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Durability of vertical bentonite barrier for old sanitary landfill containment

Introduction

Due to the cement hydration process, the permeability of cement-bentonite mixtures decreases with time, whereas the shear strength are increased.

The question is how far the reduction of permeability and increasing of strength can go with time? What is the influence of pore fluid (leachate) on above properties.

The paper presents the results of in situ tests performed during construction (control tests) as well as during the exploitation, for estimation of long term behaviour of the bentonite barrier.

The control tests are essential for quality assurance of vertical bentonite barriers. They should mainly verify continuity of the barrier wall, the demanded barrier depth related to natural aquitard layers as well as the sufficient shear strength and low permeability of the bentonite material.

The tests were performed on bentonite barriers constructed for the groundwater protection of old sanitary landfill Radiowo located nearby Warsaw (Koda, 1999).

The durability of the bentonite barriers was estimated on the basis of permeability and shear strength tests as well as chemical and physical analysis of underground water conducted according to local monitoring system.

Groundwater protection system with vertical bentonite barrier

The use of cement-bentonite, as the protection system of groundwater against pollutant migration, is increasing because, during the construction no separate backfilling operation is required, since the slurry itself sets as the consequence of cement hydration (Fratalocchi and al., 1996)

The main goal of the cut-off wall for the environmental protection is to reach the following features: high quality, i.e. low permeability, proper stress-strain behaviour, stability against erosion and chemical attack (Brandl, 1996).

For construction of vertical barriers on Radiowo landfill Solidur 274S was used. Solidur is a dry compound mixture containing clays (mainly Na-bentonite), cement and special additives. It provides high workability. The density of the bentonite suspension for the both landfills was 1.15-1.18g/cm^3, while the viscosity was 20-50N/m^2. Marsh time for slurry mixtures equalled 35-45 s (Koda and Skutnik, 2003).

The submerged counterflow system consists of a bentonite cut-off wall barrier in order to protect the first aquifer against the transport of pollutants. In the framework of the remedial design, the peripheral drainage around the landfills is constructed.

Moreover, at the bottom of berms, the "finger" pipe drains were also installed, so that to direct the leachate to the peripheral drainage. A peripheral drainage sink recovers the leachate. This design enhances containment by including a counterflow condition, in which clean groundwater from the vicinity flows towards the contaminant zone to the leachate drainage. It will also protect the bentonite barrier material against degradation, caused by the leachate.

This system is effective, easy to design and build, suitable for the environment protection, and applicable to various site conditions. This design provides favourable hydraulic conditions by forcing the lowered groundwater level inside the peripheral cut-off wall in relation to the natural groundwater level around the landfill site (Fig. 1).

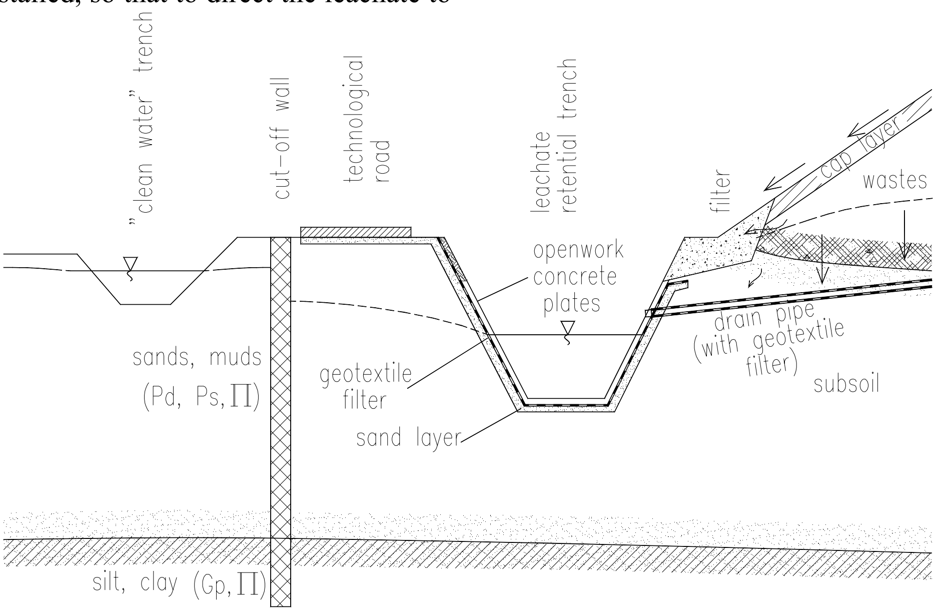

FIGURE 1. The groundwater protection system against leachate on Radiowo landfill.

