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PREFABRICATED DRAINAGE COMPOSITES: EVALUATION AND DESIGN GUIDELINES
COMPOSES PREFABRIQUES D'ECOULEMENT: EVALUATION ET PRINCIPES DE CALCUL
VORGEFERTIGTE KOMBINIERTE DRAINAGEMATERIALIEN: BEWERTUNG UND KONSTRUKTIONSKRITERIEN

Prefabricated drainage composites (also called drainage geocomposites) allow for the conveyance of relatively large amounts of fluid within the plane of their manufactured structure. The key element is the drainage core wherein both its mechanical and hydraulic properties are important. Due to the large variety of core types available, specific tests are required which are described in this paper. It is seen that three design values are required, i.e., flow rate, hydraulic gradient and applied pressure. Various products have been evaluated and compared to one another. A design guide for different application areas is also included.

Vorgefertigte Entwässerungsmischungen (auch als Entwässerungs-Geo-Mischungen bekannt) ermöglichen den Durchfluß von verhältnismäßig großen Flüssigkeitsmengen innerhalb der Fläche des gefertigten Gefüges. Das Schlüsselelement ist der Abflußkern, in dem sowohl die mechanischen als auch die hydraulischen Eigenschaften wichtig sind. Da es so viele verschiedene Kern-Typen gibt, sind spezielle Tests erforderlich, die hier veröffentlicht sind. Es wird gezeigt, daß drei Konstruktionswerte notwendig sind, nämlich die Durchflußrate, das hydraulische Gefälle und der aufgebrachte Druck. Viele verschiedene Erzeugnisse wurden ausgewertet und miteinander verglichen. Eine Konstruktionsanweisung für verschiedene Anwendungsgebiete ist ebenfalls beigefügt.

INTRODUCTION

There appears to be at least five basic functions that geosynthetic materials can provide when included in geotechnical related projects. These are separation, reinforcement, filtration, drainage and water barrier. Of these, drainage refers to the movement of fluid in the plane of the geosynthetic material and is of concern in this paper. Referring to drainage using geotextiles much has been written, e.g., Gerry and Raymond (1) report on the transmissivity of many different manufactured types, while Koerner, et al. (2,3), review the various apparatuses used for testing, and report on the transmissivity of a number of needle punched nonwoven geotextiles. These test results suggest an upper limit for most commercially available geotextiles which is found in the needle punched nonwovens. For example, a 600 gm/m^2 (18 oz/yd^2) geotextile carries about 0.037 1/min-m (0.003 gal/min-ft) of water under 2.0 kPa (2000 lb/ft^2) normal pressure. Such flow rates are generally capable of draining fine grained silts and clays, or even fine sands under low hydraulic gradients, but fall short of a wide range of problems involving granular soils under moderate or high gradients. For these problems (and others to be mentioned later) either extremely thick geotextiles are necessary, or a different type of drainage system is required. It is in this latter category where a number of composite systems have recently become available. Called prefabricated drainage composites (or drainage geocomposites), these systems consist of a mesh, waffle or net core, protected by a geotextile filter on the upstream soil side. The opposite side of the core can be placed directly against a structure, have a second geotextile on it or have a geomembrane on it. See Figure 1 which shows a number of these products. They are the focus of this paper.

Designwise, one must calculate, or otherwise estimate, the flow rate to be conveyed by the system, at the particular hydraulic gradient of concern, and at the applied pressure to be exerted against it. Note that in using prefabricated drainage composites flow rate is of concern and not transmissivity. The reason for this is that flow in the core is generally turbulent, hence Darcy's formula (upon which transmissivity is based) is not applicable. In general, the required flow rates can be categorized versus their intended use as shown in Table 1.

