GEOTECHNICS HOLLAND BV

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INVESTIGATION INTO THE BEHAVIOUR OF PLASTIC DRAINS IN ROTTERDAM HARBOUR SLUDGE

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Ing. N.G. Cortlever

Baambrugse Zuwe 220, 3645 AM Vinkeveen - Holland, tel. 02949 - 16 10 / 16 02, telex 18481

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Each year, several million cubic metres of contaminated sludge are dredged from the Rotterdam harbour. This sludge is used for raising the level of industrial and residential building sites. One method for making the sites filled in this way usable within a short time, and for speeding-up the process of consolidation, is the use of a vertical drainage system.

To test the effects and behaviour of various plastic drains, a series of compression tests were carried out on the following types of drains:

1. BIDIM, a monolithic drain consisting of a non-woven polyester membrane material with a weight of 83 g/m and dimensions of 100 mm x 4 mm.

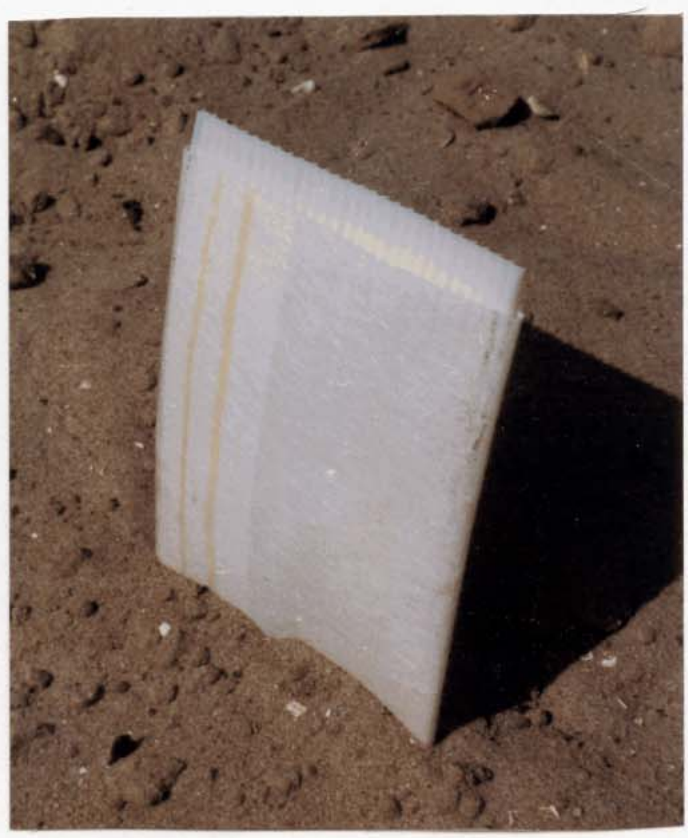
2. DESOL, a monolithic drain consisting of a flat polyethylene strip containing small tubes and with perforated walls. The weight is 48 g/m and the dimensions are 95 mm x 2 mm.

3. MEBRA, type MD 7007, a composite drain with a core consisting of a polypropylene extrusion and a filter consisting of a non-woven polypropylene membrane. The total weight is 92 g/m and the dimensions are 100 mm x 3 mm.

4. COLBOND, type CX 1000, a composite drain with a core consisting of a polyester ENKA mat and a filter consisting of a non-woven polyester membrane. The weight is 130 g/m and the dimensions are 100 mm x 5 mm.

MEBRA-DRAIN MD 7007

COLBOND CX 1000



DESOL

GEODRAIN

5. GEODRAIN, a composite drain with a core consisting of an extruded polyethylene section and a filter consisting of non-woven polyester membrane. The weight is 135 g/m and the dimensions are 100 mm x 4 mm.

The compression tests were carried out in steel cylinders with an internal diameter of 500 mm and a height of 1200 mm. The sludge was poured to within 350 mm of the top, corresponding to about 166 litres of sludge. A layer of sand 50 mm thick was deposited on top of the sludge. Tests were carried out simultaneously on six cylinders. The top pressure was applied to the sand through a steel plate. The necessary force was generated by a hydraulic system. This force was gradually increased. Over the first 720 hours the load applied was 600 kg, corresponding to a pressure of 3 t/m^2 (30 kN/sqm) From 720 to 2184 hours the pressure was 4 t/m^2,(40 kN/sqm); after 2184 hours it was 5 t/m^2 (50 kN/sqm).