Site characteristics

Since early 60's to 1991 the Radiowo landfill was used as a place, where municipal wastes from Warsaw were disposed. Actually, it covers ca. 15 ha area, and it is higher than 55 m. It is planned to be closed in the year 2005.

Now, only non-composted wastes from Radiowo compostory are stored on the landfill. The organic matter content for these wastes is ca. 4% (Koda, 1998). Central and southern parts of the landfill are filled with municipal wastes 10-30 years old, while the upper layers in the north part are filled with fresh non-composted products.

The subsoil consists of sands, the thickness of 2-15m, underlayed by boulder and Tertiary clays, the ground water level is at the depth of 0.2-1.0m.

Along the perimeter of Radiowo landfill, a cut-off wall barrier has been designed to minimise the spread of pollutants into the surrounding groundwater environment. The depth of the cut-off wall was 5-22m.

This design will provide favourable hydraulic conditions by forcing the lowered groundwater level inside the peripheral cut-off wall in relation to the natural water level around the landfill site (Koda and Paprocki, 2000).

Leachate will be collected through the retention trenches and passed on to storage tanks, in turn, water will be pumped to the crown of the landfill where it will be stored for later use. To ensure full functionality of the re-circulation system on the landfill body, a system of storage tanks has been constructed.

Quality control tests of vertical bentonite barrier during construction

For checking of the bentonite suspension stability, the principal properties should be determined directly in the field during construction (Brandl, 1996). At this stage, the continuity of the barrier wall and the demanded barrier depth related to natural aquitard layers should be ensured. The geological supervision consisted of the following tasks:

- control of the type of soils (min. 2m m below roof of aquitard layer),
- control of overlap of following section of the bentonite wall (min. 0.5m),
- determination of density and viscosity of bentonite suspension,
- run-out time (Marsh time),
- collection of bentonite suspension for further laboratory tests.

The decisions concerning the barrier wall depth as well as the location of the primary and secondary panels were taken by geological supervision (ISSMFE/ETC5, 1993).

For construction of vertical barriers on Radiowo landfill Solidur 274S was used.

Solidur is a dry compound mixture containing clays (mainly Na-bentonite), cement and special additives. It provides high workability. The density of bentonite suspension for the both landfills was 1.15-1.18 g/cm^3, while the viscosity 20-50 N/m^2. Marsh time for slurry mixtures equalled 35-45 s.

These properties proved that the tested bentonite suspension was properly mixed and homogenous. The physical properties do not provide absolute values for the shear strength or permeability but constitute an essential part of the quality control of fresh slurries. An additional commitment of the geological supervision was to take suspension samples directly from the excavation for further laboratory tests.

Control tests of vertical bentonite barriers

The hydraulic conductivity of CB barriers can be affected by a lot of factors, depending on the intrinsic characteristics of the mixture and the physico-chemical conditions during the curing time (Fratalocchi, 1995). Some of them are well-known (higher cement content gives lower permeability, and higher bentonite content allows to obtain higher elasticity), but other factors should be investigated in the proper way.

Fratalocchi et al. (1996) show the influence of curing time on the permeability. Several mixture specimens, with different dosages of bentonite cement and water, were prepared. Having been tested in a flexible wall permeameters, with continuous seepage (hydraulic gradient equal to 10) and the effective confining pressure was equal to 100 kPa. Measurements carried out through a long time of curing, demonstrate the hydraulic conductivity decreases versus time. The fact can be explained taking in consideration the cement hydration. According to Schweitzer (1989) the decrease of K value can be appreciable for 2 years of curing and even longer.

In addition, using the mercury intrusion porosimeter test (Lowell, Shields, 1984), the remarkable reduction of total porosity with an of the smaller pore fraction, has been quantified due to cement hydratation.

The results concerning specimens permeated only for short periods, under a confining pressure, showed that the presence of seepage during the curing does not affect the hydraulic conductivity.

TABLE 1. Selected *in situ* tests for the control of vertical barriers (after Manassero, 1999).

Test	Advantages	Disadvantages
Tests with tracers	Real scale of test	It allows to find only the greater problems of the wall
Pumping tests	Large scale of test	Expensive test, only one part of the barrier wall is tested
Geophisycal tests (termic, electric)	Large scale of test	Difficult execution, the tests could provide not correct results in contaminant field. Difficult correlation between different parameters.
Piezometers, BAT system	Test directly on the wall	A small part tested. Possible hydraulic fractures
CPTU	Fast and not expensive test	Not possible in mixture with high resistance

On the other hand the same tests demonstrated that the presence of an initial confining pressure can significantly reduce the hydraulic conductivity in the long term without inducing significant volumetric strains.

