RYCROFT, D.
University of Southampton, Southampton, U.K.
DENNIS JONES, P.
ICI Fibres, U.K.

Geotextile Filtration Performance and Current Filter Criteria

Les performances de filtration des géotextiles et les critères de filtre courants

The results of measurements of flow rates carried out at ICI Fibres soils laboratory in the UK through systems composed of soils and geotextiles are discussed. The results suggest that the presence of a fabric has little effect upon the permeability of the system. Preliminary results from work at Southampton University lend support to this observation. The concept of wrapping pipes directly with a fabric filter is investigated and advocated only with the use of corrugated pipes. The general trend towards specifying coarser particle sizes for graded aggregate filters in land drainage situations is discussed in relation to current criteria for fabrics.

Les résultats des débits mesurés dans le laboratoire de mécanique des sols d'ICI Fibres, RU, à travers des systèmes sol/géotextile sont discutés. Ces résultats indiquent que le géotextile n'a que peu d'influence sur la perméabileté du système. Des résultats préliminaires de l'université de Southampton renforcent cette observation. L'idée d'enrober directement des tuyeaux de drainage d'un géotextile est considéré et recommandé uniquement pour les tuyeaux ondulés. La tendance générale de prescrire une granulométrie plus grosse pour des matériaux de filtration calibrés utilisés en drainage de terrain est discuté vis-à-vis des critères courants pour les géotextiles.

1 INTRODUCTION

The wide range of materials manufactured as permeable membranes - or "Geotextiles" has been well documented (1). Their uses are wide and varied, and have been classified (2) by virtue of their primary functions - Separation, Filtration, Drainage in the Plane, and Reinforcement.

Geotextiles have been used in a variety of geotechnical 'filter' situations for over fifteen years during which time various design criteria have been developed.

Confidence has grown considerably in the use of these materials although it is often desirable to evaluate their suitability in specific situations.

The application that generated some of the work to be discussed was concerned with the use of geotextiles in place of graded gravel filters as a surround or envelope to pipes used for land drainage. Graded gravel envelopes placed around pipe drains are expensive and difficult to obtain. One example of this was on a large reclamation scheme in the Middle East (3) where an 80 mm diameter corrugated plastics drain pipe was enveloped with a minimum 50 mm thickness of gravel within (although on the coarse side of) an approved grading envelope. A layer of thin non-woven geotextile filter (Terram 140) was then placed on top of the envelope to separate the gravel from the loose trench fill.

The success of the system lent support to the view that the pipes might work satisfactorily if the gravel were omitted, and the pipes were simply wrapped with the geotextile.

The purpose of the paper is to collate results from tests of filter performance in typical land drainage models, to compare various filter criteria and comment on the concept of wrapping pipes directly with a geotextile.

2i MEASUREMENT OF SOIL PERMEABILITY

Permeameter cells are used for studying the passage of water through various soil and filter combinations under different static flow conditions; they are designed basically for measuring flows but also permit visual examination.

Usually in the ICI laboratory, permeameters are set up in batches of 4, using apparatus similar to that illustrated in Fig: 1.

A weighed 200 mm dia disc of filter fabric is bedded down on to aggregate placed in the base, and the glass top firmly clamped down. The soil is placed in layers while the cell is filled with water from below keeping the soil wet all the time to minimise air entrapment and eliminate surface tension effects.

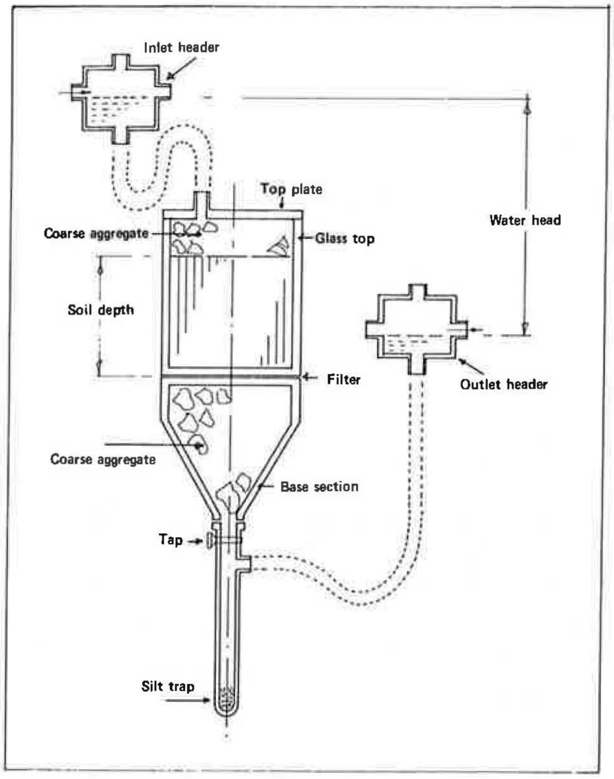

FIG. 1. SECTION THROUGH PERMEAMETER CELL.

