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LABORATORY INVESTIGATION INTO SOIL/ENVELOPE MATERIAL INTERACTIONS: INTERMEDIATE RESULTS

ir. L.C.P.M. Stuyt

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Hun inhoud varieert sterk en kan zowel betrekking hebben op een eenvoudige weergave van cijferreeksen, als op een concluderende discussie van onderzoeksresultaten. In de meeste gevallen zullen de conclusies echter van voorlopige aard zijn omdat het onderzoek nog niet is afgesloten.
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SUMMARY

A variety of drainage envelope materials has been examined in permeameter flow tests. Permeability changes of envelopes as well as the abutting soils have been recorded. Water flow drag forces may cause minor though important changes in soil sample composition. Soil particle movement within the abutting soil may adversely affect drain performance. Permeability transitions in the soil- and/or envelope area will cause relatively large hydraulic head losses. Assessing drain performance from entrance resistance figures only does not make sense; permeabilities of adjacent soil layers should be taken into account as well.

Long-term clogging phenomena cannot be simulated with the aid of permeameter tests of the type that has been used. Future research at ICW must therefore be aimed at an integration of laboratory- and field research, whereby samples of existing drains will be conserved carefully and subsequently investigated in the laboratory.

Computer modeling of flow characteristics in the vicinity of a drain will allow for a better assessment of drain performance than using merely entrance resistance figures since this modeling technique incorporates a cylindrical domain around the drain reaching as far as 4.6 times the drain radius.

Pore size distribution is an unreliable envelope parameter as regards sand-tightness prediction.

1. INTRODUCTION

Subsurface drainage of silty- and very fine sands may result in drain sedimentation especially if the soil's structure is unfavourably affected by trenching and backfilling activities. Installation under unfavourable, that is wet conditions increases the sedimentation risk. Additional sources of clogging in the long run are (bio)chemical factors and various types of very fine particles.

Drain sedimentation cannot always be prevented by current envelope types. Therefore, a continuous search for improvement of envelope design criteria is going on in various countries, notably the United States, France, the Netherlands, England, Belgium and Germany.

A good deal about (bio)chemical, and, to a less extent, mechanical clogging is known, not so however how to predict or prevent its occurrence. Consequently, relevant design criteria appear not yet to be developed.

2. RESEARCH NEEDS

Research on envelopes as conducted in the past has shown moderate progress. This is due to the complicated nature of the phenomena under study. Complete coverage of all aspects would require a multi-disciplinary approach which is hard to realize. In such an approach widely different aspects are to be integrated such as envelope pore size distribution, soil structure and -texture, water flow drag forces, biochemical factors, the influence of electrochemical forces, etc.

Recent research efforts deal with detailed investigations into primary sedimentation (DIERICKX, 1983; LAGACÉ, 1983; STUYT, 1983; WILLARDSON, 1983 and, started quite recently, DENNIS, 1984), biochemical clogging (FORD, 1983), envelope characteristics (GOURC, 1982), micromorphological studies (SOTTON, 1982) and trench permeability (BOUMA, 1981). Current knowledge indicates that advances in envelope research are to be expected only if research contributions just mentioned are integrated. Additionally it is acknowledged that trench permeability requires more attention (SCHOLTEN, 1983) as well as long-term clogging by very fine particles.

Given the wide scope of the clogging problem any research effort will be a constrained step towards a possible problem solution. Any such step is a compromise between problem complexity and available facilities in conjunction with research philosophy.

Dutch envelope research essentially consists of three stages: 1) field diagnosis, 2) integrated laboratory- and field research, and 3) field testing of assumptions and/or design criteria developed in the second stage. Field diagnoses have been made for a long period of time, allowing for mostly ill-defined determination of malfunctioning causes. Precise location of the clogged area(s) is difficult since the drain abutting envelope and soil are inevitably disrupted by excavation or injection of sampling tools. Micro-morphological investigations are too costly and time-consuming whereas the results are strongly dependent upon random factors as the investigated area is extremely small.

Laboratory testing allows for minute monitoring of phenomena linked to various types of clogging such as permeabilities of the envelope and various soil areas, particle movement, organic slime buildup, etc. Lab-tests therefore may be preferable in that detailed information regarding clogging phenomena can be recorded. On the other hand they cannot account for long-term clogging phenomena which are often detected in a field situation. Therefore, reluctancy in the interpretation of lab-tests results is a must due to the discrepancy of testing conditions to those occurring in the field.

After three years of laboratory testing at ICW it is concluded that the state-of-the-art calls for two further steps.

1) There is a need for an integrated approach of laboratory tests on soil/envelope/pipe ensembles that have been functioning in the field for some years and subsequently removed without disruption on the one hand, and tests on samples of new envelope material and soil material, equal to, and taken from the types existing in the field under investigation, respectively, on the other. The latter

type tests are equal to those currently used. In doing so, the discrepancy referred to earlier is to be bridged in order to develop a more relevant testing methodology than the ones currently available: the credibility of these is low and must be enhanced.