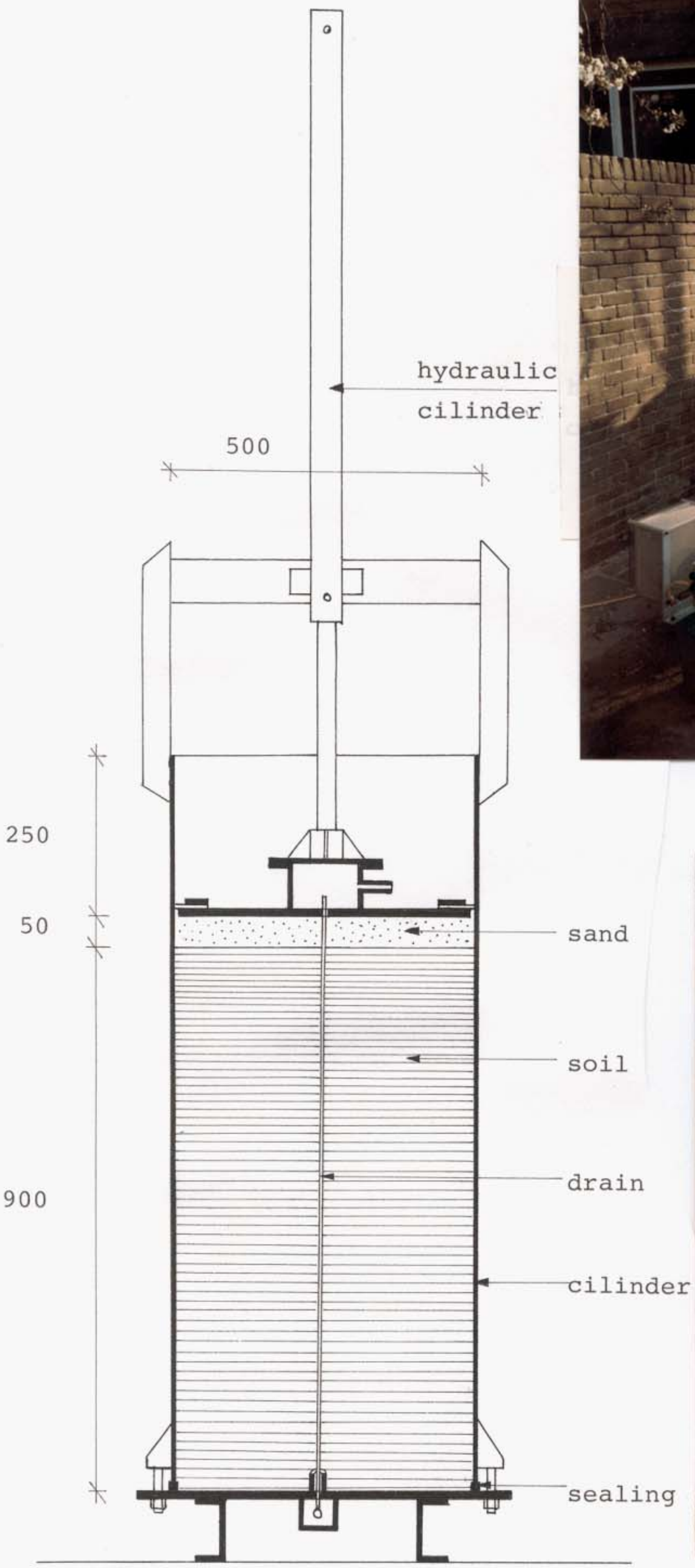
The following measurements were made:

A. Settlement.
B. Drainage capacity before and after compression.
C. Increase in the resistance to penetration.
D. Volume of sludge in the drain.
E. Deformation of the drain.