Table 1 - Flow Rate Categories by End Use

Category	Typical Flow Rate		Typical Drainage Application Areas
	ℓ/min-m	gal/min-ft	
low	<0.12	<.01	surcharged fine grained soils
medium	0.12 to 12	.01 to 1	sport fields and roof gardens
high	12 to 125	1 to 10	retaining wall and seeping slopes
very high	>125	>10	highway and airfield edge drains

Upon having the required flow rate at its specific hydraulic gradient and applied pressure, one must compare this flow rate to the value of the proposed drainage composite at the same conditions to arrive at a suitable factor of safety. If one makes such a comparison with a number of possible systems one will see that vast differences result. To give an idea of the wide variety of systems that are available note Table 2. Here it can be inferred from visualizing the core thicknesses, construction patterns and material types that a wide range of mechanical and hydraulic responses will result. It should be noted that Table 2 lists products available mainly in North America. The activity however, is worldwide, e.g., Nylex Cordrain in Australia and Culdrain in Japan. It is the quantification of these features that form the next sections of this paper.

Table 2 - Some Commercially Available Prefabricated Drainage Geocomposites and Relevant Characteristics

Product Name	Manufacturer	Core Characteristics			Usual Geotextile Filter	
		Thickness (cm)	Shape	Material	Type	Process
Amerdrain II	American Wick Drain Corp.	0.81	0.63 cm ribs corrugated	polyethylene	nonwoven	heat set
Cordrain	Burcan Mfgr. Co.	2.5 and 5.0	waffle	polystyrene	nonwoven	heat set
Enkadrain	Enka Corp.	1.0 and 2.0	wire web	nylon	nonwoven	needled
Filtram	ICI Fibres, Ltd.	0.5	0.75 cm grid	polypropylene	nonwoven	heat set
Geotech Drainage Panel	Geotech Systems Corp.	5.0	spheres with bitumen binder	0.7 mm dia. expanded polystyrene	nonwoven	needled
Hydraway	Monsanto Corp.	2.8	7 mm columns at 2.0 cm centers	polyethylene	nonwoven	needled
Miradrain 4000	Mirafi, Inc.	2.5	waffle	polystyrene	nonwoven	heat set or needled
Permadrain	NW Fabrics, Inc.	2.0	waffle	polyethylene	nonwoven	needled

MECHANICAL BEHAVIOR OF THE CORE

Two types of tests have been performed to evaluate mechanical behavior of the various cores listed in Table 2. The first is a quasi-static stress versus strain test and the second is a long term creep test.

Concerning the stress versus strain behavior, most of the materials listed in Table 2 have been evaluated. Figure 2 shows this response where vast differences can be seen. For high deformation cores (as indicated by high strain levels), the implication is that reduced flow rates can be anticipated at high normal stresses. This feature will be evaluated later in the paper. For cores which indicate a well defined yield stress, the designer must be conscious of the applied stresses in the field and design with a sufficiently high factor of safety. For cores that are both stiff and beyond the pressure limit evaluated, the decision becomes one of flow rate capability, product availability and cost.

Long term creep tests were also performed on most of the cores listed in Table 2. The deformation versus time response curves (4) reflected both the core material and its configuration. Analysis of the data was done in a manner compatible with Mitchell's three element creep model (5). This analysis resulted in the parameters listed in the data of Table 3. These values can be used in the following equation to predict strain rates at any future time. As with the short term strain data of Figure 2, the implication is that long term deformation of the core reduces its flow capability. The next section evaluates this flow behavior.

$$\dot{\varepsilon} = A \frac{e^{\alpha D}}{t^m} \qquad (1)$$

where

$\dot{\varepsilon}$ = strain rate
D = stress level
t = time
A,m,α = creep constants (see Table 3)

HYDRAULIC BEHAVIOR OF THE CORE

In order to experimentally evaluate the hydraulic characteristics of high drainage composite cores, the test device shown in Figure 3 was developed. The device has the capability of handling up to 380 ℓ/min (100 gal/min) flow rate; hydraulic gradients from 0.06 to 2.0; applied pressures up to 210 kPa (30 lb/in^2) for indefinitely long time periods and does so with a relatively large specimen size measuring 30 cm x 45 cm (12" x 18"). This latter point is felt to be quite important because the flow regime through the various cores is very complex and deviations from full scale situations must be kept to a minimum. With a large test specimen scale effects are avoided as much as possible.