2) There is a need for mathematical analysis of the effects of internal soil-, and envelope clogging upon drainage characteristics. This analysis conssists of computer modeling techniques using theories and/or techniques developed by ERNST (1962), HOOGHOUDT (1940), NIEUWENHUIS et al. (1979) and WIDMOSER (1968). Modeling activities like these arescheduled to be an integral part of ICW's research project in the upcoming years (1985-1987).

3. LABORATORY TESTING PROCEDURES

Time-dependent soil- and envelope permeabilities and envelope sand tightness are determined using cylindrical permeameters. Tests are conducted in four replicates for reasons of low reproducibility. The envelope sample is supported by corrugated pipe material. Almeresand, a very fine sandy Dutch problem soil, is dried and its structure is destroyed by aggregate crushing. Soil material is packed to a density existing at the bottom of a soil column 1 m high. Initial saturation is in upward direction, displacing air pockets. Short-term tests (340-h) were conducted by passing water vertically down through the soil. The hydraulic pressure distribution over envelope and soil material was monitored by piezometers at nine positions. Flow through the samples is regulated by floating ball flowmeters. Typical flow rates equal a drainage coefficient of 45 mm/day (drain spacing 15 m, drain diameter 60 mm). The laboratory set-up contains eight permeameters, two constant-head tanks, sediment traps and a nitrogen gas supply device. The recirculating water is refreshed continuously at slow rate. Hydraulic pressures and flow rates were recorded approx. 25 times during the test. Data-processing is automated using DEC-10 computing facilities.

Moisture retention curves of voluminous envelopes are determined in order to characterize pore size distributions. Envelope samples are mounted on porous plates and saturated with de-aerated water. A load