After placing the soil, the upper part of the cell is filled with aggregate, the top plate clamped in place, and constant flow maintained with some overflow in the top water header. The flow through the system is measured at intervals and is converted to hydraulic conductivity (m/s) on the basis of Darcy's law. Upon dismantling, all elements are dried and weighed in order to establish particle movement.

2ii FLOW RESULTS FROM PERMEAMETER CELLS

The tests described in this paper were carried out to evaluate the changes in the flow rate which were liable to occur in field situations due to saturated ground-water flow from soil through a geotextile to a highly permeable drainage blanket. Most of the tests were carried out on various combinations of fabric filter and soil types. However, in some situations a 2 mm mesh replaced the fabric in an attempt to create an extreme 'no filter' situation.

In general the flow rate declined rapidly in the initial stages and more slowly in later stages as is shown in Fig: 2, following a pattern noted as being typical (4, 5). Many results deviated from this norm due to compaction and experimental variations but reductions by a factor of 10 in the soils' initial hydraulic conductivities were common.

The experiments were undertaken using normal (as opposed to de-aired) water and the evidence of many researchers' (6) would suggest this was a root cause of the sporadic nature of the results.

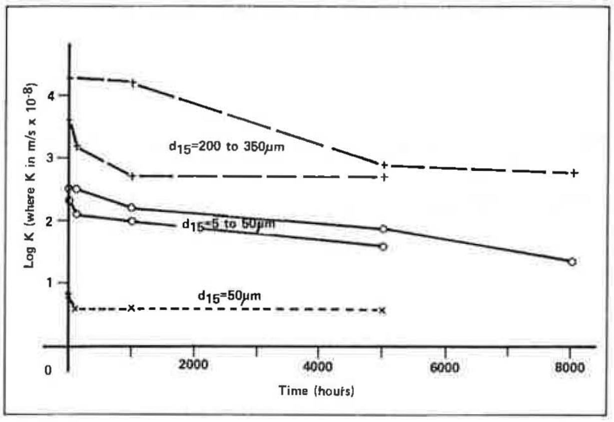

FIG. 2. GRAPH OF (LOG) HYDRAULIC CONDUCTIVITY V. TIME.

Relationships were sought between values of hydraulic conductivity and potential soil size parameters. Fig: 3 however, typifies the rather erratic nature of this relationship between, in this case, hydraulic conductivity and the soils' d_{15} size which other researchers (7) have found to be indicative of hydraulic conductivity.

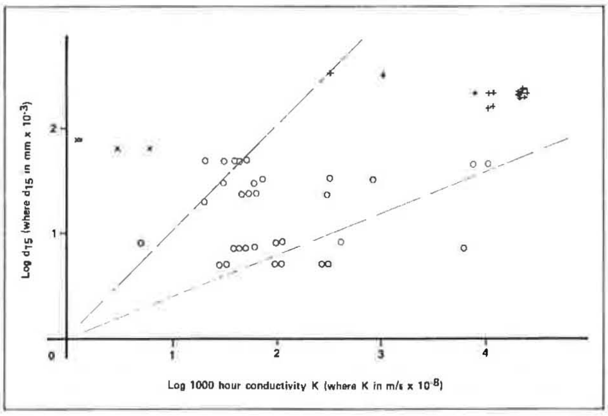

FIG. 3. GRAPH OF (LOG) PARTICLE SIZE V. (LOG) HYDRAULIC CONDUCTIVITY.

In general there was no visual or recorded evidence that the fabrics had in any way become blocked to a degree that had any measurable effect upon the system's overall hydraulic conductivity. However, situations were tested in which fines appeared able to suffose through gap graded soils and settle on the filter to form a layer of reduced hydraulic conductivity.

