Strength and permeability of single-phase diaphragm walls

La résistance et la perméabilité de parois moulées exécutés en une seule phase

F.SCHWEITZER, Dr-Ing., Institute for Soil Mechanics and Foundation Engineering, University of the Federal Armed Forces, Munich, FRG

SYNOPSIS: In recent years, diaphragm walls are more and more used in Germany to seal existing old waste deposits from the environment in order to protect the groundwater against contamination. Especially the single-phase cutoff construction method has been approved to for this purpose. This paper describes the usual mixtures and their properties. The influence of the content of bentonite, cement and filler on the strength is shown by results of systematical laboratory tests. The development with time of the long-term properties as strength and water permeability is demonstrated for an executed slurry wall in Munich, FRG.

1 INTRODUCTION

1.1 Design principle

In the past waste mostly was posed directly on the ground without any protecting sealing layer. Many of these existing waste deposits have to be improved because they endanger the groundwater. The rain leaches aggressive components which percolate into the groundwater (Fig. 1).

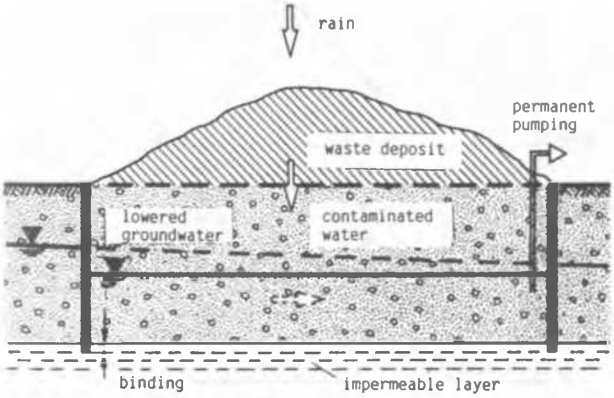


Figure 1. Sealing of an existing waste deposit by slurry walls (schematic)

An usual technical way for reconstruction is to seal such existing waste deposits by vertical barriers. This is possible, if there exist an impermeable layer in an available depth, to which the vertical wall can bind to. So, an impervious trough is made (Fig. 1). Additionally, the inside groundwater table is lowered permanently by pumping, so that no contaminated water can flow out.

1.2 Construction method

In Germany, slurry trench walls are used more and more as a vertical barrier. Very common is the single-phase construction method (Fig. 2).

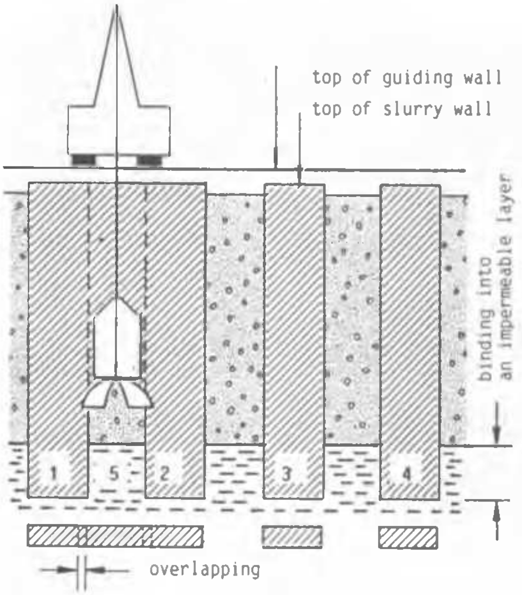


Figure 2. Construction of a single-phase slurry wall (schematic)

A trench is excavated by special equipment and at the same time a slurry is filled in. This suspension stabilizes the trench during the construction time, is being left in the trench to harden with time and remains as a permanent diaphragm wall. During trench excavation natural soil from the surrounding ground enters the mixture. Because of the alternating construction of the segments no joints consist, but a contінous wall (Fig. 2). This is an important advantage of the single-phase slurry trench wall besides of its economic technology.

Diaphragm walls for waste deposits normally are constructed with a thickness of 0,4 to 0,6 m and a depth up to 30 m. For special requirements they can be built with supplementary sealing elements,i.e. sheet piles, prefabricated concrete plates, geotextiles.

