Waste deposit encapsulation using vertical barriers

Confinement de sites contaminés par des systèmes de barrières minérales verticales

R. Hermanns-Stengele – *Basler & Hofmann Consulting Engineers, Zürich, Switzerland*

ABSTRACT: The construction of man-made barriers in the ground is one of the traditional tasks of civil engineers. During the last few years this activity has become increasingly important particularly with regard to protecting the environment from hazardous wastes. One method for the securing of old waste deposits is their encapsulation with vertical barriers, using plastic-concrete cut-off walls.

In this paper, the securing of a hazardous waste deposit in Switzerland with such a vertical barrier is described. The suitability of different materials for the cut-off walls was investigated; mineral sealing materials of different compounds were used. The workability of new concrete mixtures was tested, and their mechanical, chemical and mineralogical properties examined in the laboratory. Of great importance was the influence of the contamined ground water on the barrier material itself. The long term concrete behaviour due to chemical attack was investigated using a number of different testing methods. The determination of permeability, diffusion, retention and pore-radius were the principal areas of interest.

Finally, some general advice is given which will be usefull when isolating hazardous waste deposits using vertical barrier systems of plastic-concrete material.

RESUME: L'assainissement de sites contaminés constitue un des principaux problèmes environnementaux actuels. Des études en Allemagne et en Suisse montrent que, dans les prochaines années, de nombreux sites connus actuellement devront être assainis ou confinés. Afin que les coûts d'assainissement restent raisonnables, il est nécessaire, pour chaque cas particulier, de rechercher une combinaison optimale de différentes méthodes d'assainissement, en accordant une place prépondérante aux mesures d'isolement. Une possibilité pour confiner un site contaminé consiste à l'entourer d'un système des barrières verticales minérales avec des parois continues en béton moulées à deux phases.

Au cours des dernières années, l'institut de géotechnique de l'École Polytechnique Fédérale de Zurich a testé, dans le cadre d'un projet de recherche, l'aptitude des matériaux minéraux comme barrière pour des parois moulées à deux phases. L'étude portait d'une part sur la maniabilité de la masse fraîche et, d'autre part, sur le comportement mécanique et minéralogique à l'état durci. Soit plus précisément sur la stabilité à long terme ainsi que sur les modifications minéralogiques et chimiques des matériaux en contact avec des eaux d'infiltration de décharges.

1 INTRODUCTION

Vertical underground barrier systems may be used to minimize waterloss from hydraulic structures, reduce the inflow of water into building excavations, and prevent drowdown of the surrounding groundwatertable. It is now also practice to use vertical barrier systems for environmental protections. The principal areas are the encapsulation of old waste deposits and contaminated industriel areas. Typically encapsulation consists of four main aspects:

1. Reduction in the flow of contaminated water into the surrounding groundwater system using vertical cut-off walls. Such walls have to be keyed into a natural geological barrier.
2. Reduction in the flow of uncontaminated water into the waste deposit using cut-off walls, and/or collection of this water with drainage systems or galleries.
3. Drawdown inside the encapsulated area; the hydraulic gradient is directed from outside to inside, contaminated seepage water is collected, pumped and regenerated.
4. Covering of a contaminated area with sealing materials to reduce the entrance of rain-fall and surface-water.

Today a number of different methods exist to construct vertical cut-off wall systems. The three main principal techniques are (Figure 1):

- excavation of soil and backfill of barrier materials;
- displacement of soil and backfill of barrier materials;
- reduction of in-situ soil permeability by reducing or filling of pore volume.

