Recent Developments in

Geotextile Filters and Prefabricated Drainage Geocomposites

Shobha K. Bhatia and L. David Suits, editors

ASTM STP 1281

STP 1281

Recent Developments in Geotextile Filters and Prefabricated Drainage Geocomposites

Shobha K. Bhatia and L. David Suits, Editors

ASTM Publication Code Number (PCN):
04-012810-38

ASTM
100 Barr Harbor Drive
West Conshohocken, PA 19428-2959
Printed in the U.S.A.

Library of Congress Cataloging-in-Publication Data

Recent developments in geotextile filters and prefabricated drainage geocomposites / Shobha K. Bhatia and L. David Suits, editors.
p. cm. -- (STP ; 1281)
"ASTM publication code number (PCN): 04-012810- ."
Contains papers presented at a symposium held in Denver, Colo. on 20 June 1995.
Includes bibliographical references.
ISBN 0-8031-2047-8
1. Geosynthetics. 2. Filters and filtration. 3. Drainage. 4. Road drainage. I. Bhatia, Shobha K. (Shobha Krishna), 1949- . II. Suits, L. David, 1945- . III. Series: ASTM special technical publication ; 1281.
TA455.G44R43 1996
624.1--dc20 96-14901
CIP

Peer Review Policy

Each paper published in this volume was evaluated by three peer reviewers. The authors addressed all of the reviewers' comments to the satisfaction of both the technical editor(s) and the ASTM Committee on Publications.

To make technical information available as quickly as possible, the peer-reviewed papers in this publication were prepared "camera-ready" as submitted by the authors.

The quality of the papers in this publication reflects not only the obvious efforts of the authors and the technical editor(s), but also the work of these peer reviewers. The ASTM Committee on Publications acknowledges with appreciation their dedication and contribution to time and effort on behalf of ASTM.

Printed in Philadelphia, PA
May 1996

Foreword

This publication, *Recent Developments in Geotextile Filters and Prefabricated Drainage Geocomposites,* contains papers presented at the symposium of the same name held in Denver, Colorado on 20 June 1995. The symposium was sponsored by ASTM Committee D-35 on Geosynthetics. Shobha K. Bhatia of Syracuse University in Syracuse, New York and L. David Suits of the New York State Department of Transportation in Albany, New York presided as symposium chairmen and are editors of the resulting publication.

Overview

Geosynthetics play a pivotal role in providing filtration and drainage in geotechnical engineering applications. Many woven and nonwoven geotextiles provide filtration, while nonwoven geotextiles, geonets, and prefabricated drainage composites provide drainage. The design of geotextile filters incorporates a balance between larger pore openings for adequate permeability of the geotextiles and smaller pore openings for proper soil retention by the geotextile.

Sharing of information on geotextile filters and prefabricated geocomposites was the purpose of the symposium. The three sections of this special technical publication (STP) focus on the topics of the papers presented at the symposium. The sections are: Pore Size Characterization and Permeability, Applications, and Case Histories. A brief summary of the main points of the papers in each section follows.

In the section on Pore Size Characterization and Permeability, the authors discuss various techniques for the characterization of the pore opening size and distribution for various geotextiles. While several methods are presented, there appears not to be a clear cut conclusion as to which method provides the "true" pore size characterization across the board.

The effectiveness of a geotextile filter is a function of the granularity of the soil being protected by the filter, hydraulic conditions, and the geometry of the pore network or pore size distribution of the geotextile filter. However, the influence of the pore size distribution of the geotextile on the soil/geotextile filtration behavior is not fully understood.

Procedures for determining the largest pore opening size are well established, yet still under debate. Numerous design criteria continue to use the largest opening size (O_{95} or O_{90}) despite observations by many researchers that the largest opening size is not indicative of the filtration phenomena of soil/geotextile systems. These observations are based on the amount of soil passing and the clogging of the geotextile. The continued use of the largest opening size in the design criteria has been justified by the fact that no reasonable and reliable technique exists that can be used to evaluate complete pore size distribution.

While this justification was valid 15 years ago, significant advances in attaining the pore size distribution of a geotextile have been made over that time period. Depending on the test method used, four different categories of pore sizes and distributions can be obtained. It is important to note that each method provides pore sizes and distributions that are not necessarily a unique property of the geotextile, but rather the method of measurement. Therefore, it is critical to select a method that represents the pore sizes of geotextiles as related to filtration behavior.

The various methods discussed in the papers in this section can be grouped into three categories: sieving pore size, numerical pore size, and volumetric pore size. The sieving pore size is based on the probability of a particle of a certain diameter passing through an opening during a certain duration of shaking (in either the wet or dry condition) or cycles of immersion. The dry, wet, and hydrodynamic sieving methods are the established methods that were designed to determine the largest opening size of the geotextile. One paper presented in this section compared the dry, wet, and hydrodynamic sieving test results.