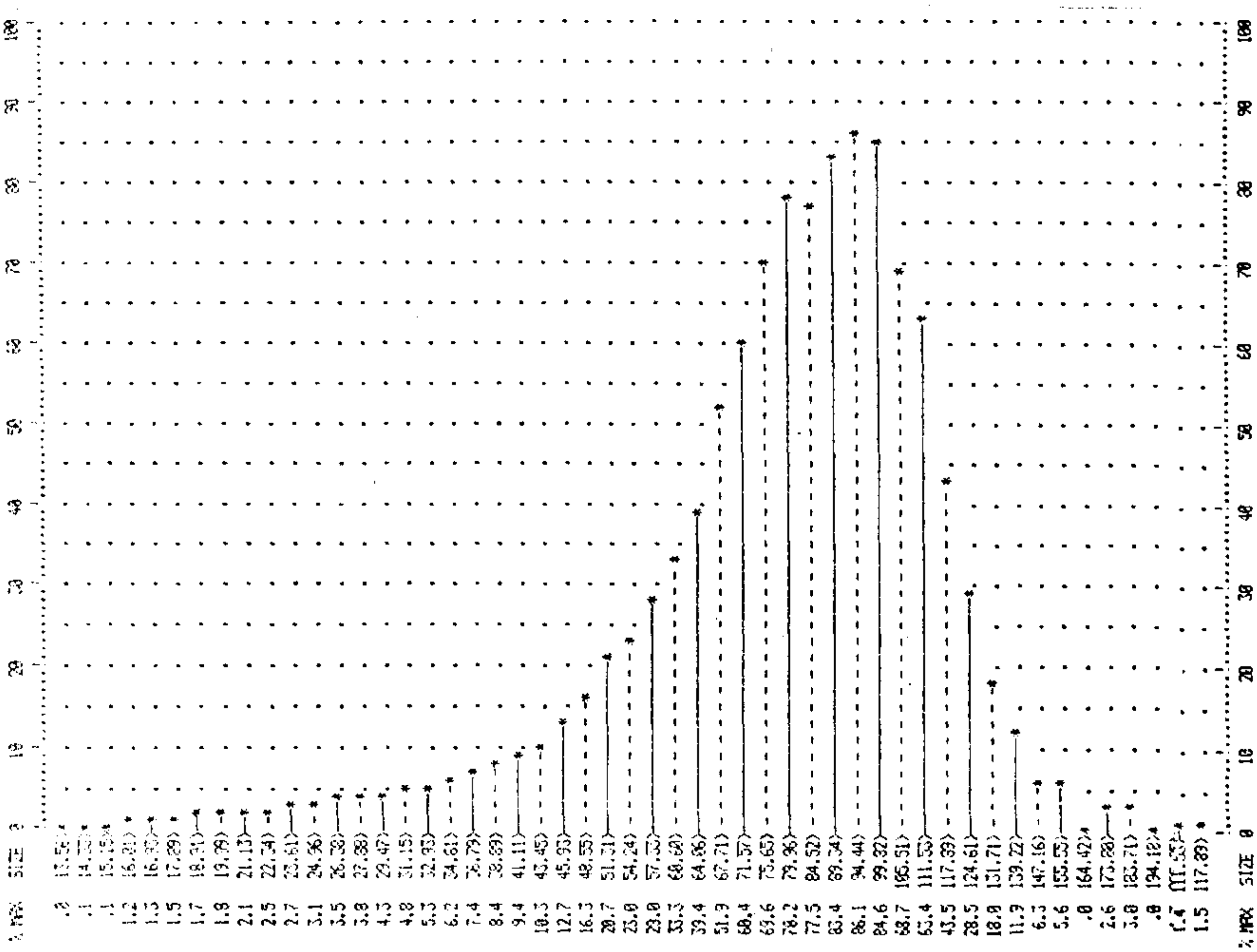

Fig. 1. The particle size distribution of Almeresand

equal to that existing at a drain depth of 1 m is applied. Water quantities released by the samples (five replicates) on each suction increase are recorded. These quantities are proportional to the percentage of pores belonging to a size class which is determined by the water suction.

It is however acknowledged that moisture retention curves are not necessarily identical to pore size distribution curves of voluminous envelopes, because the suction curves are dependent upon the dimensions of the samples and the possibilities of air invasion into the samples.

At ICW, a method is being developed to transform moisture retention curves into pore size distribution curves, taking into account sample dimensions as well as air penetration possibilities.