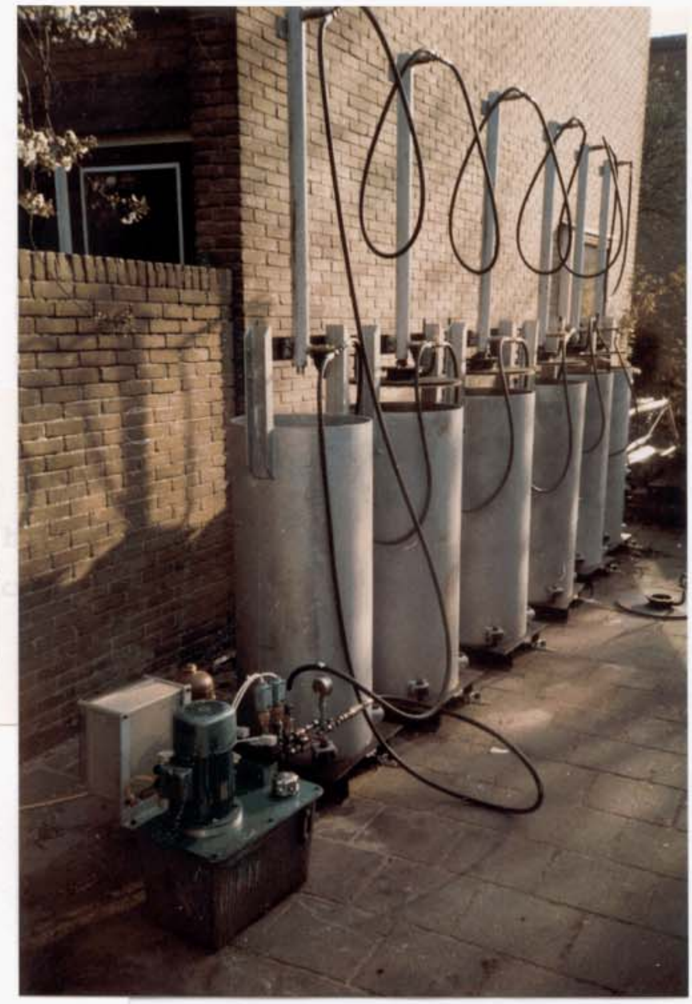
In addition, a compression test and a sieve analysis were carried out at the Rotterdam Soil Mechanics Laboratory.

A. Settlement.

The progress of settlement was virtually identical in four of the five drains tested. Of the four only Bidim drain was rather slower during the last stage. However, the Desol drain was significantly slower right from the beginning.



test instrument



Test equipment

BIDIM

The progress of settlement was rather similar to earlier results from the RW1 test section at Diemen. An explanation of the variations in settlement is given in sections on D and E.