The conclusions drawn from the many hours of tests on soils drawn from different areas of the world are that:

i Simple tests carried out on disturbed soils can vary in an inconsistent manner.

ii The hydraulic conductivities of the fabric and soil system appear to be controlled almost wholly by the hydraulic conductivity of the soil.

iii In certain soils liable to suffosion the fabric filter can retard the onward migration of fines and lead to a local build-up of material of limiting hydraulic conductivity.

2iii PIPING OBSERVATIONS IN PERMEAMETER CELLS

Piping results from the permeameter cells are limited due to the difficulty of the measurement of particle movement, which is calculated by dry weight changes between assembly and dismantling and therefore depends upon difference measurement.

The results give the impression that significant piping of soils was only evident when a gauze with a nominal 2000 μm opening size (representing the no filter situation) was used. Unfortunately there is a dearth of results between these and the 50 to 350 μm pore size fabrics, and it is difficult to relate the degree of piping to the fabric type and soil type.

Consideration should be given to the degree of particle loss in the model necessary to represent piping (8). Some piping occurred initially in several tests but this was often observed to cease after several hours. The evidence suggested that this initial phase of piping might involve the movement of up to 2-3% of the original soil mass. Quantities of transported soil in excess of 3% were associated with soils in which continuous piping occurred.

On this basis it can be said that only one of the soils tested significantly piped through a filter cloth. This was a particularly mobile silt with d_{15} = 10 μm and C_u (coefficient of uniformity) = 4. Conversely several of the soils tested appeared to suffose through the gauze, although to varying degrees, as may be expected (9).

3i THE FEASIBILITY OF WRAPPING PIPE DRAINS WITH THIN GEOTEXTILE FILTERS

Seepage towards pipe drains constitutes a very testing hydraulic condition in the sense that all the excess water from a relatively large area of land (typically 50-100 m^2/m length of pipe) has to converge and flow through a very small area of soil adjacent to the pipe in order to gain access to the pipe (typically $10^{-3} m^2$/m length).

Most of the available head generating flow to the pipe is lost in the region of convergence near the pipe giving rise to high hydraulic gradients (up to 8) (10). It follows that the conditions at, and near to, the pipe are of particular importance since they influence this headloss.

The total headloss, as flow occurs from a water table to a pipe, may be schematically subdivided into losses due to vertical, horizontal and radial flow (11). Each of these flow zones may be described in terms of a resistance, though the only ones that may be influenced by the design of the pipe and its surrounding envelope are the components of the radial flow, namely: convergence/radial resistance, Wr, and especially the entrance resistance, We (12) where:

We = entrance head loss due to the inflow to the pipe of a unit discharge/unit length of pipe. Units $T L^{-1}$.

The entry resistance can also be expressed in a dimensionless form: $\alpha = We\ K$

where K = hydraulic conductivity of the surrounding soil/envelope through which water passes to gain entry to the pipe.

Typical values of α are presented in Table 1:

Nature of Pipe	Dimensionless Entry Resistance α	Source
Clay tile drain	1.6 - 2.3	(13)
Smooth plastics	0.4 - 2.6	(14) (15) (16)
Corrugated plastics	0.02 - 0.04	(17)

Table: 1 Typical measured values of the dimensionless resistance factor.

The values reflect the different entry characteristics of pipes. Clay pipes have a small entry area poorly distributed in the form of gaps between the pipes. Smooth plastics pipes, at least in Europe, have a minimum entry area of 800 mm^2/m length whilst corrugated pipes tend to have a larger area (typically 2000 mm^2/m length) which is favourably distributed in the form of small slots.

The entry characteristics of pipes tend to be ignored in the design process since the water table midway between the drains is not affected to a significant degree by the head loss at entry (until this exceeds 0.1-0.2 m which corresponds to values of α of 0.25-0.36 respectively) (12).

In general it may be concluded that clay and smooth plastics pipes have a somewhat higher resistance than the implied minimum limit of 0.25.

The effect of wrapping pipes with the sort of thin geotextiles which only permit flow across the plane of the fabric would in the case of the clay tile drain and the smooth plastics pipe lead to a further reduction in the entry area leading to increased resistances. This in itself would be inadvisable especially as subsequent partial clogging of the filter above the entry areas might lead to even further increases in resistance.