Table 3 - Values of Creep Constants for Cores of Various Drainage Geocomposites

Drainage Geocomposite	A m/m-min.	m dimensionless	α kPa^{-1}	 psi^{-1}
Amerdrain II	0.0010	1.20	-0.30	-0.044
Enkadrain	0.020	0.79	-0.26	-0.038
Filtram	*	*	*	*
Geotech	0.0330	0.82	-0.32	-0.046
Hydraway	0.0048	1.17	-0.32	-0.047
Miradrain4000	0.0003	1.17	0.096	0.014

*not creep sensitive

As seen in Figure 3, the core is fitted to two plastic containers (the water inlet and outlet respectively) and laterally sheathed with a thin rubber membrane to prevent leaks. This assembly is then placed in a metal frame and backfilled with soil, above which is placed an air activated rubber bladder of the same size as the test specimen. When the metal cover plate is fastened over the bladder, air pressure is applied to the desired magnitude. Water is introduced at a constant head (from which the hydraulic gradient is calculated) and flow collected per unit time. Air pressure is incrementally increased and the process is repeated up to the desired level or to the level of core breakdown stress. It is interesting to observe the large amount of flow occurring in the last photograph of Figure 3.

Shown in Figure 4(a) are a series of flow rate curves at different hydraulic gradient values which were held under constant pressure of 69 kPa (10 lb/in^2) for 300 hours. The horizontal response indicates that no (or little) creep of the core and its geotextile filter occurred. From the end points of curves like these, a single design curve in Figure 5 can be drawn. Here a straight line behavior (on a log-log plot) is seen to occur. When the response of other pressures is added, the entire set of design curves results, which in this case is a series of parallel lines. Here one can readily determine the actual flow rate of the prefabricated drainage composite being tested for any particular hydraulic gradient and applied pressure. These types of curves are essential for proper design of prefabricated drainage systems. It must be emphasized, however, that these curves are very much product dependent insofar as flow capability is concerned. For a more compressible core material than the one illustrated, the curves would be separated further apart and might also be nonlinear.

In order to illustrate this point further Figure 6 has been generated which compares a number of the products listed in Table 2 at a hydraulic gradient of one. It is seen that differences in flow rates vary over five orders of magnitude. For comparison purposes the figure also includes two needle punched geotextiles and 30 cm (12") of sand of permeability 0.1 cm/sec (0.2 ft/min). In viewing these curves, the categories listed in Table 1 should now be reconsidered. Taking the flow rate categories a step further to include typical pressure ranges, Figure 7 results. This "design guide" can be used directly with the actual drainage response curves of Figure 6 to see which products fit for the various applications. Obviously, in making the final selection, cost and availability are important factors.

COMMENTS ON THE GEOTEXTILE FILTER

The geotextile filter on the upstream side of the core (i.e., facing the soil through which the water is flowing) is important. Note the differences between Figures 4(a), 4(b) and 4(c) which evaluate the same core material but with different geotextile filters (needled nonwoven, heatset nonwoven and monofilament woven, respectively). The flow rate is seen to be approximately equal for the nonwovens, but some 10-15% higher for the higher modulus (and undoubtedly more expensive) woven geotextile. Its design must consider the following points:

- It must be permeable enough to convey the water coming from the soil without building up excess pore water stress.
- It should also be permeable enough to fully utilize the flow rate capability of the core.
- It must retain the upstream soil and prevent soil piping so that the core does not transmit soil particles or become blocked.
- It must be non-clogging over the lifetime of the system.
- It must have sufficient strength so as not to fail between the asperities of the core material.
- It must be designed so as not to deform or creep into the core space thereby reducing its flow capability.
- It must have a durability compatible with the core material and the system it is to drain.

These points are felt to be reasonably within the state-of-the-art of filter and reinforcement design using geotextiels (6).

SUMMARY AND CONCLUSIONS

Prefabricated drainage composites, also called drainage geocomposites, are providing a much needed solution to a wide range of high volume drainage problems in geotechnical engineering. They are indeed welcomed and needed by the design engineer, the installation contractor and, ultimately, the owner of the facility. The problem insofar as design is concerned is that the required data base is not available for the many products that are, or are becoming, available. The experimental device presented in this paper is the type required for generation of this information. As seen in the product comparison curves of Figure 6, there is no such thing as "Product 'X', or equal" which can be written into a specification. A minimum flow rate at a stipulated hydraulic gradient and applied pressure is needed to write a specification. Figure 7 was offered to aid in these decisions.

