GEOLOCK, plastic HDPE-liner for vertical cut-off barriers around landfills.

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Japan	patent	127862/1985
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CONTENTS

1. INTRODUCTION

Geolock is a vertical plastic sheetpile barrier system especially developed for intercepting polluting liquids, and the removal of gases or groundwater from or near contaminated sites such as industrial complexes, landfills, tailings, and waste dumps. It is patented internationally and has been successfully installed in many countries around the world.

The problems associated with pollutants seeping from landfills and waste disposal sites are increasing with alarming frequency. In addition, in numerous places soils have been contaminated as a result of industrial activities or leaking storage tanks. Although soil cleansing utilizing bio-remediation, steam or incineration is available, the removal and treatment of polluted soil is a very expensive operation, and not always economically justified.

The most practical solution in these cases seems to be a total encapsulation of the polluted soils, so that the pollution is permanently contained, pending the development of a longer term solution. With this demand for vertical isolation of polluted areas in mind, Geotechnics Holland bv, in collaboration with Cofra bv, developed the watertight vertical barrier screen called *Geolock.*

Geolock is a plastic screen consisting of HDPE sheet-pile sections which are locked together. This lock ensures a completely watertight joint, so that leakage of contaminated groundwater is prevented. This report will explain the special properties of *Geolock*, the method of installation, chemical resistance, and comparison with alternative solutions.

Geolock is not only suitable for isolation of existing landfills, but can also be used as a vertical water barrier in civil engineering constructions.

2. VERTICAL SCREENS

Vertical screens for the isolation of polluted areas have to comply with a number of demands. They must;

- Be completely watertight, including the base
- Remain flexible to allow for settlement
- Be suitable for installation in all types of soil
- Have simple installation procedures
- Ensure that no break will arise in the screen
- Be resistant to chemical attack
- Have long life, at least 100 years
- Be suitable for installation depths up to 40 meters
- Be resistant to root and rodent attack
- Be resistant to decay and micro-organisms

Developing a barrier which meets all these requirements is not a simple task. The number of materials which can be used for this purpose is very limited. Only clay, bentonite, and a number of plastics can be considered to be suitable.

However, Geotechnics' extensive experience in the production and applications of plastics in geotechnical engineering simplified the choice. A High Density Polyethylene (HDPE) extruded section was developed in the form of a flat sheet pile barrier system.

3. GEOLOCK

The cross section of the sheet piled barrier is based on four distinctive features;

(1) A hammer-shaped bead (male), which fits into the lock (female).

(2) The body, consisting of an HDPE extrusion, which can vary in thickness between 1.5 and 3 mm welded onto the HDPE sheet.

(3) The lock section (female), which slips onto the previous sheet bead (male) and ensures the seal.

(4) A groove, allowing the insertion of an expansion profile for a watertight seal.

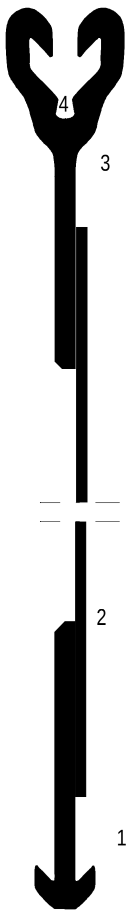

Fig. 1

A lock with a thickness of only 2 mm would normally be adequate for a good seal. With this thickness, however, the strength of the lock would not be sufficient for the load which is to be expected during and after installation.

Therefore, the lock section is 6 mm thick, providing a joint with strength exceeding that of the liner welded to it.

Consequently, with substantial soil deformation, the lock section will not release, but the liner will first elongate, which is unlikely to affect the performance of the structure.

Geotechnics Holland has conducted a test program to determine the joint lock behaviour in the event of vertical folding in highly compressible soil layers. Since the application of vertical barriers often results in the collection of intercepted liquids, groundwater tables may be lowered, with differential in groundwater tables either side of the barrier. The risk of unacceptable settlement may as a result be considerable.

The liner is welded onto the lock section of the screen by means of a hot air or wedge welding method, which is also successfully applied with construction of lining systems for secure waste containment.
In principle, the sheet section can be produced in unlimited lengths, but in view of storage and transport, a maximum length of 12 m has been established. At the jobsite, greater lengths can be created to suit the required depth, by means of butt welds. However, insertion of such lengths, deeper than 12 m will demand certain development on specially designed equipment and product modifications. The friction against the lock, together with the friction against the soil during installation, will be too great at a given moment for the strength of the sheet sections.
In addition, the stability of the trench can be a problem. However, installation in a bentonite slurry wall will facilitate installation to greater depths.

The unique feature of *Geolock* is that the lock can be made completely watertight. The impermeable sealing consists on an expansion profile, which is inserted in the appropriate groove in the lock section. The expansion profile is made of a neoprene based rubber, which is unaffected by chemical attack. Depending on the ground water condition, the material can expand up to 16 times its original volume, and is accommodated with a built-in activation delay, allowing sufficient time for installation of the barrier before the swelling process begins.

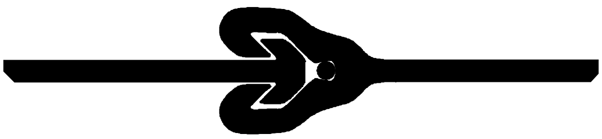

Fig. 2 Expansion profile before installation

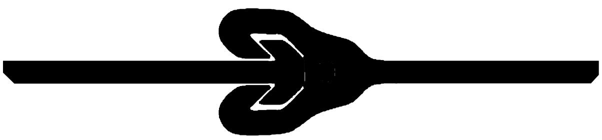

Fig. 3 Final volume after 40 hours

The material properties of the expansion profile are listed in table I.

Mass	1.3 gr/cm^3
Tensile strength	2.9 N/mm^2
Elongation	700 %
Deformation	32 %

Table I

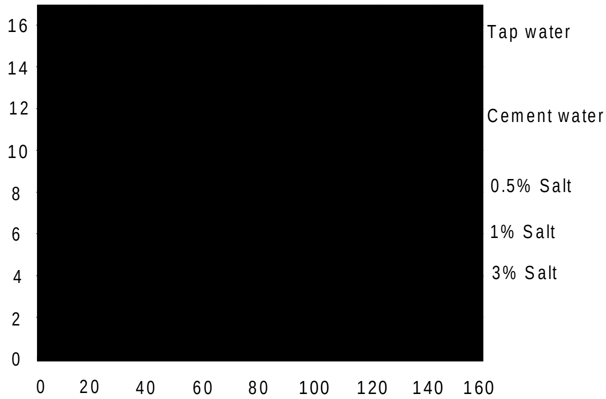

Fig. 4 Swelling properties of the expansion profile in various solutions

Corner profiles and accessories are provided to allow the construction of T-joints and curves with a radius of approx. 3 m. It is also possible to make a joint with the liner of the same composition, by means of extrusion or hot air welding, since the HDPE material can easily be fabricated.