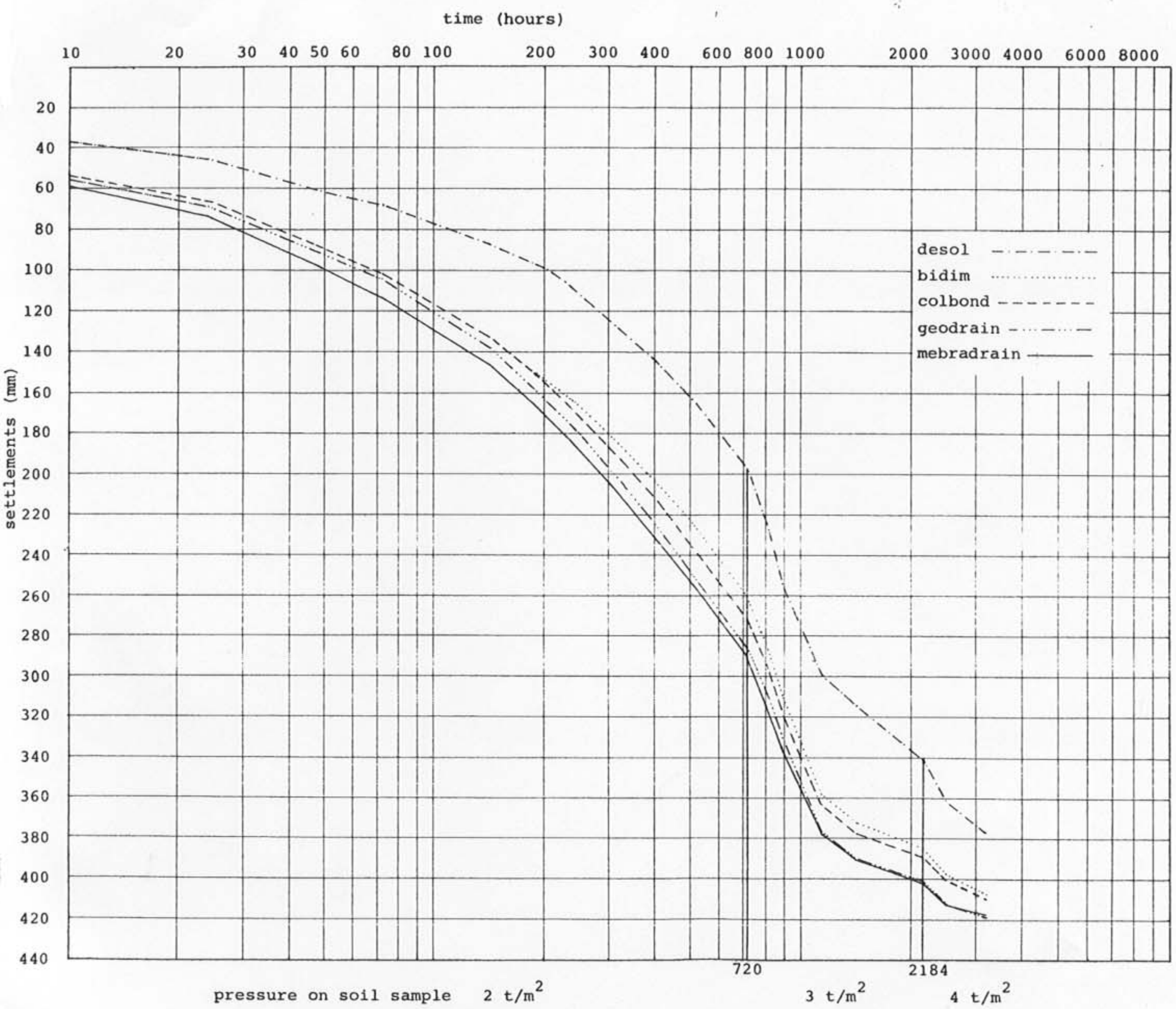
B. Drainage capacity.

Drainage capacity was measured both before and after the compression test. It was suspected that the drainage capacity would be significantly reduced, for the following reasons:

1. The filter membrane is pressed into the transport channels, or the framework of the drain itself is compressed.
2. As a result of the deformation, the drain buckles in the ground.

The following values were measured: (p.t.o.)

