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Some Bentonite Sealants in Soil Mixed Blankets

Quelques Scellements de Bentonite dans les Revêtements du Sol Mélangé

T.Å. LUNDGREN Dr. Tech., Swedish Geotechnical Institute, Linköping, Sweden

SYNOPSIS The paper summarizes the results obtained in a preliminary study of the application and durability of soil/bentonite mixtures as sealing blankets under new, sanitary landfills. The aim of the study has been to answer some elementary questions concerning the use of bentonite sealants. Application rates, mixing efficienty, chemical resistance against leaching waters and compaction are some of the items which are discussed. Some comparative studies with native clay fillings are also reported.

INTRODUCTION

Pollution of groundwater due to leakage from sanitary landfills can be avoided by sealing off the landfill from the groundwater or by draining the fill and leading the contaminated water to a treatment plant. Man-made seals at the bottom and/or the top of the landfill and sometimes also at separate layers or rock fractures are often needed. This paper deals only with bottom seals.

In Sweden, there is a decreasing supply of landfill sites which not only fulfill the requirement of being practically impermeable to leaching but also fullfill other requirements that must be specified for objects like these. In recent years, man-made seals have therefore come into use and a growing demand is foreseen. Mainly three methods of bottom sealing have been discussed in Sweden:

- o Plastic membranes
- o Soil/bentonite blankets
- o Blankets of native clay fillings

The utilization of bentonite as a protection against leaching pollution involves some basic questions concerning the application and durability of the bentonite:

- o What application rate should be used with different soils?
- o What is the mixing efficiency with different soils and methods?
- o Is there any reduction of swelling and sealing properties resulting from contamination by acids, salts or mineral solutions?
- o Are polymer treated bentonites always necessary under sanitary landfills?
- o When are native clay fillings acceptable and competitive to soil/bentonite mixed blankets?
- o What are the costs?

These questions have been raised by Swedish designers and contractors as well as by the National Environment Protection Board and local health authorities in Sweden, and they must be answered before appropriate design criteria can be specified. This paper reports briefly on some preliminary studies carried out at the Swedish Geotechnical Institute and the University of Uppsala. The main object of the studies has been to provide some answers to the questions listed above.

APPLICATION OF BENTONITE

Application rate

The specifications of a soil/bentonite mixed blanket should be applied on a strictly functional basis. However, this requires an efficient method of control, which is difficult to achieve. Specifications made on a constructional basis are more practical in most cases. The primary specification concerns the hydraulic conductivity of the compacted material and the blanket thickness.

At present, the National Environment Protection Board prescribes that the hydraulic conductivity of the untreated in situ soil must not exceed 10^{-7} m/s, but this limit value is disputed. Some specialists consider it to be too high. In view of this objection and the small thickness of a blanket in relation to a natural soil deposit, $5 \cdot 10^{-9}$ m/s is suggested as an upper limit specification for soil/bentonite mixed blankets.

Permeability studies were carried out in the laboratory and in the field. In the laboratory, both conventional permeameters and triaxial oedometer cells were used. Air was evacuated from the permeameters by means of a desiccator and in the triaxial cells, air was dissolved in the pore water by raising the cell and pore pressures. Calibration tests showed no important difference in the respective results. The results, complemented with values from the literature, are presented in Figure 1.

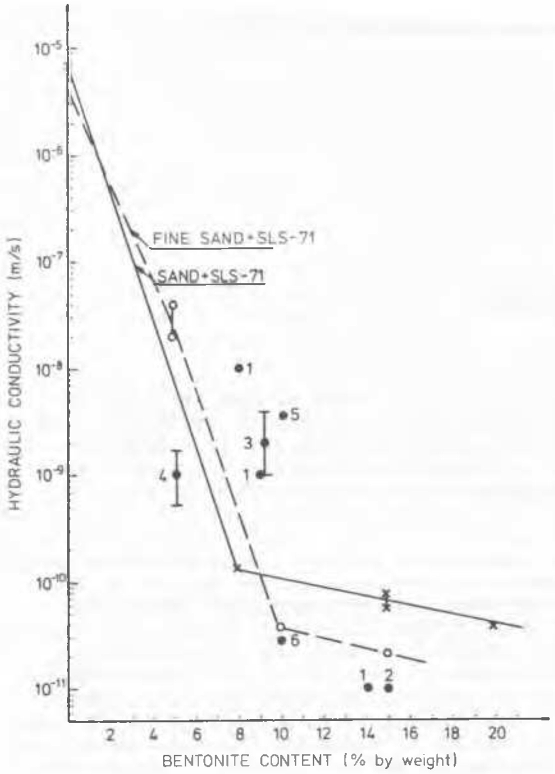

Fig. 1 Hydraulic conductivity (pure water) in some soil/bentonite mixtures (compacted) in relation to bentonite percentage.