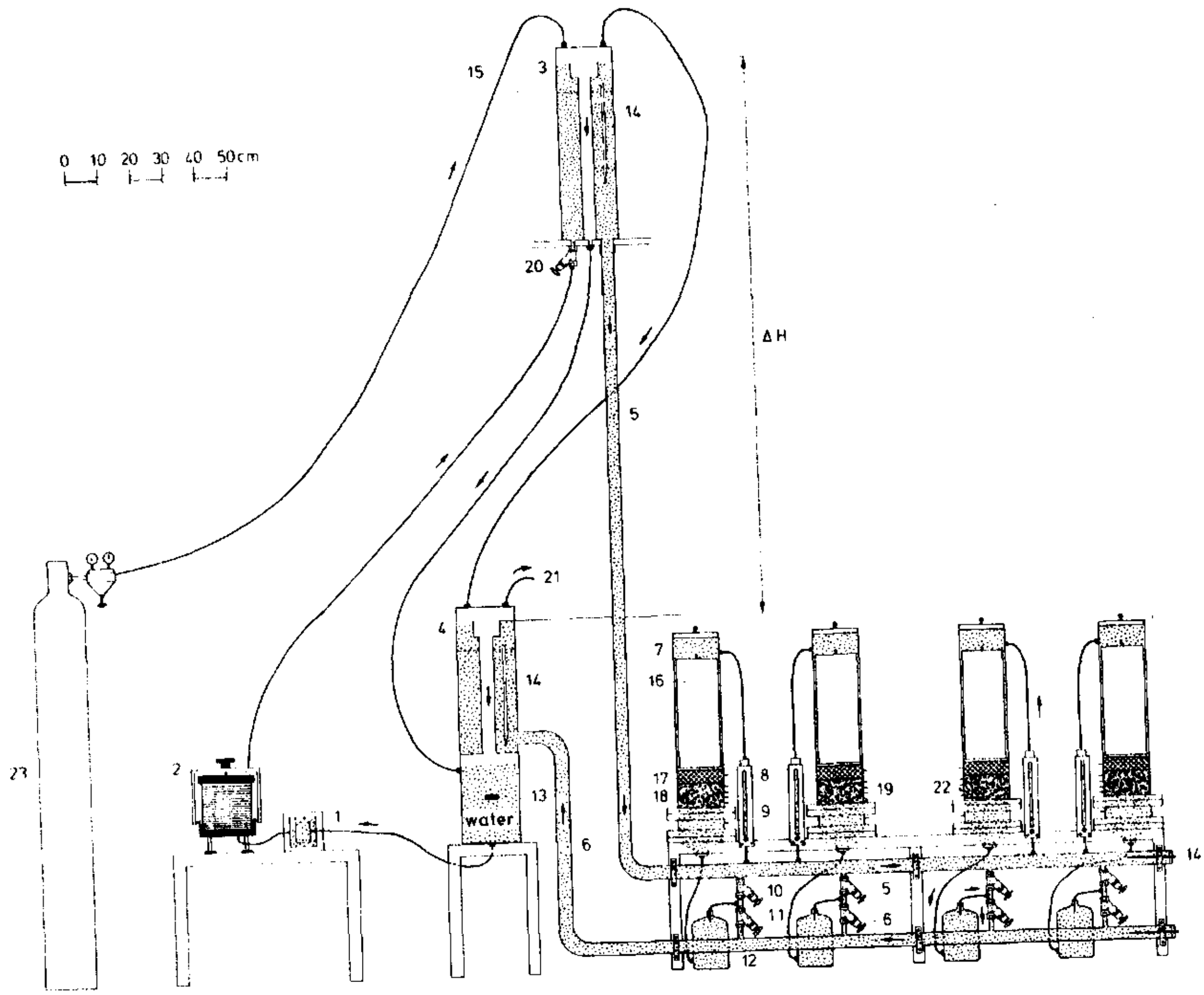

Fig. 2. Laboratory Set Up for Testing Envelopes. 1 = centrifugal pump; 2 = active carbon water filter; 3 = overflow tank; 4 = constant head and water supply tank; 5 = water supply tube; 6 = water discharge tube; 7 = cylindrical plexiglass tank; 8 = flowmeter; 9 = needle valve; 10, 11 = taps regulating flow directions on installing envelope and soil sample; 12 = sediment trap (contents 10 l); 13 = water heating device (60 watts); 14 = thermometer; 15 = supply valve nitrogen gas; 16 = metal weights in PVC cylinder casing; 17 = gravel bed diffuser (height 4 cm); 18 = soil sample; 19 = envelope sample disc; 20 = tap regulating pump flow; 21 = outlet nitrogen gas; 22 = piezometer (10 for each vertical cylinder); 23 = nitrogen supply device

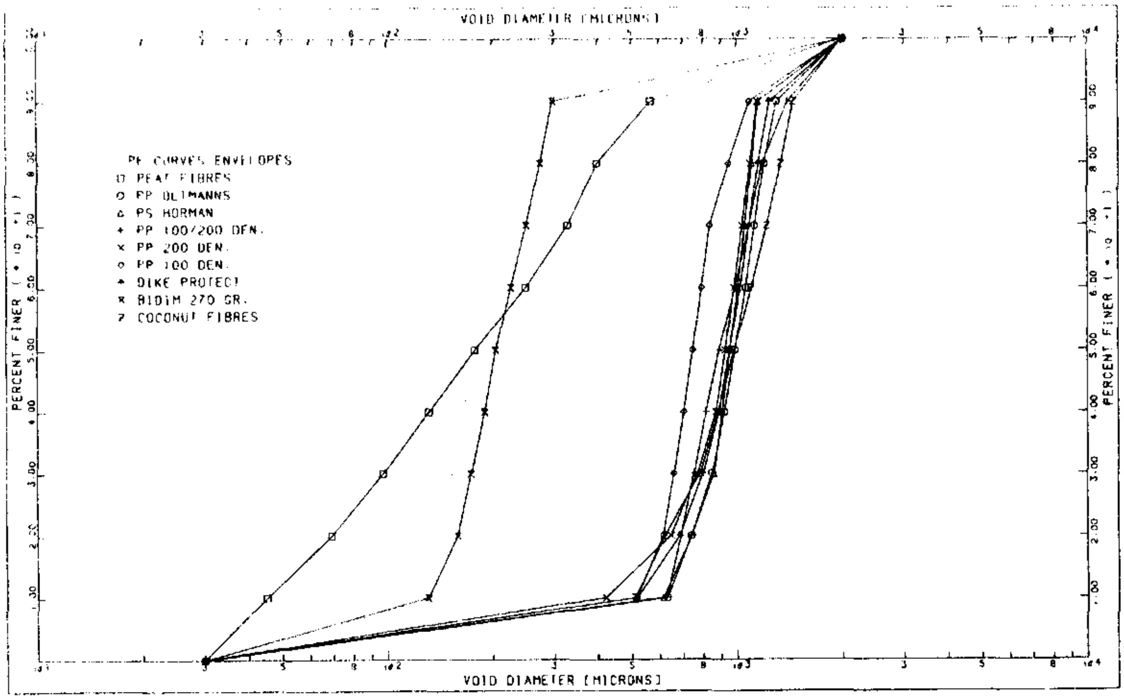

Fig. 3. Several suction curves of voluminous envelopes

Fig. 4. Air penetration into an envelope sample, simulated by computer; 4 stages

4. INTERMEDIATE RESULTS

Twenty-four envelopes have been tested. The majority (66%) consists of voluminous ones, the type most frequently used in Europe. Three envelopes (Bidim, Coconut fibres A and Polypropene fibres A) were tested in Halsema sand, a very fine silty sand. Halsema sand was used initially but rejected later due to its high iron content.

Data in table 1 summarize means of head losses over pipe and envelope, entrance resistances and effective drain radii, all computed at a drainage coefficient of 45 mm/day (drain spacing 15 m, pipe diameter 60 mm). The entrance resistance is expressed as the ratio of head loss and drainage coefficient according to

$$W_e = \frac{h}{QL} \qquad (1)$$

where W_e is the entrance resistance (day/m), h is the head loss (m), Q is the drainage coefficient (m/day) and L is the drain spacing (m).