To encapsulate old waste deposits the barrier-system used has to fulfill a number of different requirements: low permeability, low diffusion coefficient, chemical long term behaviour due to the attack of contaminated seepage water and high adsorption of

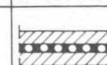
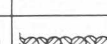
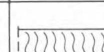
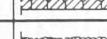
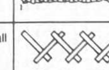
principle	cutoff-wall systems	horizontal section	soils	material
construction of cutoff-walls involving excavation of soil	diaphragm-wall - single-phase methode		generally excluding organic soils	bentonite-cement-suspension with/without filler
	diaphragm-wall - two-phase Methode		as above	bentonite-suspension, low permeability concrete
	combined cutoff-wall		as above, only using the single-phase methode	bentonite-cement-suspension with artificial sealing materials (eg. high density polyethylene)
	overlapping bored-pile wall		generally exclusing organic soils	concrete
as above and backfilling of soil with addition of cement, bentonite, etc.	backfill methode		no restrictions when casing used	soil-cement or soil-bentonite with/without additives
construction of cutoff-walls without excavation of soil	thin-wall		soils into which the construction element can be driven or vibrated	bentonite-cement-suspension with filler
	sheet pile wall			steel
	driven precast wall			concrete
reduction of in-situ soil permeability	grouted wall		soil permeability > 10^{-6} m/s	cement with additives (eg. clay, silica gel)
	jet-grouted wall		generally soils with permeabilities < 10^{-6} m/s	bentonite-cement-suspension with/without filler
	frozen soil wall		high permeability and high groundwater flow potential	liquid nitrogen, freezing agent

Figure 1. Summary of Methods for the Construction of Vertical Cut-off Wall systems (after: Jessberger, 1991)

pollution. The constructed cut-off wall also has to deform without cracks during consolidation or hardening processes.

In the course of a research project the encapsulation of contaminated areas was examined using plastic concrete cut-off walls. The investigations were conducted at the Institute of Geotechnics, which is part of the Swiss Federal Institute of Technology ETH Zurich (Hermanns 1993).

2 CONSTRUCTING VERTICAL BARRIER-SYSTEMS USING THE TWO-PHASE CUT-OFF WALL METHOD

The two-phase method for constructing cut-off walls is similar to the slurry trench construction system used for building static load-bearing walls.

The excavation of the trench occurs section by section (Figure 2) using special construction tools for slurry trench walls, such as grabs and chisels. The soil walls are supported by a bentonite suspension during excavation. Subsequently the actual sealing material is introduced into the trench during a process of exchange. It displaces the bentonite suspension, which may be pumped out and regenerated, or removed.

During the process of concreting, each section is bound by a cylindrical framework, and this can lead to gaps occuring between the individual section (Witt & Beck, 1987).

In order to displace the bentonite suspension with the sealing material, there has to be a sufficiently large enough difference in density between the two materials.

The main advantage of the two-phase method is the extensive range of potential sealing materials which may be used.

3 INVESTIGATION OF MINERAL SEALING MATERIALS USING THE TWO-PHASE CUT-OFF WALL METHOD

3.1 *Compounds*

To encapsulate an old waste deposit in Switzerland using a vertical barrier different mineral sealing materials were tested. The content of active material should be sufficient to improve the long term behaviour of the mixture and increase the retention of polluted liquids. Inert materials such as sand or gravel were not used.

In the laboratory of the Institute of Geotechnics several mixtures were tested using portland cement, powdered clay and different kinds of filler. The main results of two selected mixtures (Mixture A and B, Figure 3) are presented in this paper; the compounds used in Mixtures A and B are also shown in Figure 3. The main difference between the two mixtures was the addition of a filler to A. This filler is described as a fly ash from an anthracite power plant, and is called EFA-Filler.

The following table 1 shows different mixtures for two-phase cut-off walls used in the past (mixtures 1 - 4). The two mixtures A and B which were investigated at the ETH are also shown in this table.