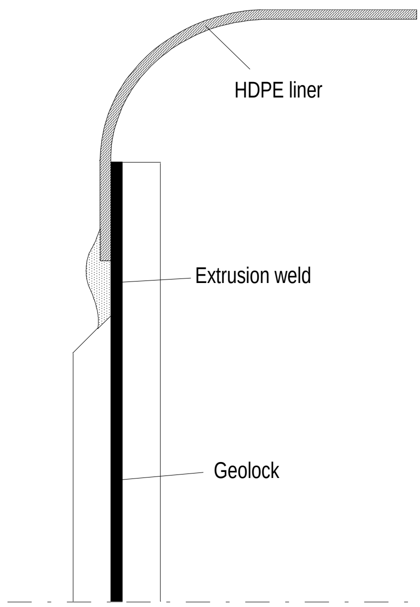

Fig. 5 Welding a liner onto the Geolock sheets

4. SEALING PANEL BOTTOM

Practical experience has shown that groundwater seepage can occur between the bottom of the barrier and the lower soil layer. If jetting is used to install *Geolock*, the jetted trench may be filled with course soil particles, i.e. sand, thus creating an area of higher permeability at the bottom of the Geolock panels.
This area can be resealed by injection with a grout or slurry mixture. An injection tube can be fitted along the *Geolock* panel, through which such a sealing material can be inserted at a later stage, in case the structure appears to provide insufficient isolation performance.
This method of sealing the bottom of the *Geolock* panel is relatively inexpensive, since no special installation equipment is required.

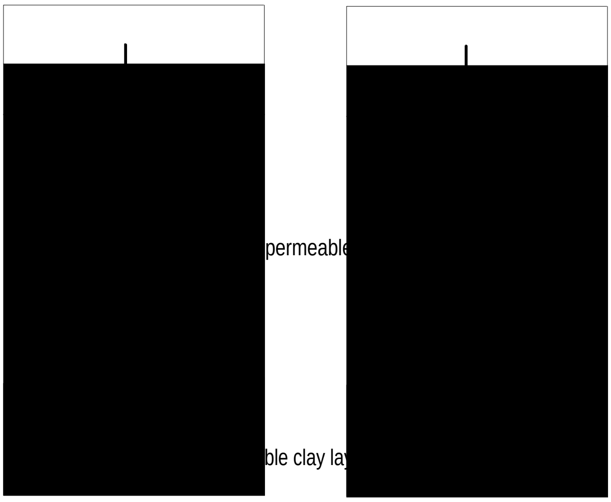

Fig. 6 Underseepage due to installation by jetting.

5. MATERIAL PROPERTIES

Geolock barrier has the following specifications;

sheet width	0.5 - 2 m
thickness	2 mm
length	4 - 30 m
weight	2 kg/m^2
tensile strength yield	34 kN/m
tensile strength lock	50 kN/m
permeability	10-13 m/s
elongation yield	18 %
E- modulus	800 N/mm^2

Table II

6. CHEMICAL RESISTANCE and AGEING

6.1. HDPE liner

HDPE geomembrane sheeting is available from a number of established manufacturers, all meeting stringent quality control specifications.
The type of HDPE geomembrane selected is determined by and should be adapted to the particular circumstances. A general review of average resistance of HDPE to various chemicals is tabulated below.
Addition of carbon black provides the HDPE material with greater resistance to the influence of ultraviolet radiation.
TNO-KRI, a Dutch testing institute on plastics, has conducted a number of tests on the HDPE-geomembrane

Aromatic Compounds		Inorganic contamin.	
Benzene	0	NH_4	+
Ethylene Benz.	+	Fluorine	+
Toluene	0	Cn	+
Xylene	+	Sulphides	+
Phenol	+	Broom	-
		PO_4	+
Polycyclic hydrocarbons			
		Other chemicals	
Naphtalene	+		
Anthracene	+	Tetrahydrofurane	0
Phenentrene	+	Pyrides	+
Fluoranthene	+	Tetrahydrothiopene	+
Pyrene	+	Cyclohexanone	+
Benzopyrene	+	Petrol	+
		Mineraloil	+
Chlorinated hydroc.		Styrene	+
Aliphatic c.h.'s	+	**Pesticides**	
Chlorobenzenes	0		
Chlorophenols	+	Organic chlorine	+
PCB's	+	Pesticides	+

Table III

liners to determine the chemical resistance of several compounds occurring in polluted soils.
The HDPE materials liner was tested in 11 different fluids during 2 months at 30°C and the change in mass, yield strength, elongation at break and environmental stress crack have been determined. The following values were found;

Fluid		Change in Mass (%)	Change in Yield str. (%)	Change in Elongation (%)
Percolation	see table V	+ 1.6	+ 5	+ 9
Domestic fuel oil		+ 7.3	- 3	+ 9
Hydrocarbons	60% toluene 30% xylene 10% methyl naphtalene	+ 9.8	- 11	+20
Aromatic hydrocarbons	30% benzene 30% toluene 30% xylene	+ 9,7	- 11	+15
Alcohols	48 % methanol 48% isopropanol 4 % water	+ 0.2	+10	+ 8
Alifatic hydrocarbons	tricloreethylene	+20,8	- 15	+ 9
Alifatic esters and ketone	50% ethylacetate 50% methyl isobutyl ketone	+ 2,8	+ 5	+14
Alifatic aldehydes	40% formaldehyde 60% water	+ 0.2	+ 11	+27
Organic acid	10% vinagar 90% water	+ 0.2	+11	+24
Mineral acids	20% sulfuric acid	+ 0.1	+11	+ 1
Inorganic alkalics	sodium hydroxide	+ 0.1	+10	+27
Water		+ 0.1	+ 9	+32

Tabel IV

Contents of artificial percolation;

Table V

Vinegar	7.5 g/l	Glucose	0.2 g/l
Propionic acid	2.5 g/l	NaCl	0.35 g/l
Isobuteric acid	0.4 g/l	Na_2SO_4	0.3 g/l
Buteric acid	7.0 g/l	$CaCl_2$	0.1 g/l
Isovaleriane acid	0.4 g/l	$MgSO_4.7H_2O$	0.2 g/l
Caproic acid	4.5 g/l	$(NH_4)_3$, PO_4	0.5 g/l
Enant acid	4.0 g/l	NH_3-solution	16 ml

Distilled water and NaOH to bring the pH on 6.

