made from natural materials,....a maximum percolation of precipitation surplus should be employed of 20 mm in 200 days, with a water pressure of 0.05 bar above the layer and 0.05 bar below the layer." Experience and understanding have therefore already led to a tightening up of the present objective.

So far, we have not gained any insight into the durability of liners composed of sand-bentonite mixtures.

Bentonite is a clay type, named after Fort Benton (Wyoming, USA), where it occurs in the vicinity. It has an enormous swelling capacity, which is connected with the nature of clay mineral in bentonite (montmorillonite) and the occurrence in the adsorption complex of natrium. This monatomic ion may cause the electric double layer to expand considerably, allowing, in particular, the American bentonite to adsorb up to 12 grammes of water per gramme bentonite. As a result, the pores in the sand-bentonite mixture are, so to speak, filled with bonded water. The percentage of bentonite must however be adequate.

It is assumed that, with a relatively low hydraulic gradient, there is no flow of any significance through the double layers. The sand-bentonite mixtures derive their low hydraulic permeability from the high density and from the swelling capacity of the added bentonite.

The extremely low hydraulic permeability may be affected by:

- a reduction of the density caused by activities of animal activity and irregular subsidence;
- a reduction of the swelling capacity by replacement of Na-ions in the clay complex by ions with a higher valency (e.g. calcium, magnesium, iron etc.);
- possible detrimental effects of a lowering of the pH value (increase in hydraulic permeability as a result of chemical changes of clay minerals);
- the bentonite being flushed away when the hydraulic gradients are very significant, although this is not very likely.

During the trial period of three and a half year at Wijster no changes have been found in the hydraulic permeability of sand-bentonite mixtures (Hoeks et al., 1987). There is no certainty however what the future will bring in this respect. At the request of Cebo-Holland BV, the supplier of the bentonite applied during the experiments at Wijster, research has been done into the current hydraulic permeability and into any changes which may have occurred since the construction of the liner itself.

2 EXPERIMENTAL SET-UP

At the test site of VAM at Wijster a site was chosen wich had a liner with a thickness of 0.20 m and a bentonite content of 7.5%. Under the present directives for design and construction of surface cappings, a minimum thickness of sand bentonite liners is required of 0.25 m, while the permeability factor, currently with a design gradient of 5, is to be less than $2.3\text{x}10^{-10}$ m.s^{-1}. In this respect, a maximum percolation rate is assumed of 0.1mm.d^{-1}. During the lay-out of the test site (1982), a percolation rate was assumed of 0.25 mm.d^{-1}. The thicknes, density and the mixing ratio adhered to at the time are based on this percolation rate. The US Environmental Protection Agency's (EPA) directives provide that the saturated permeability of mineral liners is to be less than $1\text{x}10^{-9}$ m.s^{-1} (Albrecht en Cartwright, 1989).

At three slope locations the liner was examined for the permeability factor, inward flow, if any, plant roots and animal activity or any traces of them. The liner was also examined for soil structure formation, which is indicative of a highly variable moisture content in the liner, and of changes in the composition of the adsorption complex of the bentonite.

For research purposes, a location was chosen at the top of the slope where a groundwater table is highly likely to occur during extremely brief periods; another location was chosen halfway the slope, where groundwater may occur for somewhat longer periods; a third location was chosen at the bottom of the slope, where groundwater may occur for even longer periods and where percolate may diffuse from the dump into the surface cap.

Three samples were prepared from the liner, which were fixed in a retainer (diameter 0.30 m, height 0.10 m), and on the basis of which, in the laboratory, the hydraulic permeability was measured in relation to the hydraulic gradient, followed by a determination of the dry bulk density and the bentonite content.

Infiltrometer rings (diameter 0.30 m) were placed next to the locations where the samples were taken. Water could infiltrate the liner from water containers. The same conditions were adhered to which were employed for the design of the liner thickness: an hydraulic head of at least 0.50 m above the liner. The conditions underneath the liner are unknown.