The entrance resistance factor α which is related to the permeability of the abutting soil is expressed as

$$\alpha = W_e k \qquad (2)$$

where k is the permeability of the abutting soil (m/day). The effective radius R_{ef}, which is the radius of an ideal drain (that is, a drain which has a completely permeable wall) of smaller diameter being as effective as the actual drain plus envelope combination is given by

$$R_{ef} = R_e \exp(-2\pi\alpha) \qquad (3)$$

where R_{ef} is the effective drain radius (mm) and R_e is the radius of the combination of drain + envelope (mm). In order to get an impression of the envelope clogging rate, the ratio

$$R_{ef}/R_e * 100\% = F\ (\%) \qquad (4)$$

is plotted as a function of time. In fig. 5, values of F are plotted with time whilst the information is increasingly detailed on each subsequent section.

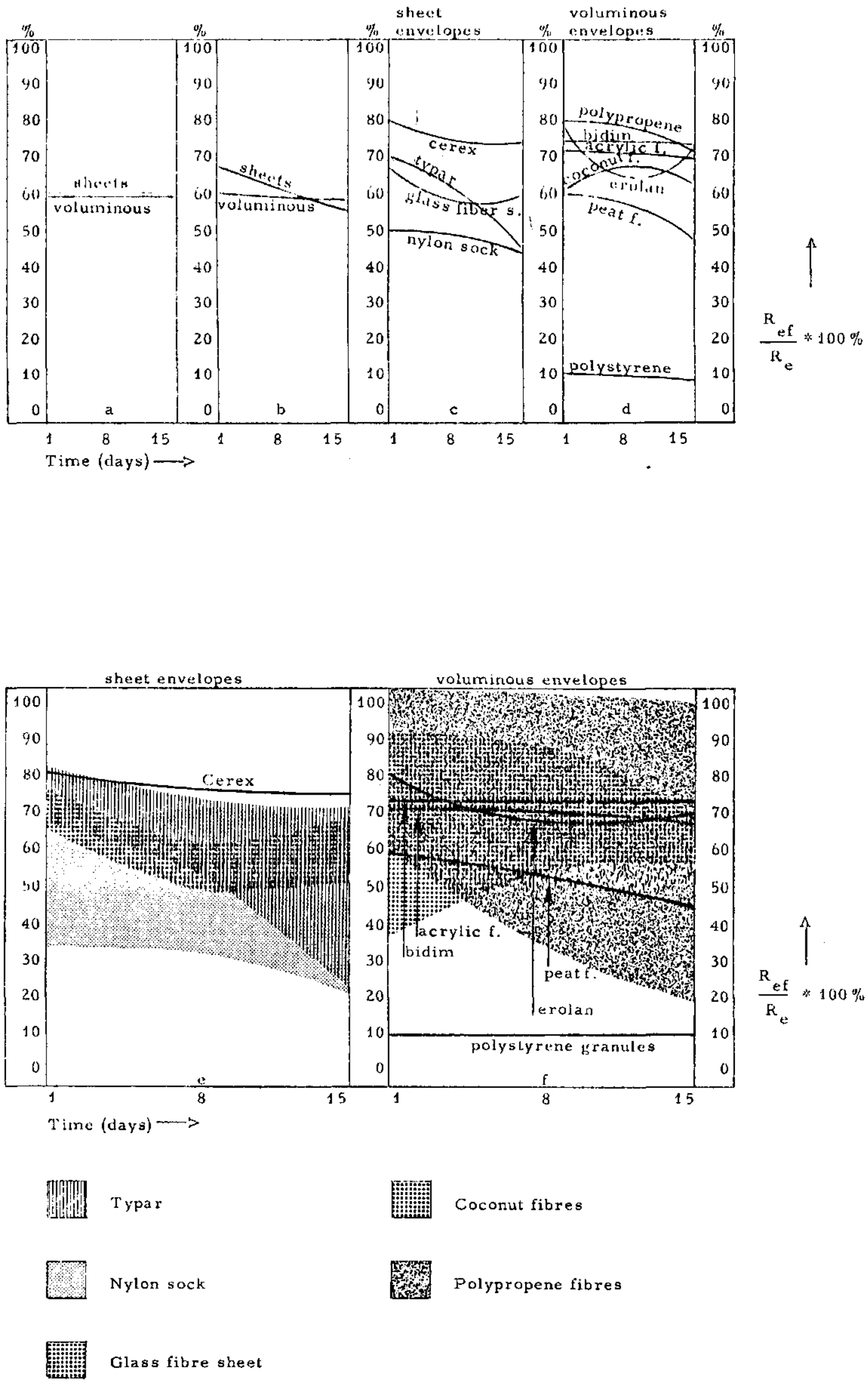

Fig. 5. Permeability of envelopes

Mean figures with respect to time, displayed in fig. 5 show that sheets and voluminous envelopes do nearly equally well. Obviously, sheets prove to clog more rapidly than voluminous envelopes: see fig. 5b. In fig. 5c and -d, means with regard to envelope type show to be more widely scattered with sheets compared to voluminous envelopes, that is if the polystyrene envelope is not taken into consideration. In fig. 5e en -f, shaded areas indicate what values of F were realized by various envelope types made of the same raw material, but differing as regards manufacturing process and/or weight class. The response of voluminous envelopes shows to be more widely scattered than that of sheets.