The effect on the corrugated pipe could be different, for two reasons. Firstly, the basic resistance of this type of pipe is lower than the suggested limit. Secondly, the effect of bridging the grooves between the corrugations of a pipe slotted on the inner grooves would increase the area of the interface bewteen the soil and the pipe.

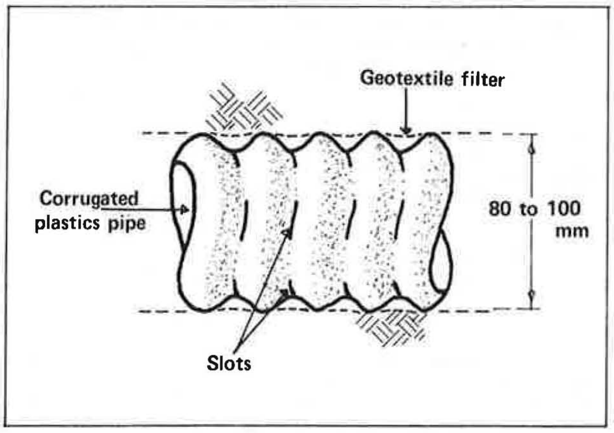

FIG. 4. SCHEMATIC OF WRAPPED CORRUGATED PIPE.

The few published values of the resistance α for pipes wrapped in this matter, suggest it to be in the range of 0.02-0.09 (18, 19).

3ii EXPERIMENTS TO DETERMINE THE EFFECT OF HYDRAULIC CONDUCTIVITY OF A GEOTEXTILE WRAPPED PIPE

Experiments were carried out in a sand tank, similar to that described by Knops (18), and illustrated in Fig: 5.

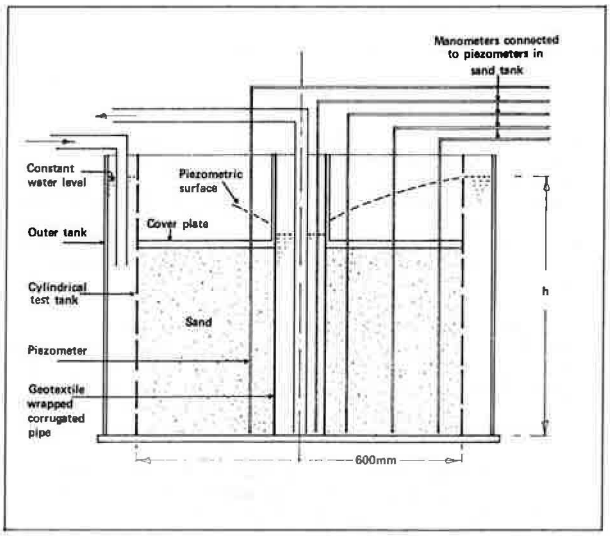

FIG. 5. SECTION THROUGH SAND TANK APPARATUS.

The objective of these tests was to identify the reduction in the hydraulic conductivity of the geotextile that would be necessary to reduce the resistance to the arbitrary limit of 0.25. The tests were carried out using a highly permeable coarse sand, while the geotextile's hydraulic conductivity was reduced by covering the wrapped pipe with porous paper, to simulate clogging. Measurements of discharge, headloss at entry, and piezometric levels enabled the entrance resistance 'We', the hydraulic conductivity of the sand K and the dimensionless resistance to be determined.

The hydraulic conductivities of the combinations of fabric and paper were determined at the conclusion of these tests by transferring a 100 mm ø dual wafer to a separate permeameter illustrated in Fig: 6. This apparatus enabled the conductivity to be determined under low hydraulic gradients (<6) theoretically preserving Laminar Darcian flow.

The test programme has not yet been completed and the results presented in Fig: 7 must therefore be regarded as being provisional, and the conclusions of a preliminary nature. (The data has been presented in this dimensionless form since theoretically α is functionally dependent upon the ratio K-fabric/K-sand.)

The data indicates that the limiting resistance of 0.25 corresponds to a conductivity ratio of 0.15.

3iii DISCUSSION

This result may be extended to drained lands where, typically, the hydraulic conductivity of the soil around the pipe might be of the order of 1.m. day $^{-1}$. In this situation the limiting value of α would occur when the hydraulic conductivities were reduced to 0.15 m.day^{-1}.