1 = Sand + untreated Volclay according to American Colloid Co
2 = Sand + untreated Volclay (laboratory tests) accordning to Hansbo & Olsson (1973)
3 = Field tests with Volclay SLS-71 in graded sand, in fine sand or in graded gravel
4 = Field tests with silt + Volclay SLS-70 according to Jerbo (pers.comm)
5 = Sorted sand + Volclay SLS-71 (laboratory tests)
6 = Fine sand + Volclay SLS-71 (laboratory tests)

The permeability tests are too few to allow complete recommendations to be made on the application rate. The bentonite percentage shows a linear relationship to the logarithm of the hydraulic conductivity down to about 10^{-10} m/s. Lower conductivity values require much higher bentonite concentrations. In general the results verify the recommendations available from the American Colloid Co for the conductivity ranges commonly dealt with.

Figure 1 indicates that the field conductivity is relatively higher than the laboratory conductivity. This divergence almost corresponds to one order of magnitude as referred to the hydraulic conductivity, corresponding to about 3 per cent of bentonite (by weight).

Mixing of soil/bentonite

Soil and bentonite are usually mixed in two basic ways, either in a concrete mixer before application or after application by use of different agricultural machines. In the first case, additional water should be introduced into the mixer. In the second case, additional water should preferably be spread after the mixing process.

The mixing efficiency (homogeneity) was measured by determining the water content and the subparticle concentration of 3 µm and 6 µm (which was performed as a conventional sedimentation analysis) on 5 partsamples (25 g each) randomly taken from the mixed material. The homogeneity was quantified by the standard deviation value of the partsamples.

Most of the pre-application mixing tests were performed on 3000 g samples in a heavy laboratory mixer of the type used by bakers.

The laboratory results are summerized up in the following conclusions:

- More than 10 min. mixing time is preferable.
- The soil may be dry, naturally conditioned (drained) or saturated, when the bentonite is added.
- Water should preferably be introduced into the mixer after the bentonite and after a couple of minutes of homogenizing.
- All investigated bentonites (5 types) were homogenized to the same degree. The homogenizing capacities of all the investigated bentonites were about the same.

Only three mixing tests were performed with the concrete mixer (10 minutes mixing time: the bentonite was added before the water). The tests were carried out with Volclay SLS-71 and well graded sand, fine sand and a coarse, graded material (fluvioglacial <60 mm). According to these few tests, the concrete mixer is less efficient than the laboratory mixer. The best mixing result was obtained with the coarse, graded, till-like material.

In this study the in-situ mixing tests were performed with two types of hand-hold, rotary cultivators on sand/bentonite test layers (0.2 m x 10 m^2). One of the cultivators was wheelless, being driven forward by its rotary teeth - a type of cultivator common in small scale gardening. The other one was bigger and had separate driving wheels.

The in-situ mixing was executed with as many passes of the cultivators as was needed to make the layers looking fully homogenized. This was achieved after 8 passes of the wheelless cultivator and 6 passes of the bigger cultivator. Despite the greater number of passes, the efficiency of the wheelless cultivator was somewhat lower than that of the bigger cultivator. Excavating through the layer revealed lenses of pure bentonite in the part mixed using the wheelless cultivator (Figure 2). The mixing in the concrete mixer for 10 minutes turned out to be more efficient than in-situ mixing with cultivators.

Fig. 2 A section through the soil/bentonite bed after 8 passes with a wheelless cultivator. Note the lenses of pure bentonite.

Compaction

Some small-scale compaction tests were carried out using a 145 kg vibrating-plate compactor (Dynapac CM 12/13) on a soil/bentonite material which had been mixed in a concrete mixer. The mixed layer was 0.2 m thick and consisted of 10% bentonite (Volclay SLS-71) and three different soil types: a well graded sand, a fine sand and a coarse, graded, fluvioglacial material. The compaction was performed 24 hours after the application and the 12 m^2 test surface (plus ramps) was divided into 12 equal squares, each of which was compacted by 2, 4, 6 or 8 passes at a constantly low speed, Figure 3.

Fig. 3 Compaction of the test blanket. The soil, bentonite and water are previously mixed in a concrete mixer.