The material is also tested for environmental stress cracking. After exposure of the material to the chemicals mentioned in Table IV according to ASTM D1693-70 for 200 hours at 50°C, no cracks were found in any of the samples.

6.2. Ageing of HDPE

The endurance of HDPE is influenced by various factors. Symptoms of the ageing process are mainly due to:

- Temperature fluctuations
- Tension fluctuations
- Ultraviolet radiation
- Physical attack
- Chemical attack

Since the first four influences mentioned above do usually not occur once *Geolock* is installed, chemical attack is the most critical influence on the performance of *Geolock*.
Ageing behaviour of the material due to tension and temperature fluctuations is determined by two laboratory tests:

1. The environmental stress crack test (ESC) - 1000 hrs.
2. The differential scanning calorie meter test (DSC) ASTM D3895-68 min.

In general, the buried lifetime of stabilized HDPE can be estimated to be 100 years.

6.3. Chemical resistance and ageing of Hydrotite

Hydrotite consists of electrolytic high molecular hygroscopic polymer dispersed in synthetic rubber (chloroprene) and extruded into a profile. The general properties of rubber products are listed in Table VI.

Specification	Chloroprene (Hydrotite)	Butyl rubber
GENERAL		
Density g/cc	1.25	0.93
Tensile strength N/mm^2	21	21
Tear strength	Good	Good
Wear resistance	Excellent	Reasonable
Oxidation	Good	Excellent
Sunlight	Excellent	Excellent
Heat	Good	Excellent
Natural ageing	Excellent	Good
CHEMICAL RESISTANCE		
Hydrocarbons	Good	Poor
Aromatic hydrocarbons	Poor	Poor
Ketone, Esters	Poor	Good
Vegetable oil	Good	Excellent
Gasoline, grease, oil	Good	Poor
Acid	Excellent	Excellent

Table VI

7. ENVIRONMENTAL APPLICATION

7.1 Hydraulic isolation

The fields of application for *Geolock* can basically be divided into three main groups:

- vertical cut off walls for soil contamination.
- seepage barrier functions in civil and hydraulic engineering projects.
- landfill gas barrier

Geolock has been specially developed for the first group. The fields of application in civil and hydraulic engineering is considerably larger, as *Geolock* is both technically and economically an attractive alternative to existing vertical screens as steel and wooden sheet piled walls or bentonite slurry walls. The following solutions are possible in the isolation of groundwater contamination, regardless of the circumstances.

Fig. 7

(1) Contamination below the water table spreading by means of existing groundwater flow. At a certain depth there usually is an impermeable horizontal layer, for example clay, which will provide a seal for the *Geolock* panels. A vertical screen installed into this clay layer provides sufficient isolation (fig. 7). Leakages, however, may still be possible, therefore it is recommended that the water table within the contained area should be made somewhat lower (about 20 cm) so that there is always a tendency for the outside groundwater to flow inward, should a 100% seal not be achieved. The water which has percolated to the surface will have to be treated before it can be released.

Fig.8

(2) If the lower sealing layer is too deep and the extent of the pollution is not mayor, it is possible to insert an artificial impermeable layer using ground injection. This is, however, very expensive (150 \$ to 250\$ per cubic meter) and is therefore not always feasible. (fig.8)

Fig. 9

(3) By placing an HDPE liner above the contamination and welding this onto the *Geolock* screen, the amount of water which has percolated upwards and which has to be treated can be limited as the addition of precipitation is

prevented. This provides considerable savings in long term maintenance costs. (fig. 9)

(4) These isolation techniques do not provide a permanent solution, as the polluted soil is not removed nor treated. Temporary rinsing will clean the soil, and may have the long term advantage that the contamination is removed and the purification of the leachates may be stopped.

7.2 Landfill gas isolation

Landfill gas is a by-product of the digestion by anerobic bacteria of putrid matter in waste used in landfill and is predominantly 65% methane together with 35% carbon dioxide. This gas can migrate vertically or horizontally through the landfill and surrounding soil. Gas migrating into houses and other buildings have caused dangerous and unhealthy situations on several places. Cement-bentonite walls may be water tight, but are usually not fully effective as gas barriers. *Geolock* can be a good solution to control landfill gas.

8. CIVIL AND HYDRAULIC ENGINEERING APPLICATIONS

Application of *Geolock* in civil engineering structures is also very effective. Deep building sites usually have to be drained, so that foundations and deep structures can be constructed in a dry environment. This drainage ensures that lowering of the water table takes place in the immediate surroundings, allowing construction to take place under dry conditions.
In addition, there is a danger of unacceptable settlement because of the removal of groundwater. By using *Geolock* sheet piled wall screen, the groundwater level remains outside the building site and facilitates more economical drainage.
On some dikes groundwater seepage is a problem, severely endangering structural stability and increasing the need to drain the adjacent areas. These problems occur predominantly with sand dikes. By placing a *Geolock* screen in the dike, the danger of groundwater seepage disappears while damage caused by burrowing and other wildlife is eliminated.

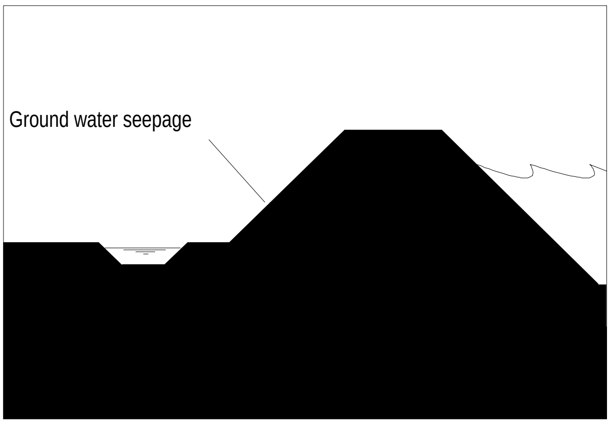

Fig. 10

9. METHODS OF INSTALLATION

Geolock can be installed in three different methods depending on quantity, depth and the nature of the soil. The prime consideration when installing Geolock is to take precautions to avoid damage to the material during installation.

9.1. Vibration

Geolock can be vibrated into the soil using a special mandrel device, usually fitted with a vibrator. The installation depth is limited and depends mainly on the subsoil. In very soft soil it is possible to install *Geolock* panels to a maximum depth of 8 meter at a sheet width of approx. 1.5 m. Shallow sheets which are placed to a depth of 3 meter can have a width of 2.5 meter.
The mandrel consists of a steel plate with a width that harmonizes with the width of the panel and a thickness of approx. 15-20 mm. At the bottom sharp pins are attached to penetrate through the liner and fix it at the bottom of the plate (fig. 13). The panels can either be stretched onto the frame of the mandrel or guided in the trench from the surface.
Anchorplates or strips are punched through the liner to provide adequate anchoring at the required installation depth.