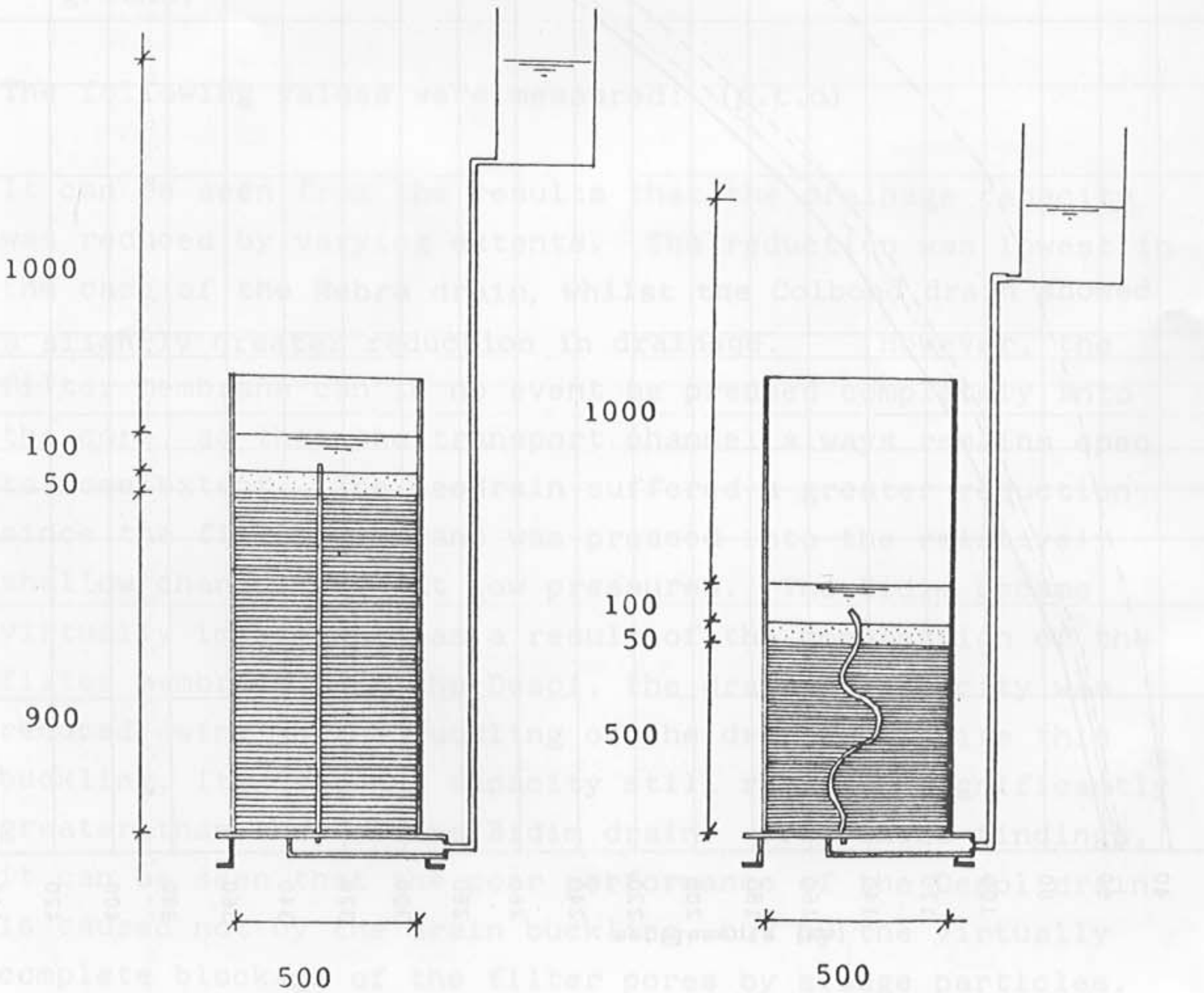
It can be seen from the results that the drainage capacity was reduced by varying extents. The reduction was lowest in the case of the Mebra drain, whilst the Colbond drain showed a slightly greater reduction in drainage. However, the filter membrane can in no event be pressed completely into the core, so that the transport channel always remains open to some extent. The Geodrain suffered a greater reduction since the filter membrane was pressed into the relatively shallow channel even at low pressures. The Bidim became virtually impermeable as a result of the compression of the filter membrane. In the Desol, the drainage capacity was reduced owing to the buckling of the drain. Despite this buckling, its drainage capacity still remained significantly greater than that of the Bidim drain. From these findings, it can be seen that the poor performance of the Desol drain is caused not by the drain buckling, but by the virtually complete blockage of the filter pores by sludge particles.



time (hours)
10
20
30
40
50
60
80
100
200
300
400
600
800
1000
2000
3000
4000
6000
8000
settlements (mm)
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
420
440
desol
bidim
colbond
geodrain
mebradrain
720
2184
pressure on soil sample 2 t/m2
3 t/m2
4 t/m2

DRAIN	before compression cm^3/min.	after compression cm^3/min.	cause of reduction
BIDIM	1130	2	compression of filter membrane
DESOL	1908	76	buckling of drain
MEBRA	2640	2080	negligible reduction
COLBOND	2355	1620	compression of total drain
GEODRAIN	2160	1085	filter membrane is pressed into channels