Bellezza (1996) demonstrated that water availability for cement hydration, strongly affects the hydraulic conductivity of a soil-cement barrier. Immediately permeation of the mixture can improve the permeability performance, reducing the K value, in the long term.

Brandl (1996) assessed, in addition, that permeability could decrease by a factor of 2 to 20 during a period of 3 to 15 years. The polluted groundwater affects long term behaviour of the cut-off wall, reducing also the hydraulic conductivity; probably the reason is in the gradual change of the sealing minerals (by ion exchange) and other characteristics such as clogging and closing of voids.

It is well known that the shear strength of cement-bentonite mixture increases with curing time. The shear resistance and stiffness of slurry walls increase with the curing time, due to the cement hydration process. Hence a higher content of cement provides a material with higher shear strength.

Brandl (1996) shows that compressive strength of cement-bentonite mixtures increases with curing time, depending on the sort of bentonite and cement. In situ strength testing of cut-off walls requires samples from borings that cause a local disturbance. For this reason Brandl (1996) introduced a modified rebound hammer test which is quick, cheap and non-destructive; it can provide reliable values of the compressive strength.

Investigation of the vertical barrier for Radiowo landfill

During the bentonite barrier construction for Radiowo landfill, the samples of the mixture have been collected into PVC tubes of 5, 10 and 25 cm in diameter for the laboratory hydraulic conductivity and shear strength tests.

In order to evaluate the hydraulic conductivity of the bentonite material in the laboratory, the triaxial cell have been modified for tests of variable hydraulic gradients. The tests were carried out after 28 and than 60 days. The test results are presented in Fig. 2. The initial gradient, where water flow occurred, is about 50, while in the field conditions the hydraulic gradients are only 2-5.

For shear strength estimation of bentonite material, after adequate time of curring the unconfined compression tests in triaxial aparatus have been carried out. The tests were carried out after 28 and than 60 days. The test results are presented in Fig. 3. The test results indicates, the increasing in the shear resistance with time, which is generally associated to a higher stiffness and lower deformations at failure.

For the estimation of the hydraulic conductivity and shear strength of the bentonite material also site investigation have been performed. In the case of Radiowo landfill, BAT system has been

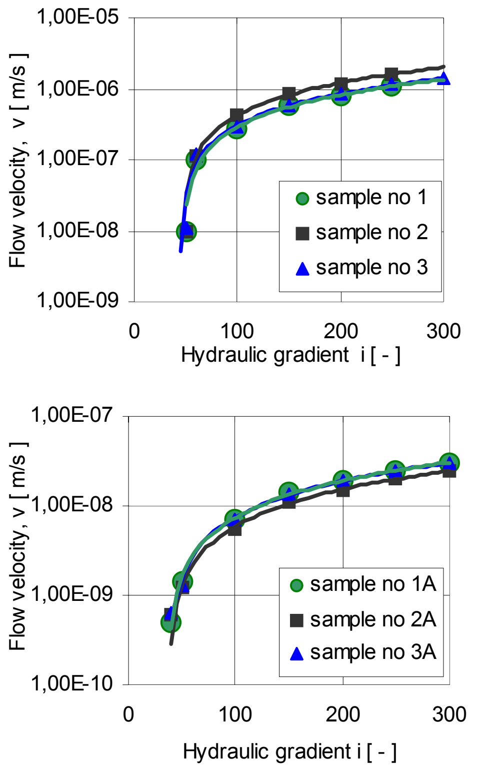

FIGURE 2. Relationship between flow velocity and hydraulic gradient for bentonite material from hydraulic conductivity tests in the triaxial cell after 28 and 60 days.

used for in situ permeability measurements of the bentonite material.