While the drainage core was the focus of this paper, one should not lose sight of the role played by the geotextile. Its primary function is as a filter, but as a secondary function it must also be considered in reinforcement. That is, it cannot protrude (much less fail) between the flow channels of the core material. It is an important item in prefabricated drainage composite systems and cannot be overlooked.

ACKNOWLEDGEMENTS

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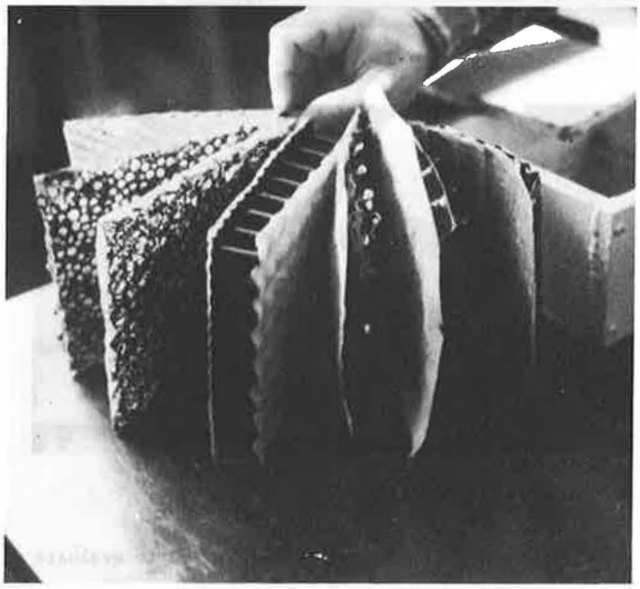

Fig. 1. - Various types of prefabricated drainage composites (or drainage geocomposites)