Soil moisture retention curves (fig. 3), an indication of an envelope's pore size distribution, have been determined of several envelopes. Following existing filter criteria, filtration properties are unequivocally correlated to pore size distributions. No significant relationship between rentention curves and washed-in quantities of particles could be detected. Sheets have better sand-tightness properties than voluminous envelopes.

5. DISCUSSION

Dutch envelope practise, mainly determined by field experience, dictates a preference for voluminous envelopes. However, sheets are applied successfully, too. A preference for voluminous envelopes has a historical background, and is partly based upon mathematical considerations.

Bad experiences with glass fiber sheets in combination with smooth plastic drains in the sixties still influence Dutch envelope type choice today. Results of this experiment, however, tend to indicate that sheets might be applied successfully just as voluminous envelopes.

Long-term clogging cannot be simulated in a permeameter set-up as used in this experiment. Therefore, two trial fields were set up in the Netherlands by august, 1983. In these, sheets as well as voluminous envelopes have been installed under excellent installation conditions. Drainage characteristics will be monitored for several years.

Results as recorded until May, 1984 indicate that system response is (still) more or less identical to laboratory outcomes.

Results as presented here are biased. Soil burden pressure as applied by the weights has been too high. This fact has adversely affected the data monitored on polystyrene granules. These were packed in a perforated plastic foil. Since the perforation grade of this foil is low, a substantial number of perforations seem to be shut off by the granules themselves during the flow tests. Moreover, the granules were occasionally deformed, a fact not recognised on field digups.

Results as regards nylon socks are unfavourably affected by testing of two types of sock designed for civil engineering rather than agricultural drainage. The latter type is lighter and more permeable.

The data-spread found for some envelope types is remarkable (cf. fig. 5e and -f). This is especially the case for polypropene envelopes. Polypropene fibers of various types are currently available, though scarce and thus expensive. Given the spread just mentioned, current popularity of pp envelopes is not fully justified.

If we were to rely upon this data only, almost all envelopes would be acceptable. Since this is not the case in the field, we conclude that this type of flow test is excellent for determining primary siltation, but not acceptable for assessment of an envelope's behaviour in the long run. Therefore, ICW will continue its research as indicated in 'Research Needs' (pag. 1). The Institute can do this thanks to the financial contributions of sponsors, at home as well as abroad: Big 'O' Filters U.K. Ltd (England/Canada); Enka BV (Netherlands); Griendtsveen Turfstrooiselmaatschappij BV (Neth.); KOMO (Neth.); Oltmanns Ziegel und Kunststoffe GmbH (Germany); Horman BV (Neth.); Landinrichtingsdienst (Neth.); BV Polvom (Neth.); Du Pont de Nemours S.A. (Switzerland); Rijksdienst IJsselmeerpolders (Neth.) and Solvic BV (Neth.). The research project is to be concluded by the end of 1987. In parallel, ochre clogging will be studied in a separate project (FORD, 1983).

Table 1. Envelope characteristics (see text). Figures have been computed from laboratory permeameter tests

	Head loss (cm)	Entrance resistance (day/m)	Entrance resistance factor α (--)	Effective drain radius (cm)	Trend with time *)	Amount of solids washed through per meter drain length (ø = 60 mm) (grams)
1. Bidim	0.49	0.006	0.01	2.31	o	5
2. Coconut fibres A	5.82	0.462	0.16	2.00	+	623
3. Coconut fibres B	0.63	0.019	0.13	1.85	o	401
4. Coconut fibres C	0.83	0.012	0.04	2.69	-	489
5. Polypropene fibres A	0.44	0.012	0.06	2.36	o	81
6. Polyprop. fibr. B	0.12	0.002	0.01	3.42	o	304
7. " " C	0.05	0.001	0.01	3.39	-	486
8. " " D	3.61	0.058	0.33	1.72	-	256
9. " " E	0.76	0.013	0.01	2.65	+	1740
10. " " F	0.18	0.003	0.04	2.90	-	78
11. " " G	1.25	0.018	0.03	2.70	o	832
12. Erolan	1.52	0.037	0.06	2.30	o	1)
13. Polystyrene granules	6.57	0.119	0.63	0.43	-	171
14. Peat fibres	2.11	0.038	0.17	1.88	o	1)
15. Acrylic fibres	0.99	0.013	0.09	2.26	o	1)
16. Cerex	0.82	0.023	0.04	2.64	o	74
17. Glass fibres A	1.22	0.027	0.07	2.28	o	8
18. Glass fibres B	2.21	0.037	0.11	1.88	o	13
19. Typar A	1.02	0.024	0.05	2.48	o	57
20. Typar B	5.20	0.082	0.25	1.53	-	27
21. Nylon sock A	4.15	0.040	0.21	1.10	-	6
22. Nylon sock B	2.62	0.029	0.08	2.19	o	17
23. Nylon sock C	2.77	0.004	0.14	1.63	-	12
24. Dike protection sheet	0.48	0.037	0.01	3.02	o	75