3 MEASURING METHODS

3.1 Profile description

The condition of a liner is assessed on the basis of the requirements to be met. These are:
- an extremely low hydraulic permeability;
- high density;
- plastic performance.

If the hydraulic permeability of the liner is too high, colour changes are perceptible in the sand bentonite liner as a consequence of inward flow of dissolved organic matter from the capping layer. Besides, as a result of an intensive exchange between dissolved substances in the percolate from the capping layer and soil moisture and the adsorption complex in the liner, the pH value in the liner will, in time, correspond with the value in the capping layer.

In the case of inadequate density, plant roots and animals in the soil (worms, beetles, caterpillars, moles, mice) will infiltrate the liner. However, this will not occur if the dry bulk density in the liner is higher than 1600 kg/m^3. The density is measured on the basis of samples (100 ml, repeated thrice) which are taken from the large undisturbed sample.

The liner needs a certain plasticity to prevent it from cracking in case of irregular deformation. It is therefore essential that the liner contains sufficient moisture. If not, and if the liner is alternately dry and wet, structure formation will take place, which can be seen with the naked eye. In the case of irregular deformation hair cracks may occur all the same, which may result in an increase of the hydraulic permeability. An adequate bentonite content may cause the bentonite to swell additionally and seal the hair cracks. The bentonite content in the liner has been determined by the sedimentation method.

3.2 Laboratory test of hydraulic permeability

In the laboratory a layer of approx. 1 cm was removed from the bottom and the top of the samples, which were prepared in the field. The vacant space was refilled with coarse filtering sand. These layers are to prevent loss of pressure during supply and effusion of water during the test. In addition, a uniform spreading of water is realized on the supply side (the bottom). In order to encourage the process of rewetting and the driving out of air present, the bottom was chosen as the supply side. The samples were saturated from a water container with a constant hydraulic head until the effusion of water went well ahead. The permeability factor was subsequently determined by the falling head method, followed by a return to the supply of water from the container. The permeability factor was measured at weekly intervals. The measurements were carried out during a period of two and a half month.

Soil samples are rarely completely saturated by water; 1 to 3 per cent of air is still present. Changes in the atmospheric pressure cause adjustments of air pressure in the sample which are accompanied by adjustment of the water volume. A variable pressure of +2 to -2% causes the volume of entrapped air to vary from -1.96 to +2.04%. The result is that, if the atmospheric pressure increases, the quantity of water flowing into the sample will be larger than the effusing quantity, and vice versa if the atmospheric pressure decreases. With extremely small permeability factors, the effusion sometimes even comes to a standstill. The required water quantity for air pressure adjustment for a sample with a diameter of 0.30 m and a height of 0.10 m ranges from -3.6 cm^3 to +3.7 cm^3. With a permeability factor of $5.0x10^{-10}$ $m.s^{-1}$ and a gradient of 5, the required water quantity is approx. 25% of the quantity daily percolating in the sample under these conditions.

A variation in the temperature of 2% has virtually the same effect as a corresponding pressure fluctuation. Besides, both effects may reinforce one another causing the results to vary considerably (a variation of 50% in the permeability factor measured is not exceptional).

During the test the atmospheric pressure was continuously monitored; the measurements were carried out in periods when the atmospheric pressure hardly changed. There is a fairly constant temperature in the laboratory. Both the incoming and outgoing quantity of water was measured during the test. The measurements were used for the calculation of the permeability factor only when both quantities were virtually the same.

The falling head method implies that, during measuring, the measuring liquid (water) is released from the stand pipe in which the hydraulic head is measured on the supply side. The pressure head falls and, because the level of the outlet of the sample remains unchanged, the pressure difference will decrease gradually. In this way a range of hydraulic head differences and gradients is traversed.