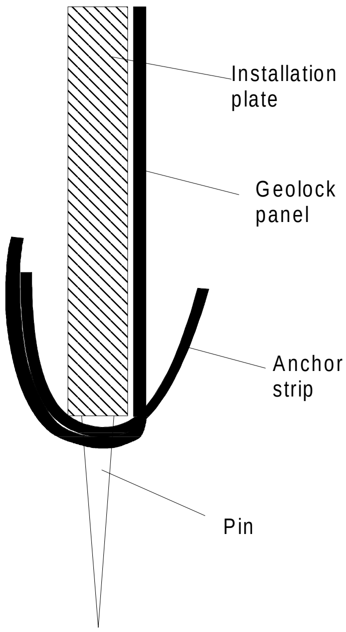

Fig. 11

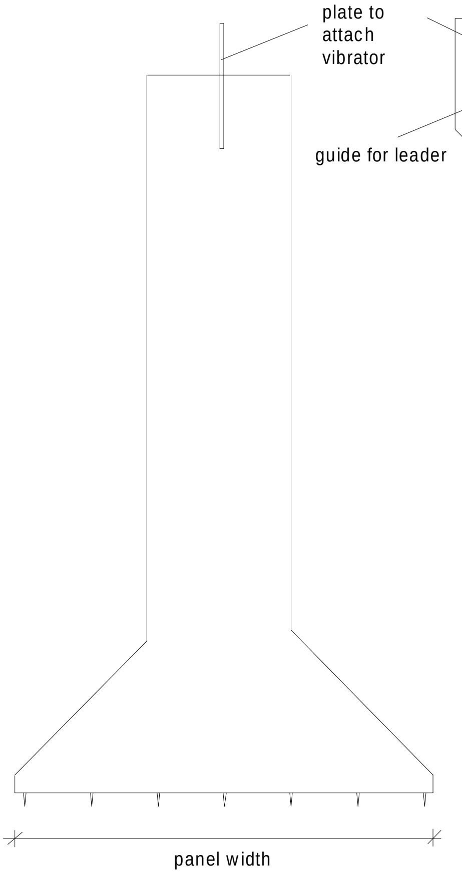

Fig. 12 Installation mandrel for *Geolock*

It is important that the mandrel can follow the last installed panel freely and that the male lock of the already installed panel is stretched during installation to avoid folding of the locks.
With this method it is possible to install 20 to 40 m *Geolock* wall in 8 hours. It is possible to create a good connection with the lower impermeable layer, because the sheet can be vibrated into this layer without too much disturbance.

9.2 Jetting

The *Geolock* sheet can be installed with a jetting frame that can be moved vertically up and down on the lead of a piledriver or like piece of equipment. The *Geolock* sheet is stretched on the frame by hooking the attached anchoring strip around the bottom of the frame and fastening at the top of the frame. The frame has steel locks on the sides to connect it to the next frame. A pressure pump provides the necessary high pressured water to insert the frame, while it is guided along the last *Geolock* panel inserted. The friction of the lock, together with the anchorplate, ensures a proper anchoring in the ground, whereafter the frame is pulled up again and the next section can be attached to it, to proceed with the installation. As jetted materials are deposited in the bottom of the trench, it may be necessary to grout the seal between the *Geolock* through layers of rock or large obstacles with this method of insertion. Such obstacles do not usually lie at a very great depth and are simple to remove using conventional equipment.
This installation technique is limited to a depth of 15 m, while the maximum width of the sheets cannot exceed 2 m. To penetrate clay layers, a vibrator can be attached to the frame to loosen the

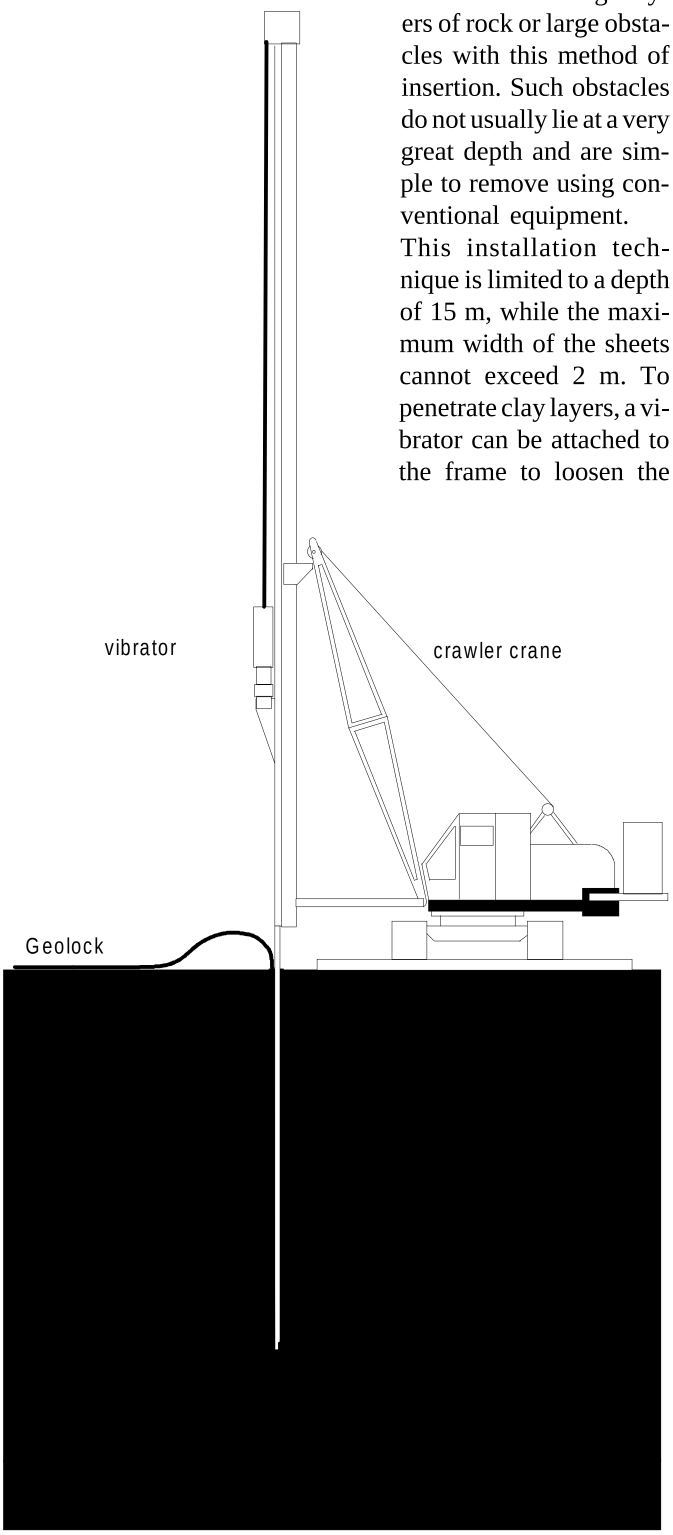

Fig. 13 Installation in a bentonite trench.

clay and lower the friction of the frame. Under normal conditions, about 300 to 500 m^2 of *Geolock* can be installed per day, depending on the insertion depth and site conditions. The installation is effected without noise or vibration, and is therefore suitable to be carried out along existing buildings and in places where nuisance must be kept to a minimum. Installation can begin a few hours after arrival on the site, as the frame for an insertion depth up to 15 meters does not need to be dismantled for transport.