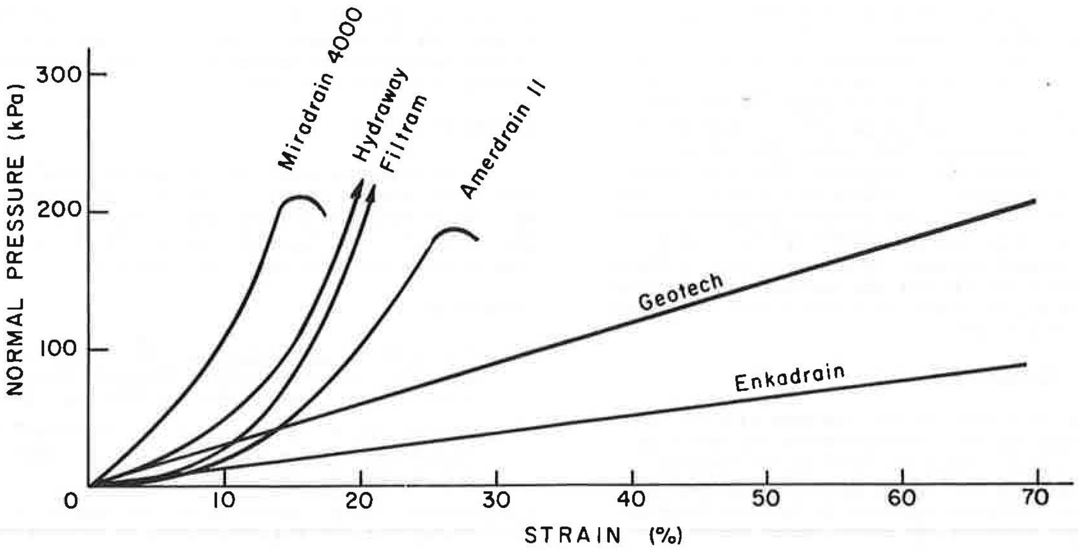

Fig. 2. - Stress versus strain behavior of various drainage geocomposites

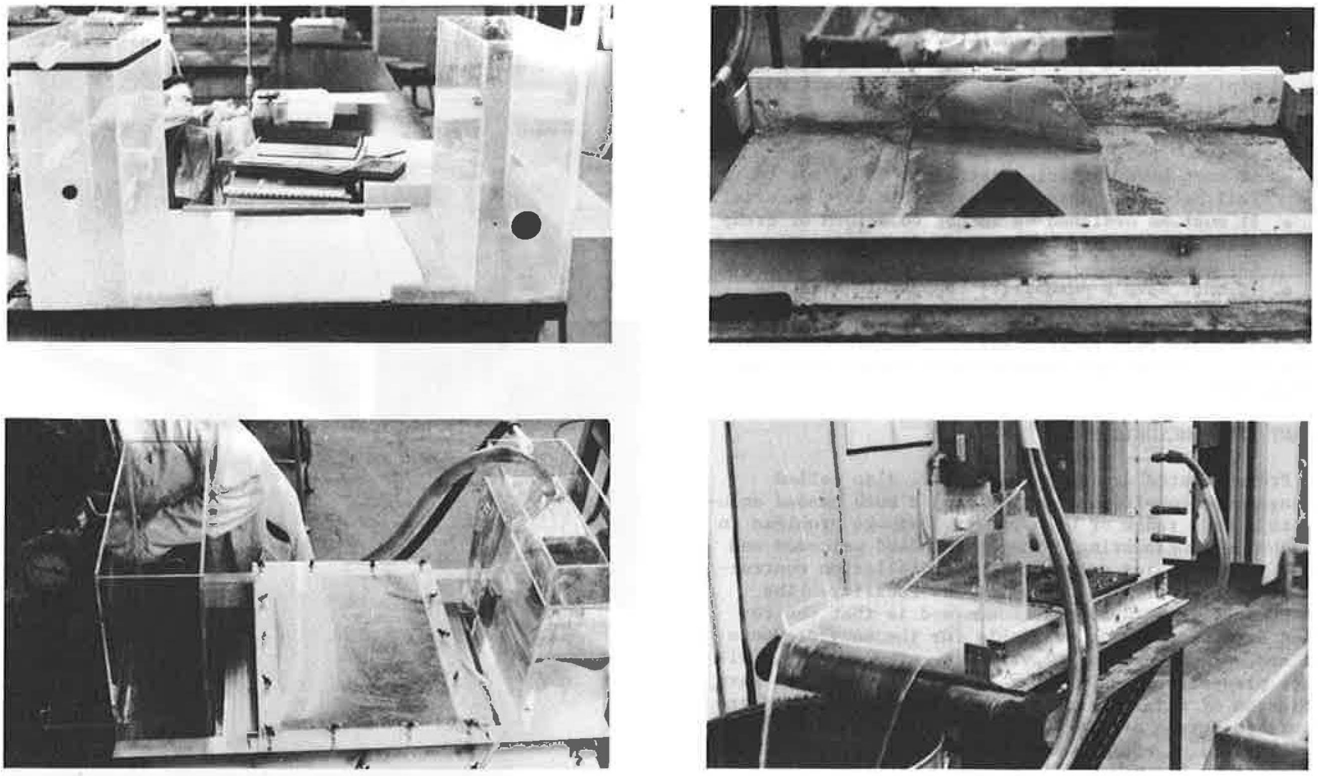

Fig. 3. - Test device to evaluate flow rate of prefabricated drainage composites

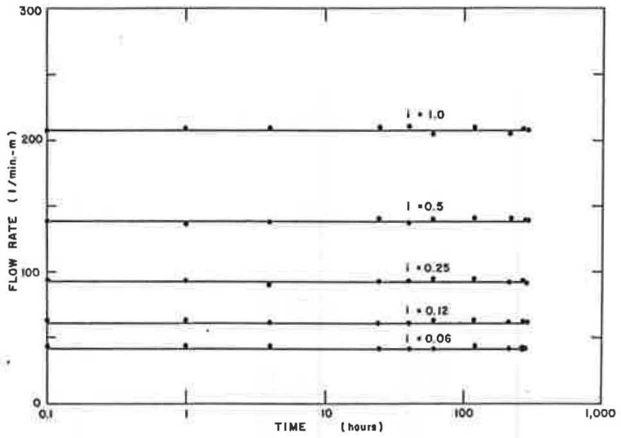

Fig. 4(a) - In-plane flow versus time response for Miradrain 4000 covered with a needled nonwoven geotextile filter tested at 69 kPa normal pressure