With each gradient, the permeability factor is calculated according to:

$$K = (D_i/D_s)^2 \cdot (L_p/\Delta t) \; Ln((H_t - H_o)/(H_{t+\Delta t} - H_o))$$

and the corresponding gradient:

$$i = ((H_t - H_{t+\Delta})/L_s) \cdot (1/Ln((H_t - H_o)/(H_{t+\Delta} - H_o))$$

in which:
K = hydraulic permeability (m/d)
D_1 = inner diameter of the stand pipe (m)
D_s = effective sample diameter (m)
H_t = water level in the standpipe at time t
H_o = level of the outlet (m)
L_s = effective sample thickness (m)

The set-up is shown in Figure 1.

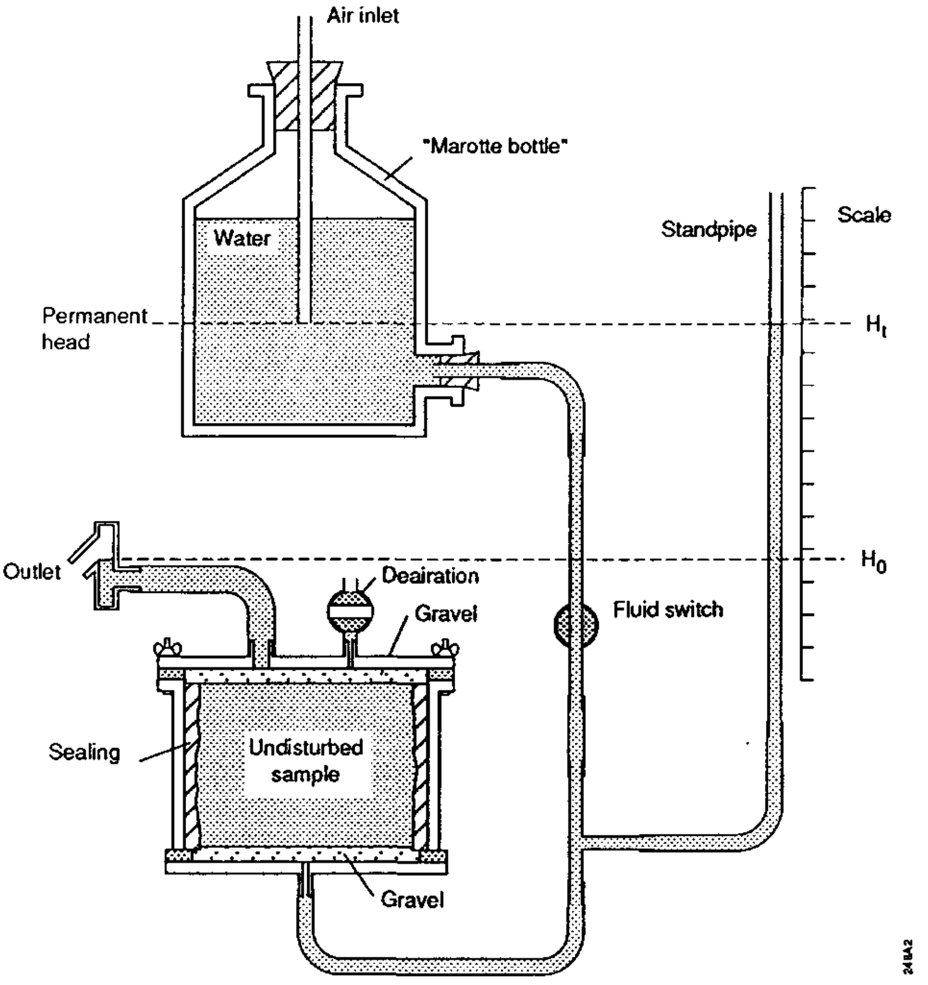

Fig. 1 Laboratory set-up permeability measurement

3.3 *In situ* infiltration measurements

The *in situ* infiltration measurement was carried out by a ring-infiltrometer (Fig. 2). This instrument consists of a ring that can be sealed at the top, which makes it waterproof. The ring without a top plate is positioned at the test field around a completely prepared ground column. The space between the column and the ring, and between the surrounding soil and ring is filled with quick-setting waterproof cement (CEBAR powder). The length of the column is approx. 8 cm. The ring is then sealed with a plate, in which a water and air passage have been made. The air passage is needed for air to escape from the space above the ground column during water filling, after which the vent is sealed. Water is supplied from a container in which a constant hydraulic head is maintained (Mariotte system).