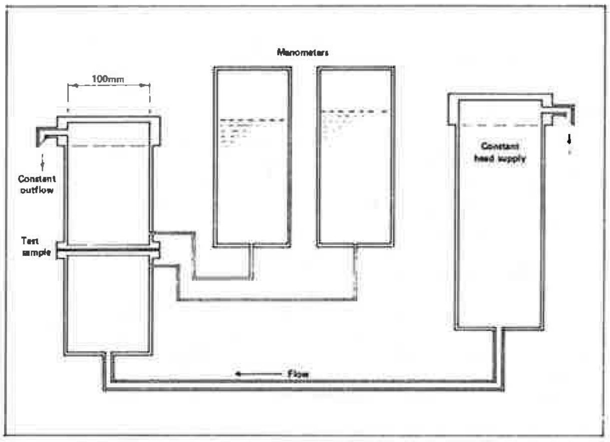

FIG. 6. APPARATUS TO MEASURE FABRIC HYDRAULIC CONDUCTIVITY UNDER HYDRAULIC GRADIENTS.

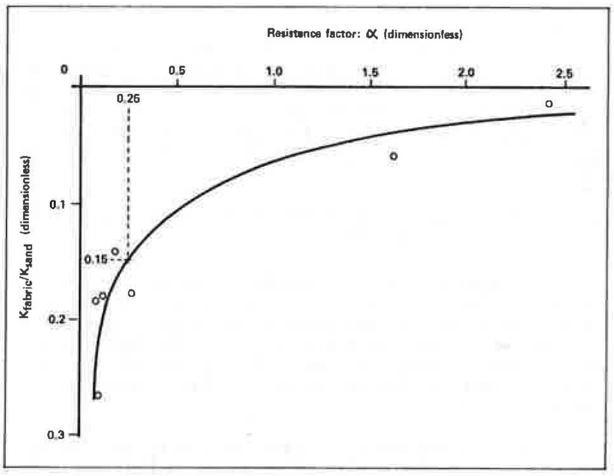

FIG. 7. RELATIONSHIP BETWEEN RESISTANCE AND FABRIC/SAND PROPERTIES.

As initial fabric hydraulic conductivities in this instance were approximately 100 m.day^{-1} we may conclude that a 500 fold reduction of the initial conductivity would be required in the field situation to bring about the limiting resistance (α).

It is clear that the thin geotextile used under the conditions described can suffer considerable clogging without affecting the performance of the drainage system.

These results, however, may also be considered as showing that very little change would be needed to the hydraulic conductivity of the soil immediately surrounding the pipe to reduce the overall resistance to the suggested limit of 0.25.

It seems fair to conclude that it is highly unlikely that the fabric would clog to a significant degree without the soil adjacent to the fabric also clogging to a similar degree; since the soil's initial hydraulic conductivity is much lower than the fabric's, the effects of soil clogging would be that much more serious. The results suggest that our attention should be directed much more towards the hydraulic properties of the soil adjacent to the filter and less at the permeability of the fabric. However, the choice of fabric indirectly influences the soils properties in the sense that fines moving in the soil may either pass through the filter and improve soil hydraulic conductivity or they may be retained in the soil near the fabric, possibly reducing soil hydraulic conductivity. The choice of fabric could therefore be vital to the conditions which will develop in the soil.

4i FILTER DESIGN METHODS.

The design criteria for granular filters for land drainage have evolved in recent years towards coarser, more permeable, materials. Fig: 8 illustrates the potential filter envelopes which could be advocated for protecting the silty soil that gave rise to this initial interest in the applications of fabrics to land drains. These represent a chronological progression of four widely used criteria: Cedergren, 1967 (20); USDA 1973 (21); USBR 1978 (22); FAO 1980 (23).