Table 1. two-phase cut-off wall mixtures

mixture	compounds per m^3 slurry mass	density ρ [t/m^3]	coefficent of permeability k [m/s]	reference
1	200 kg cement 100 kg clay flour 100 kg rock flour 810 kg sand 0/3 mm 490 kg gravel 2/8 mm 360 kg water	2,06	1×10^{-10}	Strobl 1989
2	40 kg Na-bentonite 280 kg cement 250 kg rock flour 1200 kg sand/gravel 0/8 mm 350 kg water	2,17	2×10^{-10}	Witt 1987
3	340 kg clay flour 650 kg sand 0/2 mm 990 kg gravel 2/8 mm 3 kg Dynagrout DWR A 5 kg Dynagrout DWR B 35 kg water glasss 180 kg water	2,20	1×10^{-10}	Hitze 1987
4	55 kg Na-bentonite 80 kg cement 210 kg rock flour 1080 kg sand/gravel 555 kg water	1.96	5×10^{-10}	Knappe 1988
A	368 kg cement 491 kg clay flour 123 kg fly ash 654 kg water	1.63	$< 1 \times 10^{-11}$	Hermanns 1993
B	279 kg cement 638 kg clay flour 678 kg water	1.60	1×10^{-9}	Hermanns 1993

3.2 *Requirements*

The following conditions are required of the barrier mixtures:

– in fresh condition the masses should be mixable, pumpable etc.;

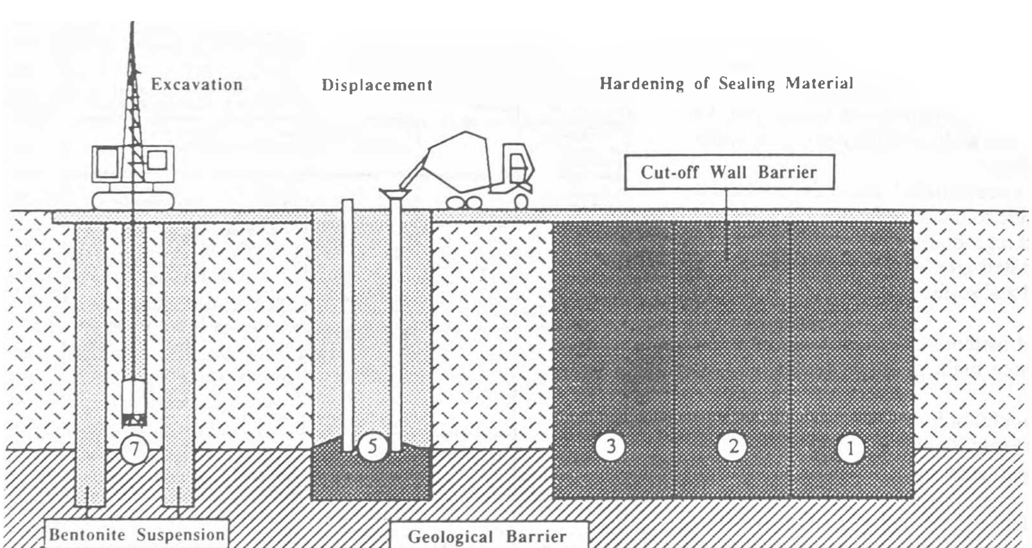


Figure 2. Construction of Two-Phase Cut-off Walls

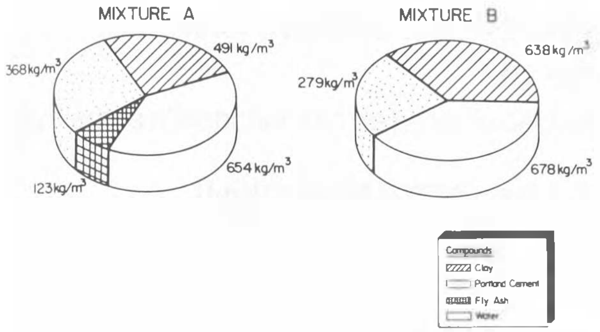


Figure 3. Compounds of the Investigated Mixtures A (left) and B (right)

- during the process of concreting the mixture should not become segregated;
- the barrier material has to replace the bentonite-suspension completely;
- during hardening no cracks must occur in the course of the consolidation (setting) or hardening processes (shrinkage);.
- when hardened, the cut-off wall should be able to deform itself without cracking;
- the permeability has to be low, and the resistance against diffusion has to be high in the presence of contaminated liquids;
- the long-term behaviour of the wall system has to be ensured against chemical attack;
- the barrier material should have high adsorbtion properties.