2 MATERIALS AND MIXTURES

Single-phase diaphragm walls consist of a mixture of bentonite, cement, water and sometimes mineral filler too. Their most important properties, strength and low permeability, depend on the

- proportion of ingredients
- type of bentonite and cement
- hardening time
- hydraulic gradient (thickness of the wall)
- accumulation by material during construction.

The quantity of solid substance is limited by the processibility of the suspension, so that its density might be between 1,15 and 1,30 kg/m^3.

In Germany , the following materials and mixtures have been approved to for single-phase slurry trench walls, which seal waste deposits with low aggressive percolating water:

Bentonite: industrial fabricated bentonites are used, marked as "activated Sodium-bentonites". They are stable to cement and have a great swelling potential. For 1 m^3 of the fresh mixture 30 to 50 kg Sodium-bentonite is mixed.

Cement: applied are blast-furnace cements, because they harden slowly and give enough time for the construction process. They are resistant to chemical aggression as well. The fineness of grinding (Blaine-value) and the content of blast-furnace sand influence the properties of the sealing wall. A quantity of 160 to 220 kg are mixed per 1 m^3 fresh suspension.

Filler: normally, no filler is mixed into the suspension. But during the construction process the mixture is accumulated by substance of the ground. In practice, sand contents (more than 0,06 mm grain-size) up to 20 % of volumen were measured. Therefore, the density is growing on from nearly 1,15 to 1,40 kg/m^3.

Water: according to the content of solids 850 to 940 kg water are given into the mixture. The ratio water to cement is about 4 to 5. A part of the water is filtered out into the adjacent soil during the construction process (filtration water).

For diaphragm walls in deposits with very hazardous waste mixtures are used with a higher content of solids, also with Calcium-bentonites (150 to 250 kg/m^3) and special hydraulic binders (Müller-Kirchenbauer et al 1987).

3 STRENGTH

The completed diaphragm wall must be firm enough to retain the water pressure and the lateral earth pressure including surcharges and must be safe against erosion. On the other hand the wall should not be too rigid so that it can deform without joints under loads. Desirable is a "plastic" wall with a strength and a deformability like the adjacent ground.

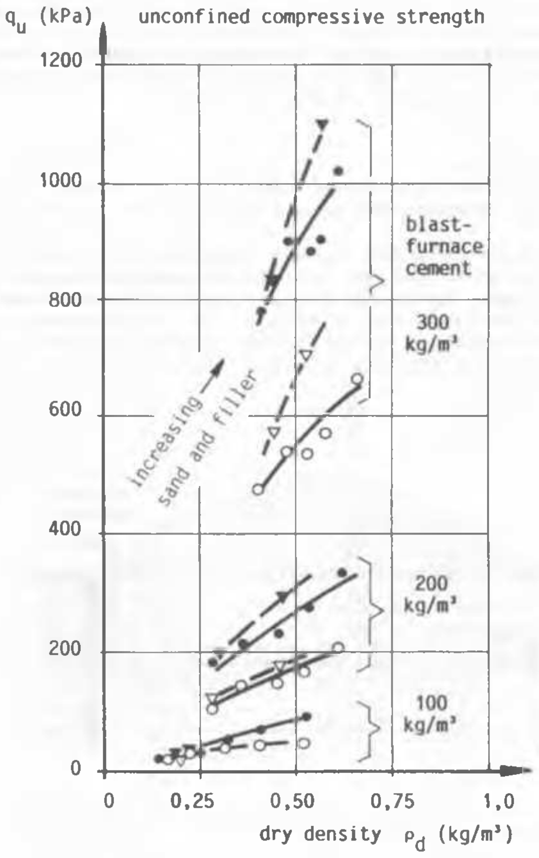
The strength of the slurry trench wall material is proved by the unconfined compression test (German Standard DIN 18 136). The samples are taken during the construction procedure in different depths and stored under water before testing. In general, the unconfined compressive strength q_u should be at least 300 kPa after 28 days (EAU 1985).