BAT Groundwater Monitoring System (Torstensson, 1984) is an integrated system for: pore pressure measurements, sampling of groundwater, in situ permeability and tracer tests. In addition to the above functions, it is also possible to utilise BAT System for making hydraulic fracture tests in soils of low permeability for the stress-state estimation (Skutnik, 2000). The tests have been carried out as "outflow test"

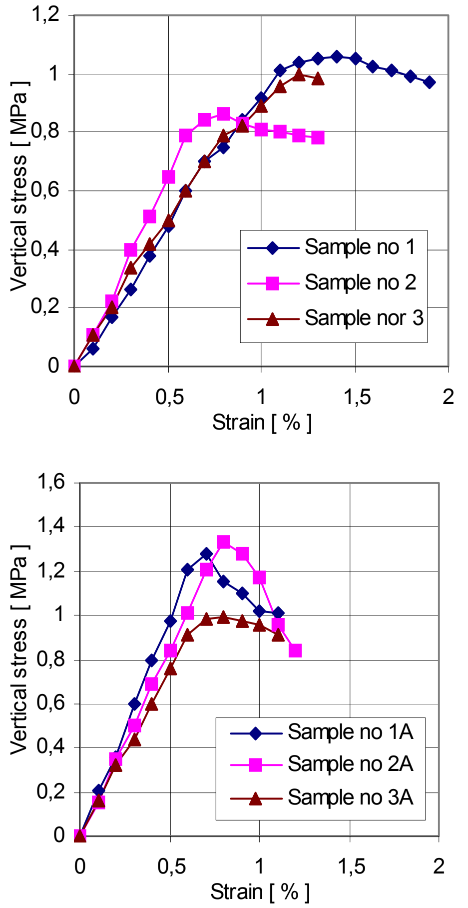

FIGURE 3. Unconfined compressice strength tests results of bentonite material after 28 and 60 days of curingl.

at the different depths of the barrier. For insertion of the BAT piezometer into the barrier body, HASON and HYSON type of CPT equipment has been used. The results of BAT tests and distribution of the hydraulic conductivity in the depth after 28 days 60 days and 1000 days is shown in Fig. 4. It can be seen, that the permeability decreases with the depth.

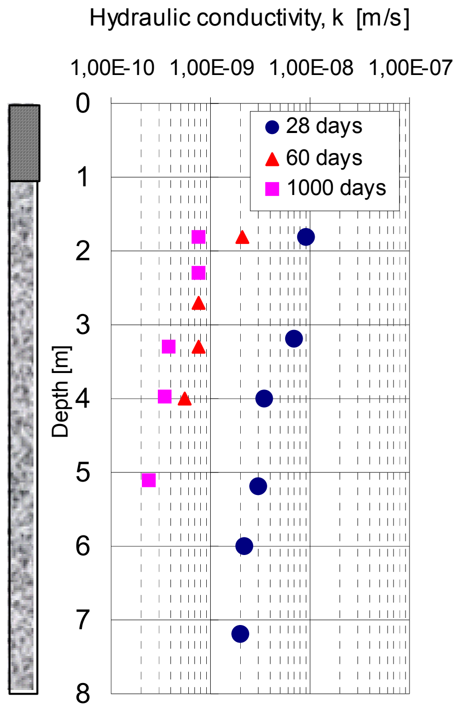

FIGURE 4. BAT tests results of vertical bentonite barrier surrounding Radiowo landfill – profil near piezometer P7.

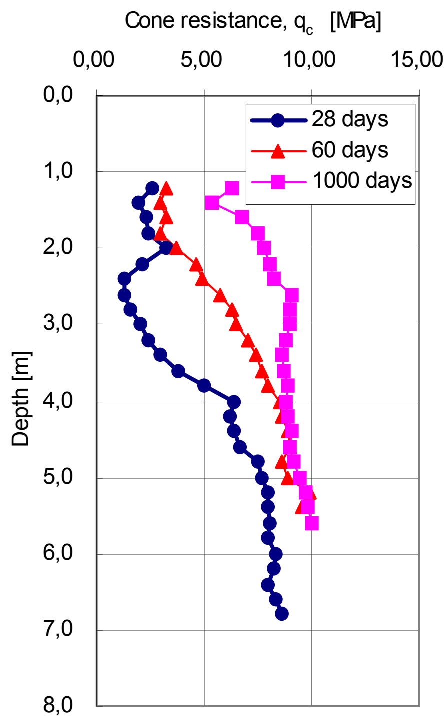

FIGURE 5. CPT tests results of vertical bentonite barrier surrounding Radiowo landfill – profil near piezometer P7.

In the regular engineering practice, CPT is carried out in order to assess the subsoil conditions. In the case of the bentonite barrier, the tests have been aimed at determination of barrier homogeneity and undrained shear strength s_u estimation on the basis of the measured cone resistance q_c. For comparison, the CPT tests have been performed in the same profile after 28, 60 and 1000 days (Fig. 5).