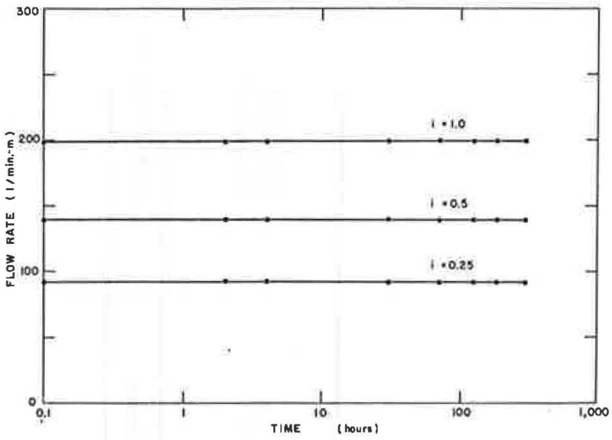

Fig. 4(b) - In-plane flow versus time response curves for Miradrain 4000 covered with a heatset nonwoven geotextile filter tested at 69 kPa normal pressure

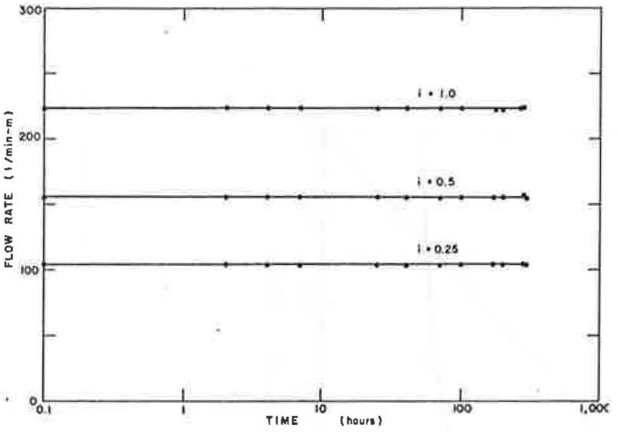

Fig. 4(c) - In-plane flow versus time response curves for Miradrain 4000 covered with a monofilament woven geotextile filter tested at 69 kPa normal pressure

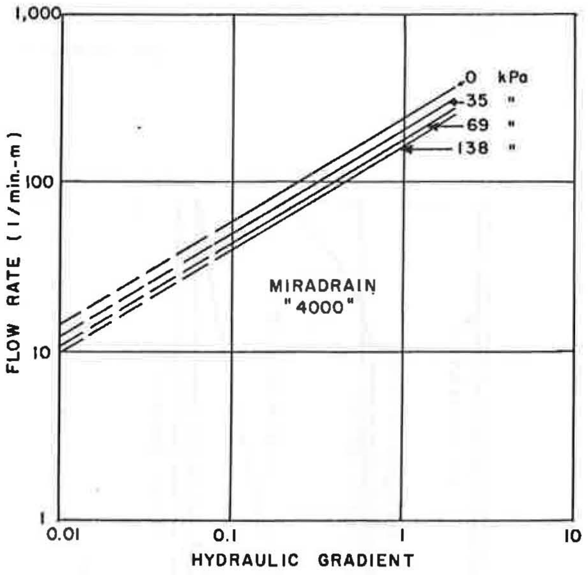

Fig. 5. - Flow rate behavior of Miradrain 4000 at various hydraulic gradients and applied pressures