The strength and the deformation behaviour of the slurry trench wall mass in particular depend on the quantity and the type of cement, the accumulation of sand during the construction procedure and the hardening time. The relations between these components are demonstrated by the results of systematical laboratory tests, in which the unconfined compressive strength was determined on samples composed of different mixtures (Fig. 3). The dry density of all mixtures varies between 0,15 and 0,67 kg/m^3. The results indicate:

(1) The strength increases with growing content of solid substances. As exspected, mostly the quantity of cement fixes the magnitude and the rising.

(2) The strength increases with time, especially marked for mixtures with higher content of cement.

(3) The concentration of bentonite is of lower influence to the strength.



content of	kg/m^3	
sodium-bentonite	30	40
sand	0 /100/200/300/300	
filler	0 / 0 / 0 / 0 /150	
age of sample 28 / 56 days	○/●	▽/▼

Figure 3. Relationship between unconfined compressive strength and dry density for different mixtures (laboratory test programme)

The development of the strength with time is shown in Figure 4, investigated on an executed single-phase slurry trench wall (bentonite/cement 37,5/200 kg/m³). During the period between 28 and 150 days the strength is rising and approximates asymptotically to a limiting value. After one month the statistical mean value is 320 kPa, after two months nearly double of this size. After three months the final strength is reached approximately, in this case nearly 1000 kPa. Some test results show also a very high strength of more than 2000 kPa. The great scatter results from inhomogenities in the mixing process and the varying accumulation with sand during construction. Similar results are reported by other authors too (Geil 1982; Düllmann & Heitfeld 1983; Meseck 1987).

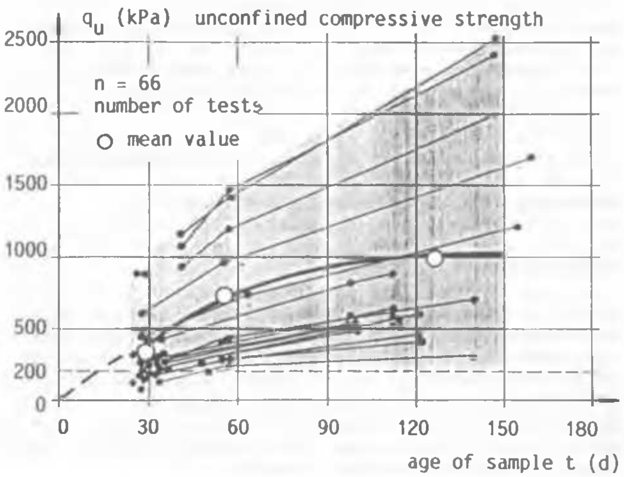


Figure 4. Development of unconfined compressive strength with time (single-phase slurry wall, Munich)

In the unconfined compression test samples from slurry trench walls break already after a low linear deformation ϵ = 1 to 2 %. So, the material is relatively rigid; more plasticity is desirable.

4 WATER PERMEABILITY

The dominant attribute of a diaphragm wall is its permeability, which is measured by the coefficient of permeability k (m/s) after DARCY's law. The k-value is given in the design and the specification and has to be proved after the construction. The k-value should be less than 10 E-8 m/s for slurry trench walls sealing "normal" waste deposits.

4.1 Test procedures

The coefficient of permeability is determined in laboratory tests (German Standard DIN 18 130, part 1). The samples are taken out of the trench during the construction procedure, filled into cylindrical containers and stored in water. A hydraulic gradient i = 30 is recommended for the purpose of comparing the results (Jessberger 1987). The belonging k-value is an index point only. In practice, the effective hydraulic gradient will be much lower.

The completed diaphragm wall can be proved in situ by seeping tests. For this purpose drillings with a small diameter are bored into the hardened wall to a depth of 5 to 10 m. The borehole is filled with water and the drawdown of the water level is measured with time. The result is a curve approximating the outside groundwater table. From this curve the k-value can be calculated for each hydraulic gradient (Horn 1986). This k-value considers inhomogenities of the slurry trench wall mass and gives the permeability of the test section in average. The in situ checked k-value is more representative than the k-value gathered from laboratory test, because the volumen of the mass percolated in the in situ test is very much bigger than the small laboratory sample. Because the permeability of bentonite-cement mixtures depends on the hardening time, the tests have to be repeated after some time (Schweitzer 1987).