Table of WATER DISCHARGE CAPACITY



before compression   after compression

A question that now arises is how the Bidim drain still works reasonably well, despite its low drainage capacity. This can best be explained by calculating the volumes of drained pore water. It is assumed here that the settlement is caused entirely by the expulsion of this pore water. In the first 24 hours, the settlement was approximately 63 mm, corresponding to an average drainage rate of 8.6 cm^3/min. At a later stage of consolidation, this drainage rate fell further to an average of 0.27 cm^3/min, i.e. during the period from 720 to 2184 hours. It is clear that the drainage rate in this case can hardly influence consolidation. However, if a layer of earth 10 or 20 metres deep has to be consolidated, the required drainage capacity also becomes 10 to 20 times as great, so that the relative performance of the Bidim drain falls off to a much greater extent.

The tendency to buckle, as found in the case of the Desol drain, was also observed in other drains, but only at the edges. This is because deformation takes place so slowly that the core of the drain can form very sharp bends under the ground without buckling. However, it is always desirable that drainage capacity should not fall below a certain level, particularly at the beginning of the consolidation period.

Let us now consider the most unfavourable situation in which maximum drainage capacity is required. This is the case with a highly permeable, compressible type of soil. Let us assume that $C_h = 5 \times 10^{-7}$ m^2/s, the expected settlement is 5 metres and that the drains are 1 metre apart. The rate of drainage of the pore water is greatest during the initial phase. For the purpose of calculation, the period within which a settlement of 10% is reached will therefore be considered. This corresponds to an average drainage per drain of 500,000 cm^3. From the calculation using Barron's formula, it follows that this period is approximately 985 min.

A maximum drainage capacity of 500 cm^3/min is required in this case. However, this required drainage rate will fall off rapidly. A drainage rate of 50 cm^3/min or even much less is therefore more than sufficient in the great majority of cases.

C. Increase in the resistance to penetration.

During the initial phase, the harbour sludge is in a thick, viscous condition, and has no cone resistance whatsoever. After a consolidation period in which the compression is about 45%, the resistance increases to the values shown in the graph.

DRAIN	before compression	after compression
BIDIM	0	2 - 3 kg/cm^2
DESOL	0	2 - 3 kg/cm^2
GEODRAIN	0	2 - 3 kg/cm^2
MEBRADRAIN	0	2 - 3 kg/cm^2
COLBOND	0	2 - 3 kg/cm^2

SOIL CILINDER

BIDIM

GEODRAIN

GEODRAIN

D. Volume of sludge in the drain.

No significant volume of sludge was found within the core of any of the drains. Blockage of the drain by sludge is therefore most unlikely, despite the fine stucture of the harbour sludge.
On the next page the sieve analysis of harbour sludge is shown.