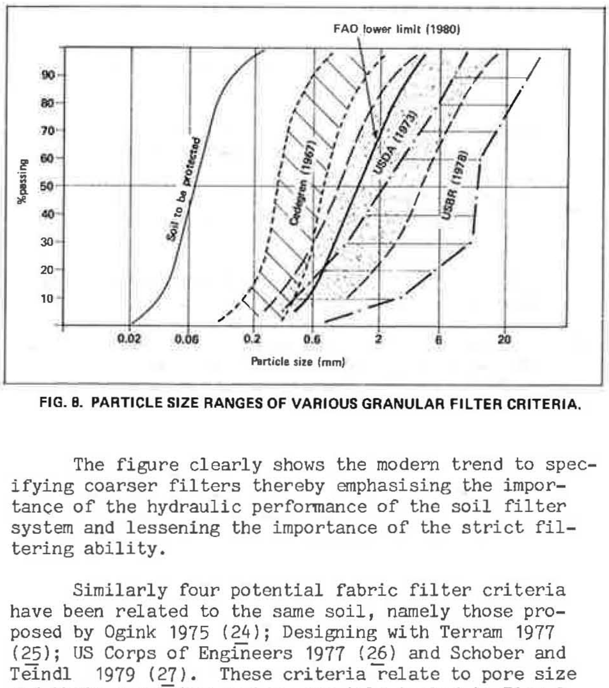

FIG. 8. PARTICLE SIZE RANGES OF VARIOUS GRANULAR FILTER CRITERIA.

The figure clearly shows the modern trend to specifying coarser filters thereby emphasising the importance of the hydraulic performance of the soil filter system and lessening the importance of the strict filtering ability.

Similarly four potential fabric filter criteria have been related to the same soil, namely those proposed by Ogink 1975 (24); Designing with Terram 1977 (25); US Corps of Engineers 1977 (26) and Schober and Teindl 1979 (27). These criteria relate to pore size and their resulting designs are illustrated in Fig: 9 where they are contrasted with the range of pore sizes of potential gravel envelope designs.

4ii PORE SIZE DETERMINATION

The measurement of aggregate and fabric pore sizes is difficult, and comparing the results obtained from different test methods a somewhat uncertain procedure. The pore sizes of the gravel filters were estimated by dewatering the aggregates with increasing tensions. The capillaric relationship between tension μ and pore diameter ($d = 0.3/\mu$ cm) was then used to estimate pore sizes. In view of the limitations of this indirect method of determining pore sizes, the lower end of the range can at best be considered indicative. Similar

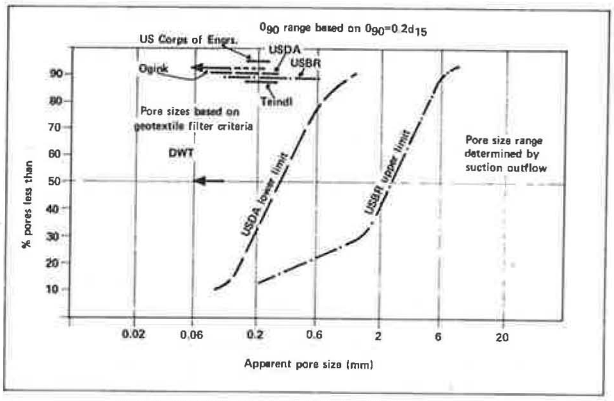

FIG. 9. PORE SIZES OF VARIOUS FILTER CRITERIA.

problems are encountered measuring the pore sizes of fabrics, since direct measuring optical methods can only be employed with woven fabrics with regular mesh size openings.

Various indirect measuring techniques have been devised, the most commonly used being the "dry sieving" method reported by several researchers (8 24 25 28). Such methods are usually specified to relate to a particular design method, the apparent opening sizes again being indicative and relating only to the larger pore sizes. Moreover, other factors may need to be considered when estimating effective fabric pore size - such as the compression of thick fabrics, or the possible opening up of loose weaves under stress.

4iii COMPARISON OF FILTER CRITERIA

The measured pore sizes of the two gravel filters appear considerably larger than the equivalent fabric filter pore sizes, though they should not be compared directly. In a gravel filter it seems logical to suppose that some fine particles are likely to encounter some of the finer pores, though this will not prevent water from moving around a blockage within the thickness (usually $>$ 75 mm) of the filter. In a thin fabric the fines are liable either to pass or to be entrapped thus limiting or even preventing the passage of water through the blocked pore. In view of this it may be that the critical pore sizes for filtration should be based upon the larger pore sizes of fabrics and the smaller pore sizes of gravels.

5 CONCLUSIONS

In conclusion the following comments appear relevant to the use of fabrics in land drainage applications:

i the performance of soil is a complex phenomenon and neither hydraulic conductivity nor piping potential can be accurately recognised from particle size alone.

ii bands of low hydraulic conductivity can occur in gap graded soils due to suffosion.

iii in hydraulic conditions where initial filter K $\gg$ Soil K, fabric filters themselves are unlikely to clog significantly.

iv the hydraulic conductivity of disturbed soils is likely to reduce in time and this may be accelerated by the choice of filters which are "too tight".

v permeameter tests indicate that the available filter fabrics ($O_{90} < 350$ um) only rarely permit soil piping.

vi by taking the coarest option from the design method chosen, soil blocking will be minimised, and fabrics can be used with greater confidence in non homogeneous soils.