Considering the self-repairing capacity, and the mechanical resistance the plasticity properties of a bottom layer must be good. Hansbo & Olsson (1973) have shown that the plasticity of a sand/bentonite material is completely lost at the optimum water content for compaction which lies in the range 9-12% according to tests by Hansbo & Olsson (loc cit) and Fagerström & Lundahl (1977). A water content slightly higher than the optimum for compaction should therefore be choosed. The water content in these tests was between 14 and 15%.

The compaction effect was studied by dry density measurements and the bearing capacity by means of a cone penetrometer (Soil Assessment Penetrometer, Model 244). The results are reported in Table 1.

TABLE 1

Dry density values and cone penetrometer values for 4 compacted layers of mixed soil/bentonite (10% Volclay SLS-71).

Soil description	Number of passes with a vibro-plate	Dry density (t/m^3)	Cone penetrometer value (CI-value) average of 8 measurements
Graded sand	2	1.5	43 (34-56)
	4	1.6	53 (35-70)
	6	1.6	71 (30-103)
	8	1.8	59 (35-87)
Fine sand	2	1.6	36 (30-44)
	4	1.6	49 (38-71)
	6	1.5	69 (53-83)
	8	1.7	66 (55-77)
Coarse, graded fluvioglacial	2	1.8	84 (72-102)
	4	1.7	114 (100-132)
	6	2.1	143 (118-170)
	8	2.1	130 (97-180)

Comparative test with native clay filling

Two large samples of a glacial clay were taken from a pit outside Linköping. One of the samples represents the dry, partly fractured, hard surface clay and the other the deeper, soft clay. The water content of the soft clay was slightly above the liquid limit, but it was not possible to dump or pour it from a truck and obtain a flat deposit without additional work afterwards. Both clay samples were therefore split up, using a shovel, into cube-like lumps which were laid out by hand to form an approximately 0.2 m thick layer on a 0.1 m thick layer of coarse gravel placed on the ground. A similar gravel layer on top of the clay completed the sandwich structure and allowed the compaction (6 passes) of both clay samples. The bearing capacity of the sandwich structure was just enough to bear the 145 kg vibrating plate compactor.

The compacted clay layers were carefully uncovered and a section was dug out. In the dry clay layer, deep, coarse fractures filled with gravel were revealed, whereas no intersecting fractures could be found in the soft clay layer, Figure 4.

Fig. 4 Two sections through the compacted clay layers. The dry clay layer is shown above and the soft clay layer below. The bar is 250 mm long.

DURABILITY OF BENTONITE SEALANTS

Bentonite is a finely graded swelling clay, the physical properties of which are collodial and dictated by smectitic minerals which dominate. The physical properties of the clay are governed by the electrostatic interaction between particle surfaces, exchangeable cations and interstitial fluid. Of course, the electrochemical status of the pore water plays a significant role in this mechanism and a deteoriation of the rather sensitive particle structure of the smectite must be expected when exposed to contaminated water. Such a breakdown may be instantaneous due to an unbalance in the electroforces or it may be transient and rather slow due to the effect of ion exchange.

The ion exchange capacity, which may be substantial, reflects the sorptive effect of these clays. Hence, the decreased swelling and sealing properties due to ion exchange are connected to a simultaneous filtrating effect caused by sorption. During sorption, ions from the leakage water will be exchanged for ions from the clay, notably sodium, which will emanate and may contribute to contamination. Since both the percolation rate and "ageing" are governed by the hydraulic conductivity of the soil/bentonite material, the latter factor will be critical.

Polymer treated bentonites, specifically designed to counteract the effect of contaminants are now available on a commercial scale. These products are said to provide resistance against dissolved ions in significant concentrations for at least 30 years. One of these bentonites, called Volclay SLS-71 and recommended for community waste landfills, was selected for the study. The principal constituent in the product, manufactured by the American Colloid Co, is a high-swelling, natural sodium bentonite of the Wyoming type. A corresponding, untreated Wyoming bentonite, "Black Hill", was chosen as a reference bentonite. In addition, a calcium dominant bentonite from Czechoslovakia, "Sabenil 650", and on some occasions even other bentonites were included in the study. A comparative study with a native, glacial clay was performed to obtain a special reference to "natural" conditions and to the clay fill alternative.