In order to prevent hydrostatic lifting, the water container is positioned on the infiltrometer ring with concrete tiles. Should this prove impossible, anchoring is

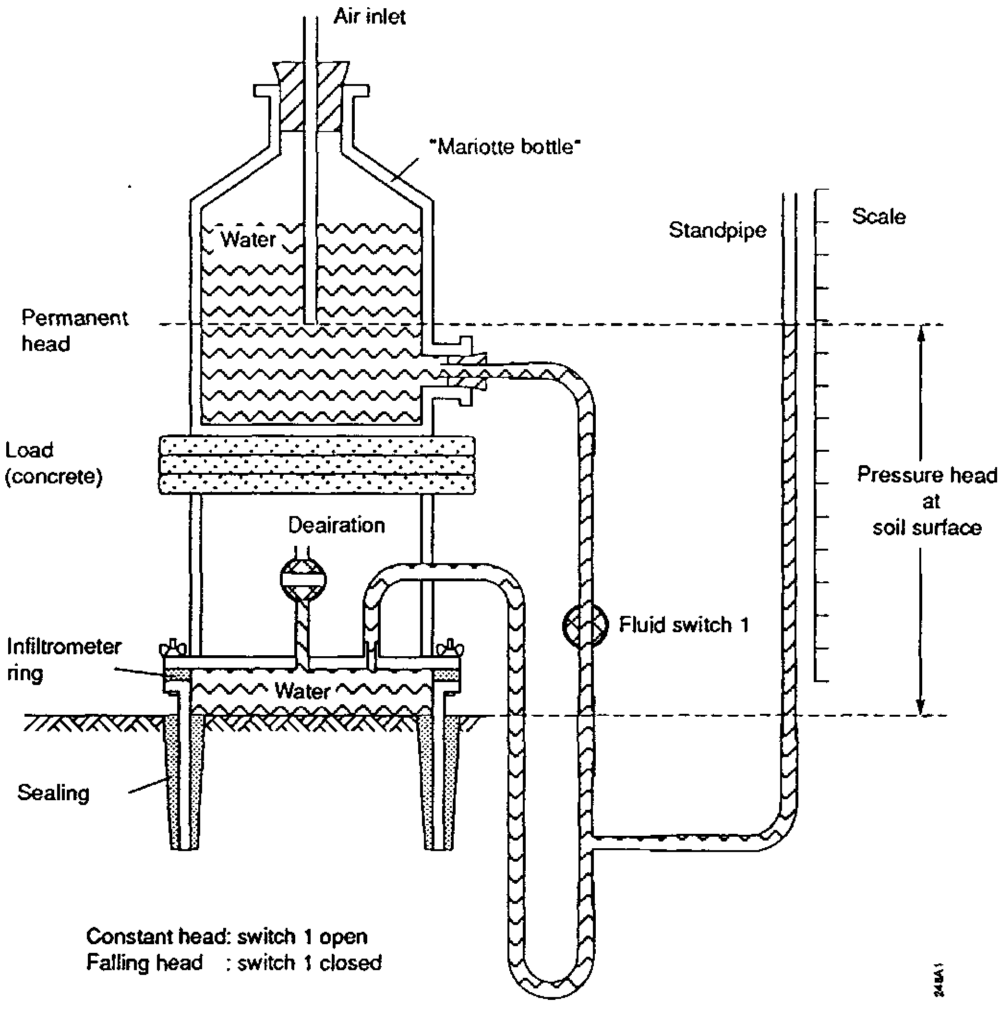

Fig. 2 Diagram of an infiltrometer

necessary, or when measurements are made in the case of hydraulic heads of more than approx. 0.5 m (above the top of the infiltrometer ring). A stand pipe has been placed next to the water container in order to carry out accurate infiltration measurements.