9.3. Cement-bentonite wall

To install *Geolock* in hard soils like gravel layers and to greater depths, it is necessary to construct a bentonite wall into which the *Geolock* is installed. There are several ways to construct a bentonite or cement-bentonite wall.

- A 30-100 cm wide excavated wall filled with cement-bentonite. This wall is constructed by using a special backhoe or clamshell bucket. The trench will be filled with cement-bentonite during excavation.

- A 30-100 cm wide bentonite wall, backfilled with the removed soil. This wall is constructed with a standard backhoe or dragline.

- A jetted bentonite wall with a thickness of 10 to 20 cm. This wall is constructed with a piledriving rig that vibrates a steel frame or H-beam into the soil, which is then pulled out again while cement-bentonite is jetted into the remaining trench.

- A cement-bentonite wall can be constructed by vibrating hollow steel rectangular tubes into the soil filled with cement-bentonite. The tubes are pulled out again afterwards.

All these walls are suitable for installation of *Geolock*. The *Geolock* sheets have to be installed before the cement-bentonite sets, so it may be necessary to add retarder to the mixture.

9.4. Quality Control

During installation it is very important that a proper quality control system is maintained. The panels may not be damaged during installation and the lock has to be connected all the way down.
There are two methods to determine if the lock is continuous. The most simple and often used method is to put a "tell tale" piece *Geolock* of 100mm over the already installed male lock and attach a rope to it. The female lock of the installed panel will push this pilot lock down and the rope shows if the lock will seperate during installation.
The lock can also be checked with two copper wire loops at both parts of the locking system. A current is put on one side while the other loop is connected to a oscilloscope. The distance between the two loops can be checked over the total length of the lock thus determining if the connection is in place.

9.5. Important tips

- **Never use Geolock in combination with a gravel fill or another drainage layer. The risk that the liner will be damaged is very high and the rate of leaking will raise with a factor 10,000 due to the fact that a free draining layer is created along the total surface of the liner.**

- **Never use Geolock as additional protection at Diaphram walls. The Geolock will not give additional protection. HDPE will not bond to concrete so a drainage path can occur along the total surface of the wall connecting leaks in the concrete wall to leaks in the liner. No additional security will be achieved.**

- **Always require for a sound quality control during the fabrication as well as the installation of the panels. This is the only way to be sure that you will get what you want.**

- **For optimum results always try to use a hybride system of HDPE and bentonite. A dual system is a factor 1,000 to 10,000 safer than a single system.**

10. LABORATORY TESTS

10.1 General

Several tests have been conducted to determine strength, durability and chemical resistance of the *Geolock* sheets, as well as of the Hydrotite sealing. *Geolock* is made from HDPE and extensive tests have been made on this material in connection with its application as a liner for landfills. The locks are also produced from HDPE and are tested for tensile strength and permeability with the *Hydrotite* seal.

10.2 Strength of the lock

Geolock was designed to achieve a higher tensile strength in the lock than the liner which is used for the sheets. Normally a 2 mm thick HDPE liner is used with a strength of approx. 16-18 N/mm^2 giving a tensile strength of max.

1800 N/50mm. The strength of the lock must exceed this value. Six 50 mm wide samples were tested at the Soil Mechanics Department of the City of Amsterdam: three samples with, and three samples without liner. The results of the tests are shown in Fig. 14. The graphs show that the strength of the lock is approx. 2200 N/50mm, 30% more than the strength of the liner being 1700 N/50mm, thus achieving a safe joint which is capable to withstanding settlements and high forces during installation.

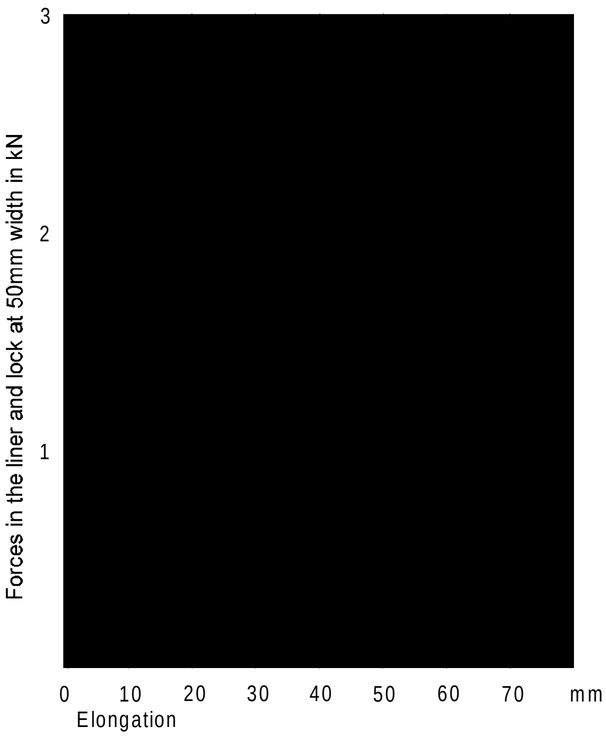

Fig. 14 Tensile-Strain diagram of the *Geolock* and 2mm HDPE-liner

10.3 Permeability of the lock

In order to determine the water permeability behaviour of the *Geolock* barrier, a laboratory scale test program was conducted, to measure the volume of water passing through the lock. The figure of the test unit shows a PVC mud-trap (Ø300 mm), attached to a standpipe (Ø125 mm) to obtain the required head. At the bottom, a drain valve leads to a measuring glass.
To avoid evaporation, the aperture of the valve was closed and made waterproof during testing. The water inlet at the upper end is connected to the water conduit, while an overflow device provides constant head.