3.3 *Laboratory Test Results*

Mixtures A and B were prepared in the laboratory, placed in cylindrical containers and deposited under water (18°C) until investigation. After 28 days permeability tests were carried out using flexible wall cells; testing liquids were tap water and a simulated contaminated water. The compounds in this liquid (Table 2) were similar to the chemical analysis of actual contaminated water. The hydraulic gradients used in the test were between $i = 30$ and $i = 100$. The percolated test liquids were collected and the coefficient of permeability k was estimated using Darcy's law. The results of the permeability tests are shown in Figure 4.

The collected percolates were analyzed chemically. One of the main considerations was the amount of calcium-ions carried out of the samples by water movement. A low release of calcium-ions is an important operating condition for barrier materials. In different papers a loss due to percolation of 30 % of the calcium content is seen as critical with regard to material permeability (Strobl, 1986). The calcium concentrations determined during the permeability tests are shown in Figure 5.

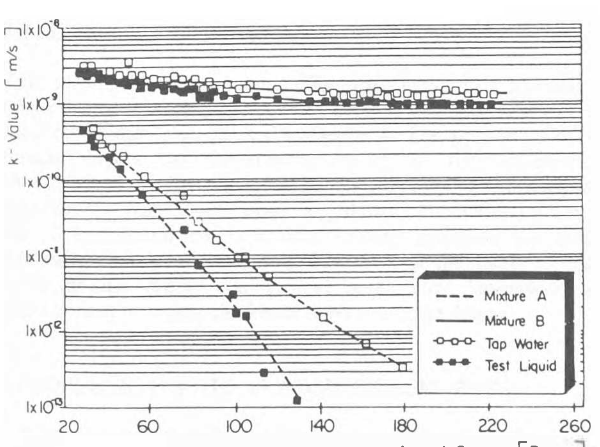


Figure 4. k-Values of Mixtures A and B as a Function of Age and Test Liquid

Table 2. Contens of the testing liquid

Parameter	Concentration mg/l
chloride	10000
sulphate	1500
ammonium	500
calcium	350
sodium	3500
potassium	2000
manganese	300
pH-value	≈ 7
electric conductivity	30000 mS/cm

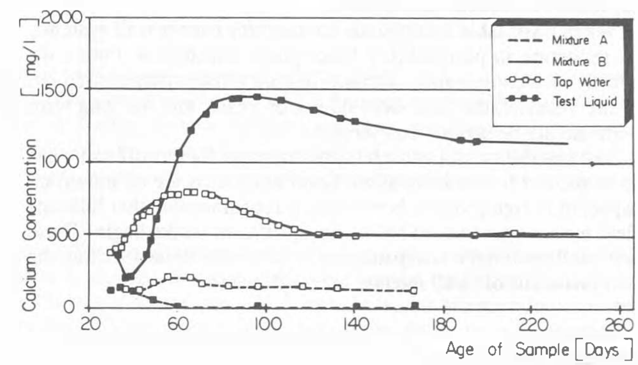


Figure 5. Calcium Concentrations in Collected percolates, Mixtures A and B

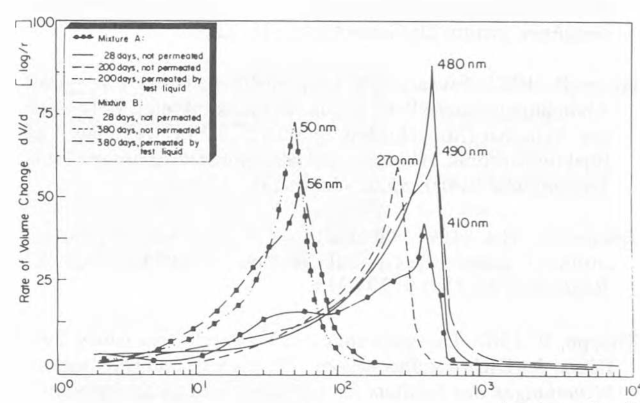


Figure 6. Sample Pore Size Distribution

The permeability of porous materials depends on the porosity and on the pore ratio. The distribution and the size of pores were measured using mercury pressure porosimetry. The results from the different treated samples are presented in Figure 6.