4.2 Results

For a single-phase slurry trench wall (bentonite/cement 37,5/200 kg/m³) executed in Munich in 1986 (Gierschik; Horn & Schweitzer 1987), the development of the permeability was investigated for 2,5 years by tests in the laboratory and in situ. The coefficient of permeability k decreased with time in the whole observed space (Fig. 5).

The test data can be described by the exponential function $k = a \cdot t^b$ (a, b coefficients of regression) with a high correlation coefficient r. So, the development of the permeability with time is a straight line in a double logarithmic graph with k-value versus time (Schweitzer 1988). The inclination b of the correlated line indicates the speed of the decreasing permeability. It essentially depends on the quantity and the type of the cement. The axis section a, i.e. the initial permeability, is considerably influenced by the content of solid material in the slurry. In this project of a diaphragm wall with 35 000 m² area totally, the average k-value decreased from 5·10 E-8 m/s after one month to less than 5·10 E-10 m/s after two years (Fig. 5).

Because strength and permeability of bentonite-cement mixtures are influenced by the same parameters, there is also a relation between these both properties. With increasing strength the permeability decreases, at least in the space of time the cement is reacting strongly. Figure 6 shows this relationship got from 1 to 3 months old samples of different mixtures. The investigated suspensions have a density between 1,14 and 1,25 kg/m³ and a ratio water/cement of 4,4 to 5,3. If for these mixtures a coefficient of permeability k = 10 E-8 m/s is demanded, the strength will be about 250 to 450 kPa. If a lower k-value is wanted, a more rigid wall must be accepted.

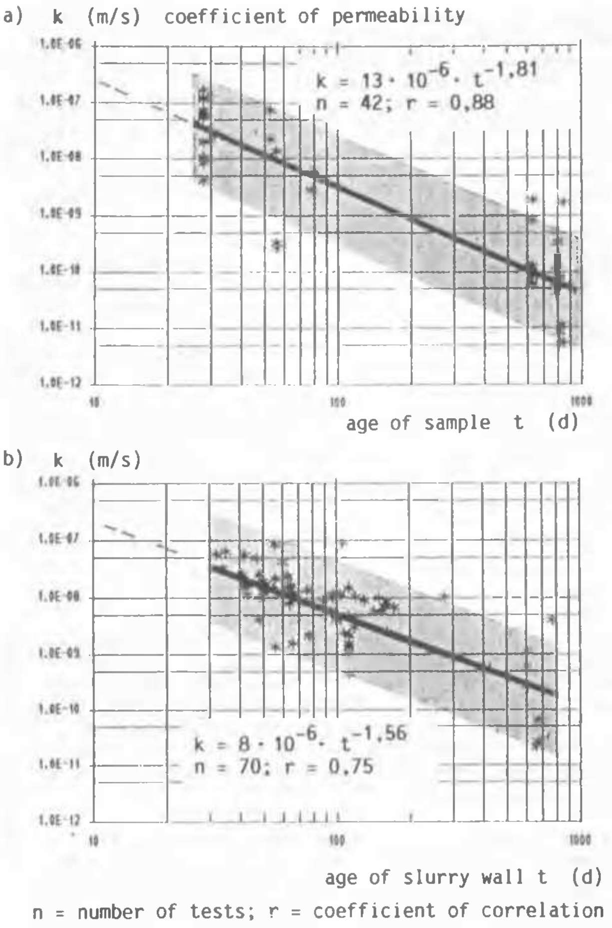


Figure 5. Development of water permeability with time (single-phase slurry wall, Munich)
a) results of laboratory tests
b) results of in situ tests