The water supply from the water container is closed off, after which supply takes place only from the stand pipe. The falling level therefore reflects the total infiltration. The infiltration rate is connected with the permeability factor of the soil, the hydraulic gradient and the geometry of the infiltrometer ring. With this test, the hydraulic gradient is higher than one (1), so that the numerical value of the infiltration rate is higher than the saturated hydraulic permeability. As a result, the (vertical) streamlines, on the whole, still run parallel in the soil enclosed by the infiltrometer ring, but diverge in the zone under the infiltrometer ring. The cross-section for the flow is larger there than the cross-section of the infiltrometer ring. If the contribution of the flow in the unsaturated soil to the total flow is negligible, the hydraulic gradient equals one (1) at a relatively great depth under the infiltrometer ring, and the flow rate there equals the saturated hydraulic permeability. The ratio between the cross-section at this depth and the cross-section of the infiltrometer ring equals the ratio between the infiltration rate and the saturated hydraulic permeability. The expansion of the saturated surface area at a great depth as opposed to the surface area of the infiltrometer ring is called lateral divergence. The infiltrometer ring has been positioned over a relatively great depth however, because the thickness of the liner is limited. Under the liner there is a sand bed with a good hydraulic permeability (base layer). The percolation flow through the liner takes place in a saturated condition. In the base layer the numerical value of the percolation rate is virtually equal to the unsaturated hydraulic permeability (gradient unity). An underpressure of soil moisture goes with it of between -0.10 and -0.30 m H_2O. If an extremely low overpressure is applied here, the ratio between infiltration rate and hydraulic permeability will be 2-3 (Bouwer, 1961). The lateral divergence will then be 40 to 70%. To be sure, it is best to stick to a lateral divergence of 20%.

4 RESULTS

4.1 Profile description

The construction of the surface capping at the waste site, from bottom to upper layer, is as follows:

- base layer;
- liner;
- capping layer.

The base layer consists of moderate coarse-textured sand, in which no discolouration has been found. Discolouration may be indicative of the percolation of water containing dissolved organic compounds from the capping layer. The base layer has a moderate moistness and clearly visible pores without water. Gas (pungent smell) was found after removal of the liner, when the base layer became exposed to the open. The pH-KCl-value of the base layer is 7.8. This relatively high pH value, which is still lower than in the liner, is an indication of very low percolation through the liner. It is assumed that the buffering capacity of sand is negligible, and that the original pH value in the base layer was 5.5. The bed thickness, the measured pH of which is a representative value, is lower than 0.1 m. It is further assumed that full mixing takes place between the percolate and the moisture in the base layer. The percolation through the liner which under these conditions would have led to the measured pH value in the base layer, is lower than 30 mm yearly. The foregoing is only an arithmetic example. As historical data are lacking, no statement with respect to the percoloation rate can be made which is based on the measured pH value in the base layer.

The thickness of the liner has been measured. At the top location of the slope it is approx. 0.10 m. The locations halfway and at the bottom have a thickness of 0.20 to 0.22 m. The latter have a thickness corresponding with the 0.20 m originally intended.

The composition of the liner is homogeneous. Soil structure formation has not been found. The liner was very moist during the excavation and seemed almost completely saturated with water. No roots were found on or in the liner. Traces of animal activity were not found either. The dry bulk density at the bottom of the slope is approx. 1650 $kg.m^3$ and in the middle and at the top of the slope approx. 1750 $kg.m^3$.

The bentonite content ranges from 7.3 to 8.0%.

Landfill gas was not found while the liner was uncovered; discolouration was not established either. The layer showed very sparse discolouration however, after the liner had been exposed to the atmosphere for some weeks, during a predominantly dry period. This type of (dark) discolouration is an indication of the infiltration of water with dissolved organic compounds. Infiltration under these conditions is possible because the liner dries up first (to a limited extent) and is then rewetted. The pH-KCl value of this liner is approx. 8.0.