The reservoir was partially filled with a 100 mm thick gravel layer, with a geotextile on top to function as a filtration medium. Next, a sand layer provided the *Geolock* sample with a certain stability. The edges were sealed with silicone caulking.
The above described method was used to conduct ten tests, for a period of one month, to ascertain the permeability rate of a *Geolock* sample piece, 300 mm long at a head of 1m.
During the first five tests, the *Geolock* sample was covered with coarse sand. During the first 12 hours, measurements were recorded each hour. Thereafter, each day a measurement was carried out under continuous flow through the sample.
On average, the permeability of the lock decreased after swelling of the hydrotite to:

3.6 liter/meter joint/year at 10 kPa

A second series of five tests were executed while the *Geolock* sample was covered with 50 mm cement-bentonite suspension, upon which a 50 mm sand layer was placed. After a hardening period of 14 days, water pressure was put onto the *Geolock* sample. The cement-bentonite suspension consisted of a mixture of 30 grs bentonite and 100 grs cement per liter water.
After a period of 30 days, the permeability of the lock decreased to:

0.6 liter/meter joint/year at 10 KPa

It is obvious that a hybride wall of Geolock combined with a bentonite cement slurry will not only be less permeable but also will decrease the risk of leaking when the liner is damaged during installation or penetrated by sharp rocks that are present in the soil.

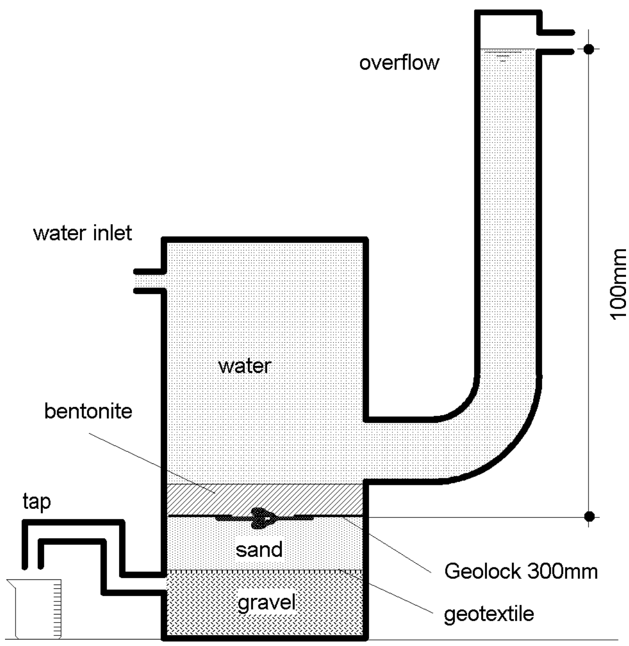

Figure 15

Table VII shows a comparison of alternative systems, regarding water permeability of various deep wall methods. Values are based on a 1m water head.

	Thickness mm	k-Value m/s	Q-total l/m²/year
Geolock (2m) jetted	2	10^{-13}	1.8
Bentonite/cement	800	10^{-8}	10.8
Geolock in bentonite sections 2m wide	2 200	10^{-13} 10^{-8}	0.3

Table VII

10.4 Specifications of the HDPE-liner

An extensive testing program was done by TNO Delft to determine all relevant properties. The results were published in report 605-'86 of TNO and the most important values are listed below.

Property	Test	Unit	Value
Density	NEN 21183/D	g/cc	0.94
Melt Flow Index Condition (190.2)	NEN-ISO 1133	g/10 min.	<0.3
Tensile Strength Yield	NEN-ISO 527	N/mm²	18
Tensile Strength Break		N/mm²	29
Elongation at Yield		%	15
Elongation at Break		%	600
Biaxial Elongation	DIN 53373	%	26
Tear Resistance	ASTM D1697-70/B	N/mm	130
Environm. Stress Crack	50°C, 10% Antarox	Hours	>1000
	100°C, 100% Antarox	Hours	>1500
Thermal Stability	ASTM D3895	Minutes	>60
Tensile Impact Strength	DIN 53448	kJ/m²	>1000
Puncture Resistance	SIA 280	500g/1500mm	No holes
U.V. Resistance	DIN 53448	Hours	>3000
Fold Test	DIN 16937		No Cracks
Dimensional Stability	NEN 3056	%	<1,5
Slot Pressure Test	DIN 16937	6 Bar, 72Hrs.	No Leakage
Tensile Strength Weld	DIN 53448	N/mm²	18
Melting Point		°C	116
Carbon Black		%	2

Table VIII

10.5 Hydrotite

Hydrotite was developed as a seal for tunnel shields. It is therefore tested in relation with strength, durability, ageing, chemical resistance and repeatability of water absorption and drying. A report called "Long-term durability of Hydrotite" is available upon request.

E = Excellent
G = Good
F = Fair
S = Satisfactory
P = Poor
?* = Leakage at lock
?** = Underseepage

	Obstacles	Chemical resistance	Life	Nuisance	Mobilisation (weeks)	Depth (m)	k-Value (10^{-8} m/s)	Thickness (mm)	Production (m^2/day)
Steel sheet piled wall (heavy)	G	S	S	P	1	20	?*	10	200
Steel sheet piled wall (light)	P	S	P	G	1	10	?*	2	250
Bentonite wall	F	E	F	F	2	25	10	100	500
Injection-moulded film wall	P	E	E	F	2	15	?*	2	400
- GEOLOCK -	P	E	E	E	1	25	0.01	4	400
Moulded film wall	G	E	E	F	1	5	?**	1	2500
Excavated bentonite wall	E	G	G	F	4	70	1	600	125
Bentonite / GEOLOCK wall	E	E	E	F	4	50	0.01	100	125

Table IX

11. COMPARISON OF ALTERNATIVES

In table IX, the advantages and disadvantages of various techniques are reproduced. From this, it can be seen that *Geolock* is not only superior in construction, but is also more cost effective.

12. REFERENCES

Geolock is in use since 1985. Since then, it has been applied successfully in various projects for pollution control as well as for waterbarrier purposes.

12.1 Rotterdam/NL

In the city of Rotterdam, several *Geolock* projects have been executed. The purpose of the *Geolock* application was to separate clean soil from polluted soil, by means of a watertight barrier.
During the first project named 'Zwaanhals' a number of tests were conducted to measure the permeability of the *Geolock* construction, with the results showing excellent long term barrier properties.
In all three projects -Zwaanhals, Vierhaven Street and Melanchton Road- the 0.25 m wide *Geolock* panels were used in combination with a *Hydrotite* rubber expansion profile in the joints of the lock.
The *Geolock* sheets were installed using a special steel casing, in which the sheets were placed and which was then driven into the ground by means of a backhoe with vibrator.