E. Deformation of the drain.

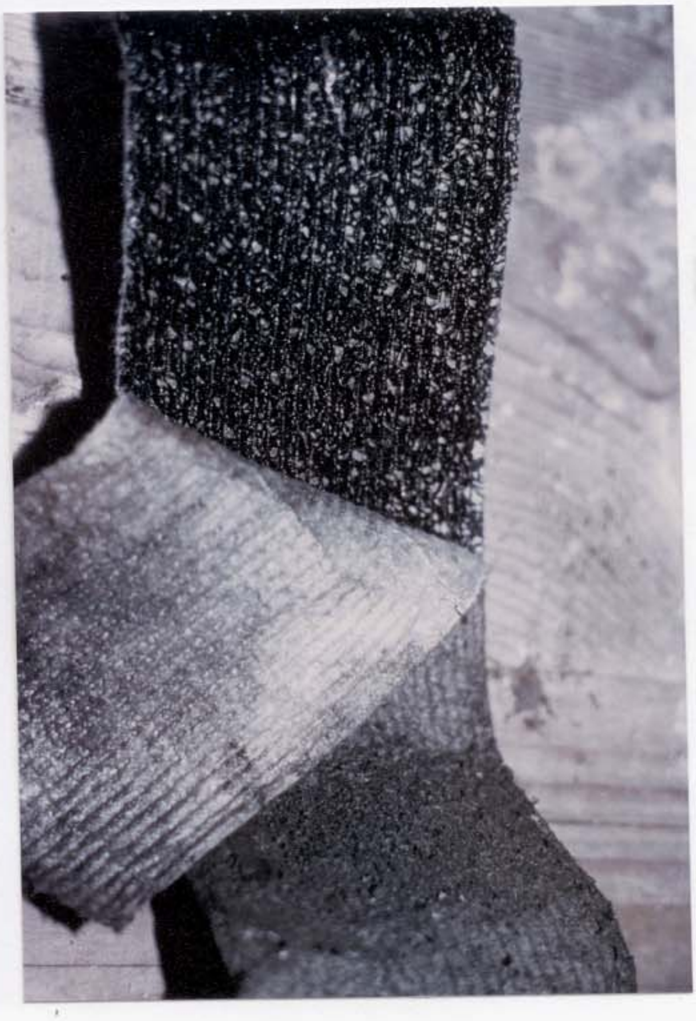
As can be seen from the photographs, deformation varied greatly among the different drain types. The deformation is determined by the bending resistance of the drain and the maximum deformation. The Mebra drain possesses not only a certain degree of bending resistance, but also a substantial maximum deformation. However, the maximum deformation is exceeded at the edges of the drain, and the core of the drain buckles. This was also found to be the case with the Colbond drain. The Desol drain has a much greater bending resistance, but only a low maximum deformation, so that the drain buckles even at low degrees of settling, and the channels become partially constricted. The Bidim drain can withstand unlimited deformation. However, this drain has no bending resistance whatsoever, so that the drain does not suffer multiple buckling like the other types, but is compressed vertically along its axis. At the same time, the filter membrane becomes completely impermeable as a result of the high horizontal soil pressure.

In principle, the Geodrain has the best core structure. The core can be folded double any number of times without the drain becoming blocked by buckling. However, the filter membrane is too weak, and is pressed to a significant extent into the relatively shallow channels.

COLBOND CX 1000

MEBRADRAIN MD 7007

DESOL



COLBOND [illegible]

The test shows that the filtering action of the drain is more important than the drainage capacity. Using Barron's formula, the C_h value of the harbour sludge can be calculated from the settlement values.

$$C_h = \frac{D^2}{8t} \left[\ln \frac{D}{d} - \frac{3}{4} \right] \ln \frac{1}{1 - U}$$

D = 0.5 m, the diameter of the cylinder
d = 0.05 m, the diameter of the plastic drain
t = 2184 hours, the time for 90% consolidation
U = 0.9, a consolidation of 90%

From the calculation, it follows that $C_h = 1.4 \times 10^{-8}$ m²/s

This corresponds to the value determined in the laboratory.