*) + = positive trend, - = negative trend, o = no significant trend
1) amount negligable

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APPENDIX

WORKING SCHEDULE Project 30.6 [Drainage envelope materials]

	Year		1985												1986												1987											
	Month		01	02	03	04	05	06	07	08	09	10	11	12	01	02	03	04	05	06	07	08	09	10	11	12	01	02	03	04	05	06	07	08	09	10	11	12
	Phase		I							II					III							IV					V							VI				
[1]	Permeameter flow tests	P	##	##	##	##	##	#				#	#	#	#	#	#	#	#	#				#	#	#	#	#	#	#	#	#						
		A	##	##	##	##	##	#				##	##	##	##	##	##	##	##	#				##	##	##	##	##	##	##	##	#						
[2]	Pore size distribution	P	##	##	#	#	#					#	#	#	#	#	#	#	#	#				#	#	#	#	#	#	#	#	#						
		A	##	##	##	##	##	#				##	##	##	##	##	##	##	##	#				##	##	##	##	##	##	##	##	#						
[3]	Field/lab-testing	P						#		#	#									#		#	#															
		A						#		##	##									#		##	##									#		##	##			
[4]	Mathematical analysis	P	#	#	#	#	#	#		#	#	#	#	#	#	#	#	#	#	#		#	#	#	#	#	#	#	#	#	#	#						
		A		#		#		#		#		#		#		#		#		#		#		#		#		#		#		#						
[5]	Reporting	P						##						#	#					##						#	#					##						
		A						#							#					#							#					#						
[6]	Meetings	P								#					#							#					#							#				#
		A								#					#							#					#							#				#
[7]	Drawing up of final report	P																																##	##	##	##	#
		A																																##	##	##	##	#
[8]	Holiday	P							##												##												##					
		A							##												##												##					
	Phase		I							II					III							IV					V							VI				
	Month		01	02	03	04	05	06	07	08	09	10	11	12	01	02	03	04	05	06	07	08	09	10	11	12	01	02	03	04	05	06	07	08	09	10	11	12
	Year		1985												1986												1987											

"P" = Project leader; "A" = Assistant

Explanation to the Working Schedule

The working schedule covers three years; 1985, 1986 and 1987. Each year comprises two phases: the first one will always last six months, the second one five; June is reserved for the summer holiday. Each phase is concluded with interim-reporting, followed by a meeting. Phase VI is reserved for the drawing up of the final report.

In the working plan, seven activities are distinguished:-

- 1]. testing of hydraulic and filtering properties of envelope materials and the surrounding soil, in the laboratory ['Permeameter flow tests'];

- 2]. the determination of the pore size distribution of voluminous envelope materials from suction curves ['Pore size distribution'];

- 3]. the digging up, in a hardly disturbing manner, and at field locations, of combinations pipe/envelope/soil material which have been functioning for several years, the plastering of these combinations with gypsum, after which some of their properties will be monitored in the laboratory ['Field/lab-testing'];

- 4]. the determination of the influence of conductivity changes of envelope materials and the surrounding soils on the dewatering efficiency of drainage systems ['Mathematical analysis'];

- 5]. the drawing up of interim-reports at the end of each phase ['Reporting'];

- 6]. the convention of meetings with the Contracting Parties at the beginning of each Phase [with the exception of Phase I (no meeting) and Phase VI (two meetings)] ['Meetings'];

- 7]. the drawing up of the final report during the last phase [' Drawing up of final report'].

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sub 1]. Permeameter flow tests

Problem Identification

The inter-action between soil material and envelope material caused by the water flow drag forces is extremely complicated and is influenced by many, often hardly quantifyable boundary conditions. This is reflected in the many existing, partly contradictory filter criteria which are currently applied. The majority of these criteria have a - often regionally bound - constrained validity; only the granular filter criteria are widely accepted.

For envelope materials which are applied in the temperate climatic zones criteria exist, based upon empirical research which is executed in the field as well as in the laboratory, during some 20 years. The applicability of these criteria now seems to be less a matter of course than it has been assumed in the past. Two developments are responsible for this mainly:-

- 1]. Regularly, complaints are made regarding the long-term behaviour of coconut fibre envelopes after installation; decomposition phenomena seem to be causing the trouble to a large extent;
- 2]. Only lately, many new synthetic materials are proposed as envelopes; it is however not yet known whether these are applicable as envelopes, especially in the temperate climatic zones;

Research Objectives

See the Contract: 1.0 ['Motivation'] and Article 2.2.

Procedure

During two weeks, disc-shaped envelope samples [diameter 15 centimeter] are monitored as regards their hydraulic- and filtering properties, in plexiglass permeameters [two dimensional flow]. The materials are tested simultaneously in combination with disturbed as well as with [more or less] undisturbed soil; both in four repetitions. In doing so, an attemption is made to link the tests to current installation practise [i.e. trenching, and trenchless].