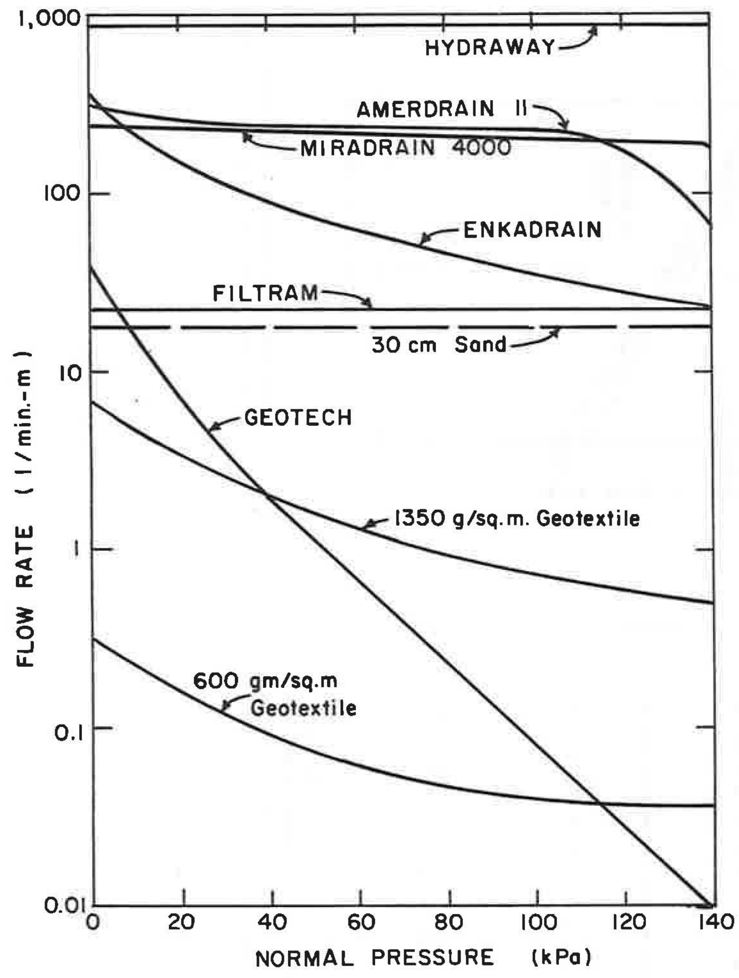

Fig. 6. - Flow rate capability of a number of drainage geocomposites at various applied pressures at a hydraulic gradient of one

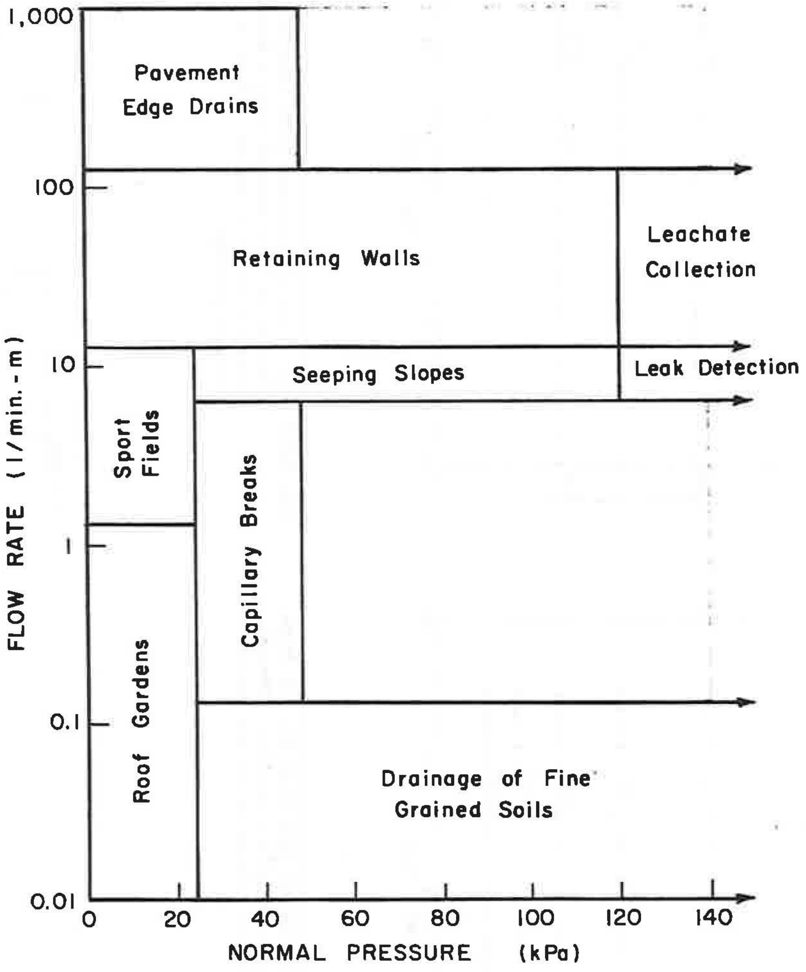

Fig. 7. - Approximate required flow rates and typical normal pressures for a number of common drainage application areas