The capping layer or mould consists of peat-like material (approx. 25% of organic matter) and is approx. 0.90 m thick. This top layer showed evidence of tillage with a subsoiler down to a depth of 0.5-0.6 m. Down to this depth the top layer was rich in roots The soil underneath showed few or no roots at all and was considerably moister than in the (dry) root-zone. The roots in this capping layer reached down to the sand bentontine liner, but penetration into the liner had not taken place. The pH-KCl of the mould is between pH 5.15 and 5.65.

In some places of the interface between the capping layer and the liner, large populations of rainworms were found. The soil there is aerobic. Penetration of landfill gas into the liner would have resulted in an anaerobic (oxygen-free) condition just above the liner, a condition under which rainworms cannot survive. On the basis of the presence of rainworms in the interface, it may be concluded that the liner is at least gasproof.

4.2 Laboratory test of hydraulic permeability

On the basis of the undisturbed field samples, the connection between the hydraulic gradient and permeability has been determined by the falling head method. The samples were saturated from the bottom with tap water from a water container, in which a constant water pressure is maintained by the so-called Mariotte method. The saturation took the system one up to two weeks before effusion was regular. On many occasions from then on, the relationship was determined between the hydraulic gradient and permeability. In this respect, both the incoming and outgoing quantity of water was measured in order to determine whether the requirements were met with regard to the measuring process: no change in the sampled watervolume during measuring. Minor deviations were accepted.

A significant connection between the time factor and permeability was not found. Therefore, the gradients and permeability of all measurements may be averaged per gradient class. The gradient class used was: 4 to 19 inclusive. A gradient of 4 was used as the upper limit of class 4 and a gradient of more than 3 as a mimimum. A gradient of 19 was used as the upper limit of class 19 and a gradient of more than 18 as a mimimum.

The possible connection between permeability and gradient was put to the test. As a starting point a hypothesis was used in which such a connection does not exist ("zero"). A one-sided 1% significance level was used, because, after all, the alternative hypothesis says that there is no correlation and that only exceptions lead to an ostensible correlation (Wijvekate, 1964). The correlation was calculated between the normalised gradient (measured gradient, i, less the average gradient of all measurements) and the normalised permeability. It was examined next whether the correlation calculated was higher than the value which is just still acceptable for the zero-hypothesis. The results are shown in Table 1, which show that there is a connection between the measured permeability and the gradient. The correlation

Table 1 Average permeability in relation to the average gradient per Gradient Class (= GC)

G	Sample 1			Sample 2			Sample 3			All samples		
C	N	grd	K_{sat}	N	grd	K_{sat}	N	grd	K_{sat}	N	grd	K_{sat}
4				3	3,74	1,80				3	3,74	1,80
5	4	4,74	2,08	9	4,61	2,92				13	4,65	2,66
6	8	5,76	1,26	12	5,55	2,37	6	5,61	1,31	26	5,63	1,78
7	12	6,30	1,61	8	6,54	2,26	7	6,47	1,92	27	6,42	1,88
8							5	7,48	2,24	15	7,56	2,67
9	13	8,43	2,56	16	8,55	3,18	1	8,64	4,84	30	8,50	2,96
10	7	9,53	4,09	11	9,44	3,56	1	9,84	5,18	19	9,49	3,84
11				2	10.24	4,33	2	10.70	2,24	4	10.47	3,28
12							6	11,51	2,66	6	11,51	2,66
13							4	12,63	3,21	4	12,63	3,21
14							3	13,61	3,29	3	13,61	3,29
15							3	14,81	3,95	3	14,81	3,95
16							4	15,53	2,81	4	15,53	2,81
17							4	16,59	2,43	4	16,59	2,43
18							3	17,29	5,34	3	17,29	5,34
19							1	18,30	4,98	1	18,30	4,98
A		7,21	2,26		7,17	2,90		11,19	2,79		8,40	2,69
CC			0.659			0.421			0.440			0.394

N = number of observations per gradient class;
grd= gradient (m/m);
K_{sat} = saturated permeability (10^{-10} m.s^{-1}).
A = average;
CC = Correlation Coefficient.

coefficients are not particularly high, which means that the relationship is not very clear. A connection exists for sample 1, if the correlation coefficient for the relevant number of observations is higher than 0.386, for sample 2, if the correlation coefficient is higher than 0.302, and for sample 3, if higher than 0.361. The coefficients calculated are all higher than the minimum values, so it is safe to say, with a certainty of 99%, that a significant connection exists between permeability and gradient. The permeability that goes with a gradient of approx. 5 is lower than $3x10^{-10}$ $m.s^{-1}$. The percolation losses with this gradient are less than 23 mm over a period of 200 days. All this exceeds the original design, while the present requirements have been met as well.