12.2 Heiligerlee/NL

In September 1985, a 546 m long *Geolock* barrier, type GL4000, was installed to a depth of 4.2 m, around a former bell-foundry in Heiligerlee that had to be renovated for use as a museum.
The soil under the bell-foundry was contaminated with heavy metals and steps had to be taken to avoid spreading

of the contamination to adjacent areas.
From the facade to the *Geolock* barrier, a PVC-liner was placed to prevent precipitation dissipation into the soil behind the barrier. Additionally, a dewatering system was installed to drain the surplus water to a water treatment plant. Tests showed that after 1 year no contamination was found outside the *Geolock* barrier.

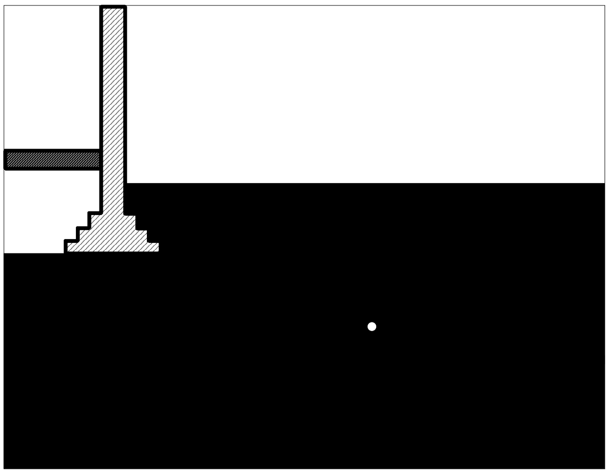

Fig. 16 Heiligerlee

12.3 Wesel/BRD

Near Wesel, a watertight cement-bentonite slurry wall had to be constructed along the Rhine, to avoid river water penetration into the permeable soil and thus flooding on the land behind the dikes. At this particular location, because of tunnelling activities under the river, the river banks were anticipated to settle approx. 4 m in the near future and if no steps were taken to seal the dike soils, the adjacent land would be flooded. The permeable layer was situated at a depth of around 25 to 30 m. A cement-bentonite slurry wall with a thickness of 0.6 m was provided to construct the impermeable wall.
To be certain that even with the expected high settlements the wall would be watertight, steel sheetpiles were placed

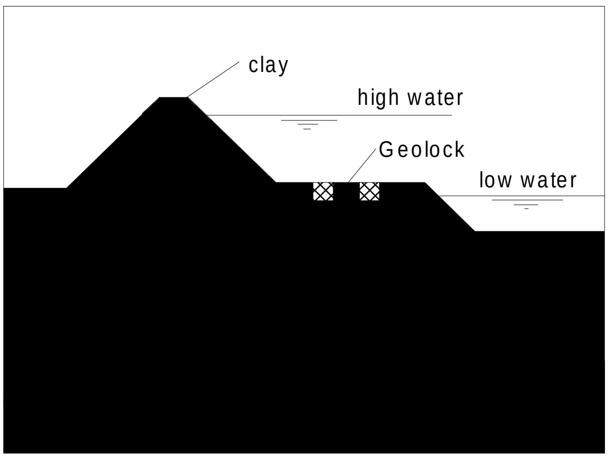

Fig. 17 Wesel

in the wall. Part of this project was used to experiment with *Geolock* panels within the bentonite wall, since *Geolock* would be more economical and watertight than steel sheet pile. A saving of 30% of the total costs could be effected, if *Geolock* proved a viable solution over steel sheet piling.
A number of tests were successfully conducted, installing the *Geolock* barriers up to 30 m depth. To check for damage and performance, they were withdrawn after insertion and found to be completely free of damage.
For future projects along the Rhine, the *Geolock* system will be a suitable alternative to steel sheetpiling.

12.4 Volgermeerpolder/NL

The Volgermeerpolder is a notorious area in the Netherlands, where continuous work is undertaken to prevent spreading of the present contamination. As part of these works, a 6 km long plastic barrier was scheduled to surround the area, reaching to a depth of 15 m. An investigation as to the feasibility of a *Geolock* barrier combined with a bentonite slurry wall, was done by testing within this area.
The bentonite slurry wall had a width of 100 mm, and was constructed by using a system of steel rectangular profiles. In total 6 *Geolock* panels of type GL4202 were placed to an average depth of 11 m and a maximum depth of 15 m. The actual installation of the permanent barrier around this area is scheduled for execution in 1993.

12.5 Belfast/UK

A large landfill along the Belfast shoreline leaked significant leachate, giving rise to foul odours, especially during summertime, restricting recreational use of the area.
To limit the flow of the leachate to the sea direction only,

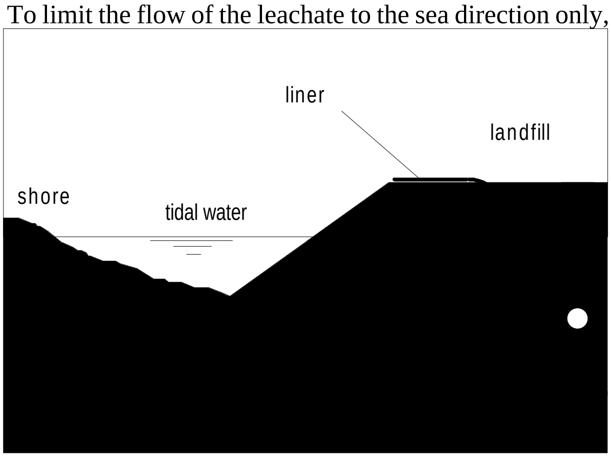

Fig. 18 Belfast

a watertight barrier was planned along the former shoreline where the ditch was located. For practical and economical reasons a *Geolock* barrier was chosen. The barrier had to be placed into the silt layer on a depth of 4.5-7.5 m.

On the inside of the *Geolock* barrier a HDPE drain with a 300 mm diameter was placed to drain the leachate directly to the sea. The top of the *Geolock* was sealed to a horizontal liner cap that covered the landfill in the future, to prevent the entry of precipitation..