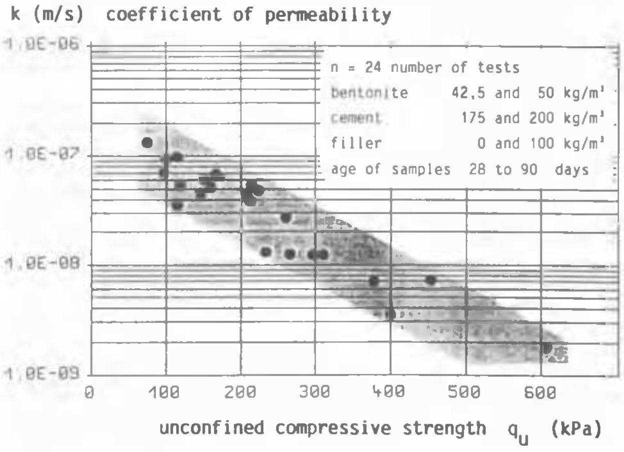


Figure 6. Relationship between water permeability and unconfined compressive strength for different mixtures (laboratory test programme)

5 SUMMARY

(1) In Germany, slurry trench walls, constructed by the single-phase method, have proved true for sealing existing waste deposits in order to protect the groundwater. In the case of low aggressive contaminated liquids the mixtures consists of Sodium-bentonite (35 to 45 kg/m^3) and blast-furnace cement (160 to 220 kg/m^3) with water.

(2) The strength of these mixtures increases with the hardening time. After 3 months nearly 80 % of the final strength are reached.

(3) The coefficient of permeability k should be determined in laboratory tests and in situ tests as well. The results of both testing methods scatter until two decimal powers.

(4) The k-value decreases with time. This development can be approximated as a straight line in the double logarithmic graph with k-value versus time. This kind of plot allows also a prediction of the long-term permeability based on initial test results.

(5) Diaphragm walls with usual bentonite-cement-mixtures reach a k-value less than 10 E-8 m/s after a certain time.

(6) The durability is given for bentonite-cement-mixtures with an unconfined compressive of permeability less than 10 E-8 m/s, if the hydraulic gradient is not more than 25.

REFERENCES

Düllmann, H.& Heitfeld, K.-H.(1983). Erosionsbeständigkeit von Dichtwänden unterschiedlicher Zusammensetzung. Vorträge zur Baugrundtagung 1982 Braunschweig, S.317-336, Deutsche Gesellschaft für Erd- und Grundbau, Essen.

EAU (1985). Recommendations of the Committee for Waterfront Structures (EAU 1985) 5th Engl. Ed. Ernst und Sohn Verlag, Berlin 1986.

Geil, M.(1982). Entwicklung und Eigenschaften von Dichtwandmassen und ihre Überwachung. Mitteilung des Instituts für Grundbau und Bodenmechanik, Braunschweig, H.8, S.113-144.

Gierschik, H., Horn, A.& Schweitzer, F. (1987). Dichtwand um den Müllberg München-Großlappen zum Schutz des Grundwassers. Wasserwirtschaft, Jhrg. 77 (1987), H.9, S.483-488.

Horn, A.(1986). In-situ-Prüfung der Wasserdurchlässigkeit von Dichtwänden. Geotechnik,H.1,S.37.

Jessberger,H.L.(1987). Empfehlungen des Arbeitskreises "Geotechnik der Deponien und Altlasten" der Deutschen Gesellschaft für Erd- und Grundbau. Bautechnik 64 (1987),H.9, S.289-303.

Meseck, H.(1987). Mechanische Eigenschaften von mineralischen Dichtwandmassen. Mitteilung des Instituts für Grundbau und Bodenmechanik, Braunschweig, H.25.

Müller-Kirchenbauer,H., Friedrich,W.& Rogner,J. (1987). Ergebnisse der Dichtwandtestmaßnahme im Rahmen eines F + E-Vorhabens für die Sanierung der Sonderabfalldeponie Gerolsheim. Symposium, Ministerium für Umwelt und Gesundheit des Landes Rheinland-Pfalz, Mainz, S.63-77.

Schweitzer,F.(1987).Prüfung der Wasserdurchlässigkeit an der Dichtungs-Schlitzwand um den Müllberg in München-Großlappen.Berichte zur 6. Nat. Tagung Ingenieurgeologie,Aachen, 1987,S.79-88.

Schweitzer,F.(1988).Die langzeitige Wasserdurchlässigkeit von Dichtwänden und deren Prognose. Geotechnik,H.3, S. 153-157.