Several European countries participated in this study. The study resulted in the wet sieving method being recommended as the European standard. It was pointed out in other papers that pore sizes obtained from sieving methods depend on the pore channel constriction size. However, there is not a clear understanding of this fact. In addition, sieving methods cannot provide the geotextile pore size distribution.

Numerical pore size methods are based on counting the number of pores and sizes of pore constrictions in a geotextile. The methods that fall into this category are image analysis and the minimum bubble pressure technique. Two papers included in this section used the image analysis technique to measure the pore size distribution of nonwoven geotextiles. Image analysis results presented in one of the papers indicate that the thickness of the geotextile has an insignificant influence on the pore size distribution of geotextiles from the same manufacturer. In this paper the authors also found that the O_{95} values from the image analysis were much higher than the results of wet or hydrodynamic sieving. The authors did point out that such a comparison has no logic since sieving results are influenced by surface porosity, thickness, and other structural properties of the geotextile; whereas the image analysis results are a function of pore spaces and pore volume in the geotextile. In the second paper referred to above, the authors evaluated the pore size distribution of nonwoven geotextiles under different compressive pressures using the image analysis technique. They observed a trend of decreasing pore size distribution with increasing compressive pressures.

Several authors found the image analysis technique to be difficult and expensive to perform. It was pointed out that this method can only measure a pore size at a particular location within the pore channel, and therefore does not take into account the shape of the pore channel and porosity.

Volumetric pore size methods are based on the percentage of total pore volume occupied by each pore size. These methods provide no information regarding the number of pores and pore constrictions. Papers presented on this topic discussed two different methods. They were the mercury intrusion method and the capillary flow porometry method. In mercury intrusion, mercury is intruded into the geotextile from all sides; whereas the capillary flow method, also called bubble point method, air and non-wetting liquid are extruded, one-way, through the geotextile by creating a pressure gradient across the thickness of the geotextile. Thus, one method is an intrusion method, and the other is an extrusion method. In the mercury intrusion test, all free volume is measured, but not the volume specifically available for flow. In the capillary flow method, a modified porosity is obtained because of the one-way flow of liquid out of the geotextile. Thus the voids associated with flow through the geotextile are measured, In this paper, the authors described in detail the differences between the mercury intrusion and capillary flow methods. They concluded that the mercury intrusion method probably provides the largest pore size distribution because of its multidirectional intrusion procedure, while the capillary flow method gives the smaller pore size distribution because it measures constriction size. This conclusion can be verified by comparative results by other investigators, such as work done at Syracuse University.

Pore size distribution results using the bubble point technique were presented for several nonwoven geotextiles in one paper. It was pointed out that the measured opening sizes (O_{95} and O_{50}) were significantly influenced by the pressure supply. The measured opening sizes increased with increasing pressure supply, thus indicating the measured pore openings are a function of the testing procedure.

In general, a consensus exists that the capillary flow porometry method is a simple and rapid method for the measurement of the pore size distribution of geotextiles. Further, it was pointed out that the volumetric distribution obtained from this method is more meaningful because it allows an evaluation of the pore constriction size distribution. It was also pointed out that the size of the pore constrictions that determines whether a soil particle will pass through the geotextile. It should be pointed out that capillary flow porometry is not free from limitations, and additional work is needed before these limitations are removed. In addition, unless it is shown that a complete pore size distribution of geotextiles is critical in retention and clogging performance, designers will continue to use the largest pore openings measured from sieving methods.

Papers presented in the Applications section present reviews of current geotextile filter design methods. Included in the papers are suggested improvements to existing design methods. These include the proposal of a new test, modification of the current gradient ratio test, and a proposed empirical approach to the design process.

Presented in one paper is an empirical method of computing the gradient ratio of a soil/geotextile system. Basis for the method is the opening size distribution of the geotextile and particle size distribution and Atterburg limits of the soil. Hydrodynamic sieving and image analysis established the opening size distribution. Results of long-term gradient ratio tests were used in developing the empirical relationships for the proposed technique. Testing and analysis has not been completed. However, preliminary results show a moderate to high degree of association between the proposed empirical approach and the long-term gradient ratio compatibility tests run.

In another paper, a modified gradient ratio test is presented. The paper reports that limitations in the current test method and device hinder the test being used to its fullest potential. These limitations result in an incomplete representation of the conditions existing in the field following installation of the geotextile. Objectives of the proposed modifications include: testing at targeted normal stresses, more control of the flow regime, and better monitoring of any piping that may take place during test preparation and performance. Results of preliminary testing done at the University of British Columbia show that normal stress has an insignificant influence and that most soil particles pass during sample preparation. The latter has important implications when interpreting piping failures in soil/geotextile systems.