12.6 Reference list Geolock Projects 1985-1993

Date	Project	Location	Contractor	Sheet width mm	Area m^2	Depth m
Jan-85	Zwaanhals	Rotterdam	Cofra	250	60	2,4
Sep-85	Volgermeerpolder	Amsterdam	Cofra	2000	70	15
Oct-85	Bell Foundry	Heiligerlee	Cofra	250	546	4.2
Nov-85	Test project	Wesel/BRD	Wayss+Fr.	2000	405	30
Nov-85	Vierhaven Str.	Rotterdam	Cofra	250	245	4
Nov-85	Melanchton Rd.	Rotterdam	Cofra	250	192	4
Mar-86	Total station	Rotterdam	Cofra	250	416	3.5
Sep-86		Bork/BRD	Stade	250	930	3
Nov-86	Chemical plant	Marschacht/BRD	Stade	600	740	4.2
Feb-88	Castle Peak	Hong Kong	Bachy	2350	4,000	4
Mar-88	Kralingen	Rotterdam	Cofra	250	66	2
Jun-88	De Heining	Amsterdam	Cofra	500	250	5
Jul-88	Landfill	Belfast/UK	Taggart	1250	6,700	7.5
Aug-88	Gas plant	Dordrecht	Cofra	1150	1,850	8
Nov-88	Landfill	Randers/DK	P. Aarsleff	1150	850	6
May-89	Chemical factory	Savona	Acna	2350	10,210	6-12
May-89	Contaminated site	Saijo City	Taiyo	1350	6,400	6.5-12
Jun-89	Contaminated site	Hokkaido	Taiyo	1350	1,200	12
Mar-89	Aquaduct	Grouw	Bachy	2350	7,880	33.5
Apr-89	Chunnel	Best	NGT	2000	20,000	27
Jun-90	Contaminated site	Sydney	Klika	4000	740	4
Jul-90	Contaminated site	Japan	Taiyo		5,000	8-12
Jul-90	Contaminated site	Pori-Finland	Kitos	2350	6,700	7.5
Sep-90	Gasplant	Genova	Italdreni	2350	1,230	4-4.5
Oct-90	DSM 'Katberging'	Geleen	NGT		6,500	20-25
Oct-90	Contaminated site	Uusikaupunki	Kaitos	2350	4,000	12-14.5
Nov-90	Test project	Gent	Herbosch	1450	2,400	6-22
Nov-90	Contaminated site	Rotterdam	Visser&Smit	1200	620	5
Jan-91	Contaminated site	Rotterdam	Mourik	1300	390	20
Feb-91	Landfill	Kazo City	Taiyo		500	4
Aug-91	Dam	Trento	Italdreni	1200	1,030	10
Sep-91	Landfill	Irlam	Taggert	2350	1,350	7
Nov-91	Contam. Dike	Nederweert	Cofra	2350	13,100	2.5
Dec-91	Chemical Plant	Savona	Acna	2350	3,500	6.5-13
Dec-91	Superfund Site	Carlstadt,NJ	Gundle	1800	3,000	4.5-5.7
Mar-92	Landfill	Glasgow	Bachy	2350	1,320	22
Aug-92	Landfill	Peel, Canada	Nilex	1500	5,000	12
Sep-92	Contaminated Area	Butte,MT	Gundle	1800	1,000	4
Dec-92	Subterrain highway	Ljungskile,Sw	Cofra	1800	6,000	6
Mar-93	Landfill	Dordrecht	NGT	2350	9,600	26,5

Table X

13. STANDARD TENDER SPECIFICATION

13.1 Scope

The works include the installation of vertical sheet-piles at the locations shown on the plans and as directed by the engineer.

13.2 Construction

The contractor shall demonstrate that his equipment, method and materials produce a satisfactory installation in accordance with these specifications. For this purpose the contractor will be required to install several trial sheets at the locations within the working area designated by the engineer. Trial sheets according to these specifications will be paid for at the same rate unit price as the production sheets.

The vertical sheets shall be installed at depths as shown on the plans or as directed by the engineer. The contractor shall provide the engineer with a suitable means of verifying the plumpness of the installed sheets and determining the depth of the sheet at any time. The equipment shall be carefully checked for plumpness and shall not deviate more than 20 mm per meter from the vertical.

It may be necessary to excavate a trench, to loosen the soil and to clear obstructions and

facilitate the installation of the sheets through the working platform or a natural soil strata. The depth on which excavating is used shall be subject to approval by the engineer but should not be deeper than the bottom of the sheets.
Where obstructions are encountered in the subsoil, preventing the installation of panels, the panels will be overlapped over a distance of at least 1 m. The soil in between the overlap has to be injected with grout to avoid leakage between the two wall sections.
Installation of the sheets should be considered and be coordinated with the geotechnical instruments shown on the plans. Special care should be taken to install sheets in such a manner so as not to disturb the instrumentation already in place. The replacement of instrumentation damaged as a result of the contractor's activities will be the responsibility of the contractor.

13.3 Equipment

The vertical sheets shall be installed with equipment which will not cause any damaging to the sheets. The sheets shall be installed using a mandrel with a single or double steel plate, driven into the soil by a vibrator. The mandrel shall protect the sheets against tears, cuts and abrasions during installation and shall be withdrawn after installation of the sheet. The sheet shall be provided with a reliable anchoring foot to ensure anchoring of the sheets at the required depth after removal of the mandrel.

At least three weeks prior to the installation of the plastic sheets, the contractor shall submit to the engineer, for review and approval, details of the sequence and method of installation. The submittal shall, at a minimum, contain the following specific information:

1. Size, type, weight, maximum pushing force, vibratory hammer, rated energy and configuration of the installation rig.

2. Dimension and length of the mandrel.

3. Details of the anchoring construction.

4. Detailed description of proposed installation procedures.

5. Proposed method of overcoming obstructions.

Approval by the engineer will not relieve the contractor of his responsibility to install the plastic sheets in accordance with the plans and specifications. If, at any time, the engineer considers that the method of installation does not produce a satisfactory construction, the contractor shall alter his method and/or equipment as necessary to comply with the plans and specifications.

13.4 Materials

The prefabricated plastic sheets shall consist of a High Density Polyethylene liner with a minimum thickness of 2 mm with HDPE interlocks at a minimum distance of 1 m. The locks shall be welded onto the material at the factory or at the site. The welding method shall be a hot air welding, wedge welding, or an extrusion welding system. The strength of the weld shall be at least 85% of the strength of the liner material. One test sample shall be taken every 25 welds to control the quality of the welding. The joints shall be provided with an expansive material which will seal the lock and be resistant to chemicals which are locally present. The plastic sheets shall meet the following specifications:
The contractor shall submit a 1 m sample of the plastic material. The sample shall be stamped and labelled by the manufacturer as being representative of the sheet material having the specified trade name. Approval of the material by the engineer shall be required prior to the site delivery of the plastic sheet material. The sheet material shall be free of defects, rips, holes or flaws. Manufacturer certification shall be provided for all sheet material delivered to the project.

UNIT	VALUE	
Sheet width	m	1
Thickness	mm	2
Length	m	--
Tensile strength at yield	kN/m	34
Tensile strength lock	kN/m	50
Specific density	g/cc	0.94
Permeability	m/s	$<10^{-13}$

Table XII

13.5 Measurement for payment

The sheets shall be measured by square meter, to the nearest meter, of sheets installed in accordance with the plans or as directed by the engineer.

Amsterdam, Februari 2, 1995