-ooOoo-

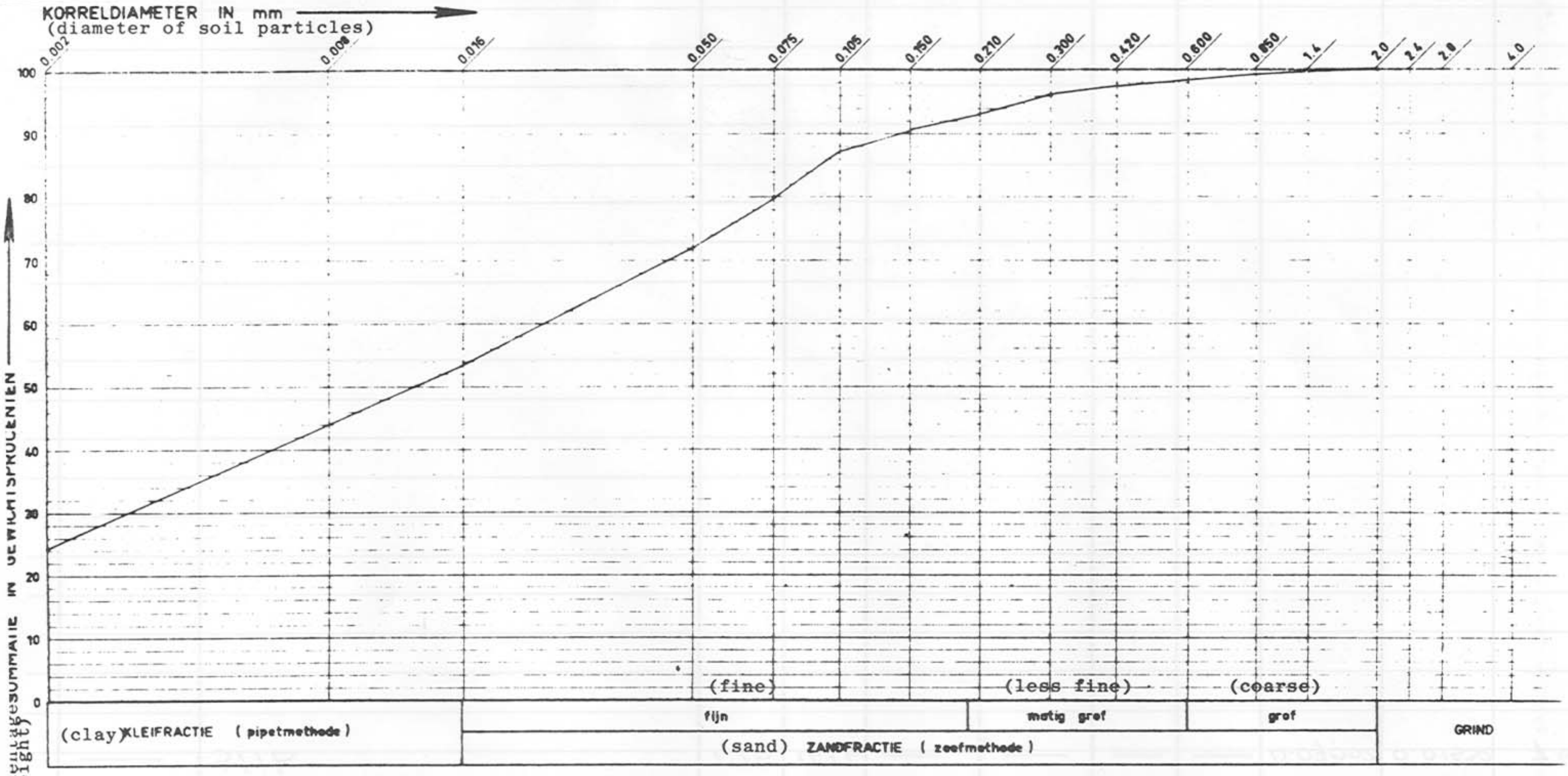
ENTEWERKEN ROTTERDAM 2 GRONDMECHANICA	SAMENDRUKKINGSPROEF	WERK D.W.L TERREIN							BORING —— M.V. t.o.v. N.A.P. ——		
ER	O.K. MONSTER t.o.v. M.V.	GRONDSOORT	V.G.	VOCHT-GEH.	$1/C_p$	$1/C_s$	$C_{10}{}^4$	P_g	$1/C'_p$	$1/C'_s$	$C'_{10}{}^4$
	——	Slib	1.26	153.6	——	——	——	——	0.06568	0.01608	7.7
	——	Slib	1.26	153.6	——	——	——	——	0.07002	0.01532	7.6

(Public Works Dept. Rotterdam)
GEMEENTEWERKEN ROTTERDAM
(Geotechn.Dept.)
AFD.2 GRONDMECHANICA

KORRELVERDELINGSDIAGRAM
(diagram on speading of soil particles)

(site)
WERK: **KORTENOORDSEHAVEN** (name of harbour)

BORING (meters ab
sea level
in m. t.o.v. N.A.



	DIEPTE IN m - (depth)	ZAND IN %	SLIB IN % (sludge)	HUMUS IN %	$CaCO_3$ IN %	(u-figure) U cijfer	GRONDSOORT (nature of soil)
		36.28	41.77	9.83	12.12		