The values of the cone resistance q_c increases with the depth and with time elapsed since the barrier construction. It confirms the permeability reduction (Fratalocchi and Pasqualini, 1998), and increase of bentonite mixture shear strength with time.

Other investigations and estimation of durability of vertical bentonite barriers

The durability of the bentonite barriers was estimated on the basis of permeability and shear strength tests as well as chemical and physical analysis for underground water conducted according to the local monitoring system.

In the surrounding area of Radiowo landfill, the local monitoring was installed for the assessment of water quality and the estimation of remedial works efficiency. The water monitoring system for this site contains 17 shallow piezometers for the first groundwater level control, one deep well for second groundwater level control and six points on surface streams.

The monitoring observations were started in 1997, i.e. 3 years before the vertical barrier construction. Comparing water monitoring tests results before and after vertical barrier construction, il can be concluded that this barrier effectively protects groundwater against pollution from the landfill. A few years of investigation indicate the tangible decrease in the level of groundwater contamination. The changes of pollution concentration in the groundwater from piezometer No 7, located outside the western part of the barrier in the groundwater outflow from the landfill area, are presented in Table 1. For example, total suspended, BOD_5 and COD_{Cr}, during three years were reduced approximately 10 times, while ammonium more than 100 times. There is observed systematically decrease of all tested indicators for the groundwater quality. Similar results of remedial works were received for Łubna landfill (Golimowski and Koda, 2001)

TABLE 2. The influence of the vertical bentonite barrier on the quality of groundwater in the vicinity of Radiowo landfill in piezometer No 7.

No.	Pollution indicator	Unit	Concentration of pollutants			
			Sampled in 11.07.2000		Sampled in 20.06.2001	Sampled in 14.05.2003
1	Colour	--	Black-brown	Closure of the vertical bentonite barrier (November 2000)	Brown	Light
2	Turbidity	--	Turbid		Light turbid	Light turbid
3	pH	pH	7.8		7.3	7.1
4	Electrolytic conductivity	µS/cm	10 830		8 370	4 060
5	Dissolved matters	mg/l	7 970		6 336	2 963
6	Total suspensions	mg/l	146		99	19
7	BOD_5	mgO_2/l	650		75	50
8	COD_{Cr}	mgO_2/l	1 758		226	136
9	Ammonium nitrogen	mgN_{NH4}/l	97.7		14.1	0.8
10	Chlorides	$mgCl^-/l$	2 374		1595	470
11	Sulphates	$mgSO_4^{2-}/l$	690		630	308
12	Total chromium	mgCr/l	0.6		0.3	0.04
13	Lead	mgPb/l	0.2		0.05	0.01
14	Zinc	mgZn/l	1.2		0.7	0.2
15	Petroleum extract	mg/l	11.6		6.8	3.2
16	Carbohydrates	mg/l	0.006		0.003	<0.001

Conclusions

The aim of the research was the trial of durability estimation of the bentonite cut-off wall. This task involved the study of the factors affecting hydraulic, mechanical, and chemical compatibility of slurry wall during its curing time as well as laboratory tests and field investigations performed during and after construction.

Quality control tests performed during construction confirmed, that the received parameters of tested barrier meet requirements of the design.

On the basis of permeability and shear strength tests performed after 28 days, 60 days and after more than 1000 days prove that fundamental properties of the barrier are improved with time.

Also chemical and physical analysis for underground water, conducted according to the local monitoring system indicate the considerable decrease in the level of groundwater contamination after the vertical barrier construction.

On the basis of the above it may be concluded that the bentonite barrier is resistant for leachate from landfill and fulfil also durability requirements.

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Summary

The control tests are essential for quality assurance of vertical bentonite barriers of landfill areas containment. They should mainly verify the continuity of a barrier wall, the demanded barrier depth related to natural aquitard layers as well as the sufficient shear strength, low permeability and durability of bentonite material. The paper presents the results of control tests performed on bentonite barrier constructed for groundwater protection of old large sanitary landfill located nearby Warsaw. The results of the quality assurance investigation of bentonite barrier were achieved both in field and laboratory tests. The hydraulic conductivity for the barrier wall were below 10^{-9} m/s, resulting from laboratory and in situ BAT tests. The shear strength of the bentonite material from laboratory and field CPT tests were higher than 1 MPa. The changes of the permeability and shear strength with a lapse of time and in the depth of barrier are also presented. The water monitoring results in the landfill surrounding indicate effective isolation of groundwater against pollution.

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