The flow orientation is variable in the vertical plane [angle of interval: 45 deg., eight directions available]. Groundwater flow directions in the vicinity of the pipe can be simulated in the laboratory accordingly.

The following variables will be monitored as a function of various hydraulic gradients: the hydraulic conductivity of the envelope, and at several imaginary layers of the soil material, and the soil texture caused by particle transport due to the water flow drag forces, including the composition of those fractions which are washed into-, and through the envelope material.

The findings of these experiments will be compared with data, acquired in conjunction with the measurement programme, described in 3].

Time available: Project Leader: 58 weeks;
Assistant: 90 weeks.

Number of materials to be tested: 30

Available time for each material: 3 weeks

sub 2]. Pore size distribution

Problem identification

An important parameter of voluminous envelope materials is the pore size distribution. It is however hardly known how to define a pore size distribution which is relevant for the filtering action, let alone that a method exists which is suitable to measure such a distribution.

The suction method seems to be most suitable to be used in case we are dealing with voluminous envelopes [thickness > 2 mm.]. This measurement technique is easily implemented; moreover, the pore size distribution can be investigated while the envelope material is put under pressure, according to field conditions. - However, the suction curve which is recorded is not identical to a pore size distribution curve as it is still often assumed. As a consequence, the method should be developed further, particularly the mathematical conversion of a suction curve into a pore size distribution curve of an envelope. The concept of this project more or less coincides with recent developments in this field in the Federal Republic of Germany.

Research Objectives

The development of an applicable definition of the pore size definition of envelope materials, and a practical, reliable method to determine this distribution.

Procedure

Disc-shaped samples of envelope material [diameter 12 cm.] are, in state of compression, saturated with de-aerated water. Next, the water suction is increased step-wise and the evacuated water quantities recorded. This phenomenon is studied using a computer model which simulates it. This computer model must be developed further in such a manner that it can be used to convert recorded suction curves into pore size distributions.

Time available: Project Leader: 50 weeks;
Assistant: 90 weeks.

sub 3]. Field/lab testing

Problem identification

The implementation of permeamater flow tests in the laboratory is a compromise. On the one hand, high-accuracy measurements must be made and on the other hand, the experiments must have a definite link with field conditions. It is not sure whether laboratory outcomes are transferable to field conditions. In order to get more certainty regarding this matter, laboratory outcomes are to be compared with the status of soil- and envelope material, several years after installation.

Research Objective

The assessment of the applicability of laboratory permeameter flow tests with envelope materials in conjunction with the prediction of the suitability of envelope materials in the field.

Procedure

A number of sites is selected where subsurface drainage systems are a] in operation five years at its highest, and where b] envelope materials are applied, analogical to those which are screened in the laboratory, at least, materials, similar as much as possible.

The status of pipe-, envelope-, and soil material immediately around the pipe must be investigated in detail; this should be done in the laboratory. The digging up-, and transport of such combinations is a laborious and difficult job. The materials selected are dug out carefully, plastered with gypsum, and monitored in the laboratory as regards the variability of hydraulic conductivity, perpendicularly to the pipe wall, the status of the envelope material, the textural composition of the soil material, etc.

Time available: Project Leader: 12 weeks;
Assistant: 30 weeks.

Number of materials to be screened: 10

sub 4]. Mathematical analysis

Introduction

The research into the possible consequences of defective envelope materials is mainly conducted following three concepts:-

- 1]. laboratory permeameter flow tests, determining envelope entrance resistance figures;
- 2]. pilot area research, where the relationship outflow/phreatic level is partially linked to the visual inspection of envelope samples which are dug out, inevitably disturbed;
- 3]. mathematical analysis of the impact of the clogging rate of envelope materials and the surrounding soil on the effectiveness of a drainage system;

Problem Identification

ICW's research programme into drainage envelope materials during the past three years has indicated that not enough attention has been paid to changes in hydraulic conductivity of the soil abutting the envelope material. These changes, caused by the relatively high flow rates in the vicinity of the drain lead to critical examination of the use of the concept of entrance resistance in this case. The entrance resistance is linked to the conductivity ratio of the envelope material and the immediately abutting soil. The soil conductivity may be quite variable; its value may even be lower than the envelope's conductivity; as a consequence, the current concept of entrance resistance has become less relevant, and must be replaced by an analysis of the conductivity changes of both media [soil and envelope material] in the vicinity of the pipe.

Procedure

It is unlikely that the field research activity referred to in 2] is a reliable means of studying the clogging processes in the vicinity of the pipe minutely due to the inevitable disruption of the samples. The analysis mentioned in 3] must be modified in such a manner, that both media around the pipe are included in the analysis. This concept will be elaborated further, whereby data will be retrieved from the permeameter flow tests mentioned in 1].

Time available: Project Leader: 56 weeks;
Assistant: 30 weeks.