REFERENCES

1 Rankilor, P.R., "Membranes in Ground Engineering", John Wiley & Sons Ltd, 1981.

2 McGown, A., "Fabric Membranes and Their Application to Highway Engineering", University of Strathclyde, 1976.

3 ICI Fibres "Lower Khalis Irrigation Project" Case study report C14/1 1979.

4 Marks B.D., "Behaviour of Aggregate & Fabric Filters in Subdrainage Applications", University of Tennessee, 1975.

5 McKeand, E., "Behaviour of Non-woven fabric filters in subdrainage applications". IICG Paris, 1977.

6 Muth, W., "Drainage of Earth Covered Structures", Karlsruhe, 1981.

7 Elmer, J.O., "Investigation of the Geometry of Piping", University of Connecticut, 1973.

8 Ragutski, G., "Determining the Filtering Efficiency of Permeable Synthetic Materials".

9 Dieleman, P.J., and Trafford, B.D., "Drainage testing". Irrigation and drainage paper No. 28, FAO of UN, Rome, 1976.

10 Luthin, J.N., "Effectiveness of various sand and gravel separates for drain envelopes". In "Factors influencing water and particle movement into drains". USDA Science and Education Admin., 1979.

11 Ernst L.F., "Grondwaterstromingen in de verzadigde zone en hun berekening bij aanwezigheid van horizontale evenwijdige open leidingen". Versl. Landbouwk. Onderz. 67-15. 189 pp 1962.

12 Wesseling, J., "The Entrance resistance of drains as a Factor in design". Paper 2.08 Proc. Int. Drainage Workshop. Pub.25. ILRI Wageningen, 1979.

13 Wesseling, J., and C.L. Van Someren. "Provisional report of the experience gained in the Netherlands". FAO Irrigation and Drainage Paper 6: 55-71, 1972.

14 Widmoser, P., "Etude de l'écoulement au voisinage immédiate des drains". Paper R2 Q 28.1. I.C.I.D. Congress.Varna, 1972.

15 Cavelaars, J.C., "Problems of Water entry into plastic and other drain tubes". Symp. National College of Agricultural Engineering, Silsoe, Bedord, UK. 13p 1967.

16 Segeren, W.A., Zuidema, F. "Ontwikkelingen in de drainage technik cuituurtechnische Verhandelingen" Min van Landbouw's - Gravenhage, 1969.

17 Meyer, H.J., "Enkele resultaten van metingen aan plaskick ribbelbuizen". Research Report I.C.W. Wageningen, 1969.

18 Knops, J.A.C., "Research on envelope materials for subsurface drains". Paper 210. Proc. Int. Drainage Workshop Pub. 25 ILRI Wageningen, 1979.

19 Zuidema, F.G., and Scholten, J., "Model tests on drainage materials". Paper 2.11. Proc. Int. Drainage Workshop. Pub 25 ILRI Wageningen, 1979.

20 Cedergren, H.R., "Seepage, Drainage & Flow Nets" John Wiley & Sons Ltd., 1967.

21 USSCS, "Drainage of Agricultural Land". USDA Soil Conservation Service National Engineering Handbook, Washington D C, 1971.

22 USBR, "Drainage Manual". US Bureau of Reclamation, USDI, Denver, 1978.

23 FAO, "Drainage Design Factors". FAO Irrigation & Drainage Paper No. 38. FAO of UN, Rome, 1980.

24 Ogink, H.J.M., "Investigations on the Hydraulic characteristics of synthetic fabrics". Delft Hydraulic Lab Publn No. 146, 1975.

25 Rankilor, P.R., "Designing with Terram". ICI Fibres Pontypool 1977, (reprinted: 1978)

26 US Army Corps of Engineers, "Plastic Filter Fabric" Civil Works Construction Guide Specification CW02215 1977.

27 Schober, W., & Teindl, H., "Filter Criteria for Geotextiles", VII ECSMFE Brighton, 1979.

28 Calhoun, Ch. C., Development of design criteria and acceptance specification for plastic filter cloths. US Army Eng. Waterway Exp. Station, Vicksburg, 1972.