The bentonite and clay samples were subjected to ion exchange tests. The natural ion contents of the samples were determined by washing with NH_4-Ac at pH 7 (Jacksson, 1962). The contents of Na^+, Ca^{2+}, K^+ and Mg^{2+} were measured with an atomic absorption spectrophotometer. The exchangeable quantity of these ions, the cation exchange capacity (CEC) and the sodium adsorption ratio are reported in le 1. The sodium adsorption ratio (SAR) racterizes the exchangeable sodium content relation to the total exchange capacity of cium and magnesium.

TABLE 2

Echangeable quantity of important cations, cation exchange capacity (CEC) in mekv/100 g and sodium adsorption ratio (SAR) of the studied clay/ bentonite samples.

Samples	Na^+	K^+	Ca^{2+}	Mg^{2+}	CEC	SAR
Leca-Clay	2.2	1.1	10.6	4.2	18.0	0.82
Sabenil 650	43.5	1.8	26.0	13.3	84.5	9.8
Black Hill	67.3	2.5	20.5	15.9	106.2	15.8
Volclay SLS-71	85.2	1.2	16.0	7.0	109.5	25.1

The ageing effect was studied in a series of ion exchange tests which were performed with a natural leaching water. Four partsamples containing a fixed amount of each sample were shaken in a plastic bottle with a leaching water content corresponding to 10, 25, 50 and 100 years of exposure. Due to the successive ion exchange effect and subsequent increase in permeability, the leakage rate increases continously with the exposure time. However, constant conditions are assumed in our calculations of the leaching water quantity and these yield only approximate results. The bentonite/soil ratio was 12.5/87.5 and the corresponding initial hydraulic conductivity 10^{-9} m/s. The ion content after the shaking was measured in the same way as in the ion exchange tests. The results are reported schematically in a graph in Figure 1.