4.3 *In situ* infiltration tests

The set-up was installed mid-July 1990. From then on an overpressure was maintained of approx. 50 cm H_2O. A measurement check was carried out on 8 August 1990. The loss of water at the top of the slope was relatively high (1,5 mm/day infiltration over the wet surface). Halfway the slope the infiltration was 0.072 mm/day.

The final measurement was carried out on 17 September 1990. The loss of water at the top of the slope was still very high. The soil around the infiltrometer ring was not wet, from which may be concluded that the connection between ring and soil was inadequate. The insignificant thickness of the liner there allows the percolate to permeate quickly into the bottom layer, and allows it to move freely because it is no longer checked by impermeable ground. It was decided not to carry out any further measurements there. The loss of water during the measuring has been converted into a loss per 200 days, in terms of layer thickness. Only the cross-section of the infiltrometer ring has been taken into consideration as the infiltration surface area. Therefore, no corrections have been made with regard to the lateral divergence of the streamlines. In this case, the percolation losses represent losses which are currently part of the design criteria for the dimensioning of liners according to present-day views (Hoeks et al., 1990). The percolation losses are not constant, but show a connection with the lift in the infiltrometer ring. The measured percolation losses are considerably lower than the 50 mm in 200 days, which was the basis for the dimensioning of the liner. The hydraulic permeability factor may be derived from the infiltration measurements on the basis of the assumed expansion of the saturated surface area at a relatively great depth under the infiltrometer. For safety's sake, a lateral divergence has been assumed of 20%, so that, at a relatively great depth under the infiltrometer, the wet cross-section is approx. 1.44 times as big as the cross-section of the infiltrometer ring. Then the hydraulic permeability factor is less than $6x10^{-10}$ $m.s^{-1}$ at the bottom of the slope and $3x10^{-10}$ $m.s^{-1}$ halfway the slope. Compared to the measured permeability on the basis of laboratory samples, these estimates are somewhat conservative. Assuming that the average measured hydraulic permeability is in the gradient classes 4 to 6 inclusive, with a size of approx. $2x10^{-10}$ $m.s^{-1}$, the lateral divergence would have to be 25 to 35%. The percolation loss under the conditions of the test site would be at least approx. 5 mm per 200 days and approx. 10 mm per 200 days at the most.

Table 2 Loss of water from infiltrometer rings and calculated percolation losses through the liner

Location	Loss of water ($cm^3.d^{-1}$)	Duration	Average hydraulic head ($cm\ H_2O$)	Percolation ($mm200d^{-1}$)	Remarks
At the bottom	5.72	130	55.6	16.2	1st series
	6.79	60	53.9	19.2	2nd series, 1st period
	4.81	55	50.2	13.6	2nd series, 2nd period
	5.84	115	52.2	16.5	2nd series, 1st and 2nd period
	3.45	65	47.8	9.8	2nd series, 3rd period
	4.98	180	51.1	14.1	2nd series, 1st, 2nd and 3rd period
	5.63	85	50.9	15.9	3rd series
			weighted average 15.2		
halfway	2.90	130	50.9	8.2	1st series
	4.24	60	51.7	12.0	2nd series, 1st period
	1.85	55	49.9	5.2	2nd series, 2nd period
	3.10	115	51.2	8.8	2nd series, 1st and 2nd period
	1.72	65	48.9	4.9	2nd series, 3rd period
	2.60	180	50.6	7.4	2nd series, 1st 2nd and 3rd period
			weighted average 7.7		

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