The determination of diffusion coefficients using different test liquids showed that this transport mechanism is relatively unimportant for the two mixtures examined. Because of the choosen testing methode the evaluation of the coefficient of diffusion results of Fick's law. This law discribes the diffusion stationary:

$$I_S = D_S \times i_S \times A_S$$

where I_S = permeat rate, D_S = coefficient of diffusion, i_S = diffusion gradient, A_S = area.

Using chlor-phenole (1 %), a coefficient of diffusion of about $D_S = 5 \times 10^{-11}$ m²/s was determined. Heavy metals like zinc were precipitated because of the high pH of the pore water.

4 CONCLUSIONS

The encapsulation of old waste disposal sites with vertical barrier systems using the two-phase cut-off wall method is possible. Qualified materials are portland cement, clay, electro-flyash and water (Mixture A). The permeability of the vertical barrier can be decreased to extremely low values using appropriate compounds. A reduction of permeability from $k = 10^{-9}$ m/s to $k < 10^{-11}$ m/s can be obtained, which corresponds to the accumulation of calcium-ions during the test period (Mixture A, Figure 4). This accumulation leads to a reduction of pore sizes. Permeation processes were minimized when the average pore ratio was less than 100 nm. In the case of the investigated Mixture A, diffusion transport processes will not reduce the barrier properties of a cut-off wall over realistic time periods.

When unsuitable compounds are used for barrier wall systems, no reduction in permeability takes place (Mixture B, Figure 4). Which such compounds, calcium-ions are prferentially carried out of the material, the pore sizes do not decrease, and the long term permeability behaviour may increase.

The suitability of a chosen barrier mixture for cut-off walls has to be proved for each situation. Laboratory tests are an important aspect of design process, however it is recommended that fullscale field tests are performed before encapsulation works begin. These tests will enable the encapsulation of old waste deposits using the two-phase cut-off wall method to be optimized.

REFERENCES

Hermanns, R. 1993. *Sicherung von Altlasten mit vertikalen mineralischen Barrierensystemen im Zweiphasen-Schlitzwand-verfahren.* Institut für Geotechnik, ETH Zürich

Hitze, R. 1987. Einsatz von schadstoffresistenten Dynagrout Abdichtungsmaterialien, geschildert an konkreten Beispielen der Schadstoffumschliessung durch Schlitzwandbau und Injektionstechnik. *Altlasten und kontaminierte Standorte - Erkundung und Sanierung*, Bochum: 131 - 151

Jessberger, H.L. 1991. Geotechnics of Landfills and Contaminated Land. Technical Recommendations "GLC", *Bautechnik 68,* Heft 9: 294-315.

Knappe, P. 1987. Die gerammte Schlitzwand - ein neues Verfahren der Dichtwandherstellung, Dichtwände und Dichtsohlen. *Mitteilungen des Instituts für Grundbau und Bodenmechanik, Technische Universität Braunschweig, Nr. 23*: 75 - 89

Strobl, Th 1987. Einsatz von Dichtwänden an der Brombachtalsperre. *Mitteilungen des Instituts für Grundbau und Bodenmechanik, Technische Universität Braunschweig, Nr. 23:* 171 - 184

Strobl, TH. 1989. Erfahrungen über die Untergrundabdichtung von Talsperren, dargestellt am Beispiel des Brombach-speicher-systems, *Wasserwirtschaft 79, Heft 7/8*: 372 - 377

Witt, K.J. & Beck, W. 1987. Symposium "*Erfahrungen bei der Sanierung der Sonderabfalldeponien Gerolsheim und Sprendlingen*". Ministerium für Umwelt und Gesundheit des Landes Rheinland-Pfalz, Mainz