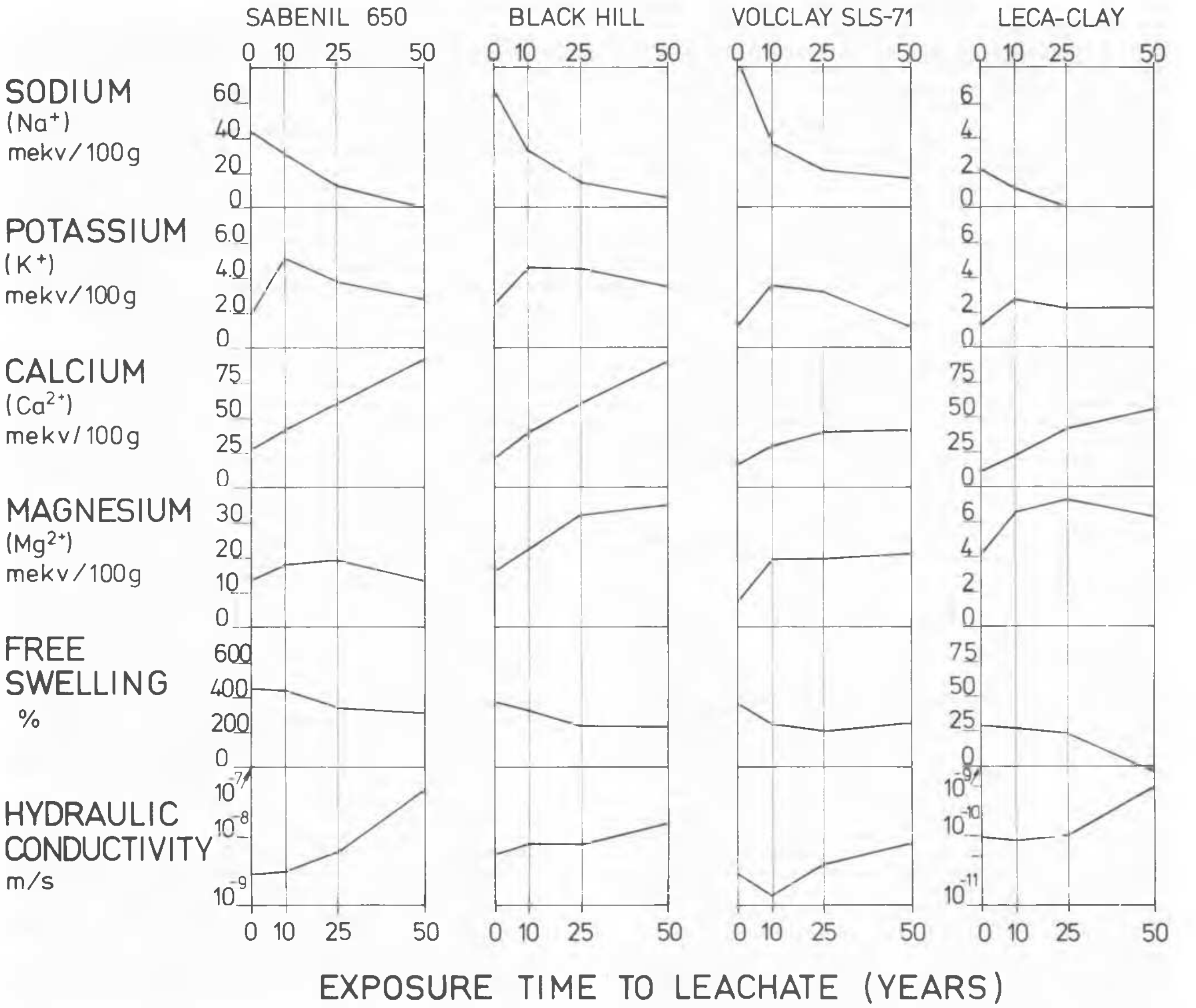

Fig. 5 A graphic representation of the results obtained from 3 sand samples mixed with different bentonites and from a native clay (Leca-clay) under washing with water in quantities corresponding to varying exposure times.

COST ASPECTS

The total cost per unit area of a sealing blanket strongly depends on the following factors:

- Permeability specifications.
- Raw material prices - especially that of bentonite.
- Total size of the area to be treated.
- Equipment used.

A decrease in permeability by one order of magnitude requires an additional bentonite rate of about 4 kg/m^2. The bentonite prices in Sweden range from about SEK 800 per tonne to about SEK 1800 per tonne depending on the quantity and type. At a bentonite rate of 21 kg/m^2 an additional 4 kg/m^2 corresponds to a 3-20% increase in the total costs, depending on the type of bentonite and the other factors listed above.

Of course, there is a quality dependency in the bentonite prices which makes a quality selection interesting. For instance, in Sweden, polymer treated bentonites are 50-100% more expensive than other high swelling sodium bentonites. As indicated by the leaching water experiments above, the positive sealing effect of the processed bentonites (at least to some leaching water) may be achieved equally well by an extra dose of an ordinary high swelling bentonite. In our case, the addition of 2 kg of such a bentonite per m^2 would be enough to compete with the Volclay SLS-71 for 50 years. This alternative would definitely be cheaper.

The type and size of the machines that should be used will generally depend on the size and character of the work. On areas smaller than 1.000-3.000 m^2, small, hand-held vibrating machines and rotary cultivators or concrete mixers will be advantageous. On larger areas, the use of construction equipment will be the cheapest alternative. The concrete mixer will always be a relatively expensive alternative, even if more than one mixer is used.

The native clay fill alternative will also be relatively expensive - at least in the manner used in this study.

CONCLUSIONS

The present study reports no immediate, drastic increase in the hydraulic conductivity due to any disturbance of the internal, electrostatic forces in the bentonite. However, such effects are reported elsewhere as is the resistance to such effects which is provided by polymer treatment of bentonites (Hansbo & Olsson, 1973, Karlqvist, Lindqvist & Qvarfort, 1977). The present study indicates that the exchange of cations may be an important effect which does not seem to be fully excluded by the polymer treatment. Even if the processed bentonites showed the best resistance to the leaching water, the difference between the untreated and the treated sodium bentonite is not very great. In this case it would probably be compensated by a small, extra dosage of bentonite.

In view of the varying chemical composition of leaching waters, differing effects on bentonites must be expected. Considering the significant bentonite price difference the resistance capacity of the bentonite to current leaching should be of vital interest.

Even the native clay is affected by the leaching. In this case, the permeability increase is not slowed up with time in the same way as for the sodium bentonites. This means that the long-term sealing properties of a native clay layers may also be questioned.

The sealing properties of a fixed amount of bentonite are most economically used when the bentonite is mixed with a soil. The mixing efficiency is therefore a relevant factor. Surprisingly long mixing times or many passes with cultivators, etc are required to produce an adequate homogeneity. Compaction of soil/bentonite layers involves no problems as long as normal specifications for similar materials are followed. In general the bearing capacity of such layers is sufficient to allow passage of most vehicles. Coarse, graded soils seem to be very suitable for mixing and compaction but these operations should be avoided in rainy weather. As the strength of a compacted clay surface is easily reduced by rain, a protective surface layer is recommended.

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