As part of a National Cooperative Highway Research Program (NHCRP) project, exhumation of geotextiles or geocomposite drains from 91 sites throughout the United States took place. The findings of this study resulted in a critique of the various geotextile filter design methods currently in use. Results of the study are presented in the Case History section. An analysis is made here as to the relationship the findings have to the various design guidelines. The results of the study show the current Federal Highway Administration (FHwA) guidelines for filter design to be suitable. However, the authors do recommend the use of either a proposed long-term flow test or the hydraulic conductivity test rather than the gradient ratio test.

Papers presented in the Case History section describe the performance of geotextiles in highway, landfill, and building foundation drainage installations. The papers detail design procedures followed in the projects reported on. Recommendations for improved design procedures resulted from the various studies.

The three-year NCHRP project referred to previously consisted of exhuming samples from various types of geosynthetic drainage systems on 91 different field sites in 17 different states throughout the United States. Sites included drainage systems of prefabricated geocomposite underdrains, geotextile wrapped underdrains, perforated pipe underdrains, and geotextile socked perforated pipe. There were some geotextile wall drains and geotextile erosion control filters exhumed also. The age of the sites ranged from less than two to sixteen years old. Materials exhumed at each site were examined and tested in the laboratory to evaluate their condition and performance. The basic conclusion reached from the study was that there needs to be more attention paid to installation and maintenance techniques for each system.

A study of the performance of a geotextile filter in a landfill system in New York City evaluated the impacts of burial and filtration of leachate on the hydraulic and mechanical properties of the geotextile. Evaluation of the weight, grab strength, elongation, and permittivity of the exhumed samples of the geotextile provided the basis for the study. Microscopic evaluation of samples helped to decide the extent of clogging occurring in the geotextile. The investigation showed approximately an order of magnitude decrease in permittivity. This, however, was not detrimental to the performance of the filter. Results of the other index property tests showed them to be very similar to the initial values for the material. The observations also showed no biological clogging.

Performance of a pressure relief system using a geotextile, geonet, and geogrid in constructing a combination office building apartment complex in Taipei, Taiwan showed it to be a cost-effective solution to hydrostatic uplift pressure problems. Design of the system had to meet filtration and drainage criteria that would allow transfer of water, retention of soil, and free movement of water under the foundation load. Monitoring of the site showed significant differences in pore pressure dissipation in the areas where the system was installed versus the areas where there was no system. The results of the field monitoring were in reasonable agreement with expected values.

Geotextiles used in the drainage and filtration applications in highways are subjected to cyclic loading. In fine grade soils, this results in fines being pumped into the geotextiles. Dynamic consolidation testing done at Ecole Polytechnique in Montreal, Canada, simulated the action of the pumping loads experienced in the field. The entrapment of soil particles in the geotextiles reduced the porosity. However, it was felt that there was no significant effect on the permeability of the material. The filtration opening size of the geotextile O_{95} as determined by hydrodynamic sieving, is an adequate indicator of the geotextile's soil retention potential under dynamic loads.

A research contract between the Ministry of Transportation (MTO), Ontario, and Queen's University resulted in revised pavement edge-drain design techniques for the MTO. Four types of edge drains were evaluated. They included a geotextile sock-wrapped pipe with clay subgrade, a geocomposite edge drain with clay subgrade, a geotextile-wrapped open-graded aggregate drain with a clayey gravel subgrade, and geocomposite edge drain with a sand subgrade. The revised design includes placing the edge drain beneath the pavement rather than beyond the pavement edge. The author's also recommend that the drainage conduit be placed either on the shoulder side or center of the excavated trench. The trench should then be backfilled with clean sand. These last two findings agree with similar research conducted in the United States.

In the past 15 years, significant progress has been made in the understanding of filtration and drainage behavior of geosynthetics such as nonwoven geotextiles and prefabricated drainage composites. It is recognized that pore size characterization of nonwoven geotextiles is important for their filtration performance. Significant effort has been focused on attaining pore size distribution of nonwoven geotextiles. In general, a consensus exists that the capillary flow porometry is the best method among available methods. However, this method needs further modification before it can become a standard for evaluating pore size distribution.

This overview presents a brief review of the papers presented in this STP. The papers include case histories of field experience of the performance of drainage geosynthetics, along with papers on laboratory and theoretical research carried out in an effort to better understand and characterize their performance. Recommendations are made for improved design procedures and improved installation techniques. While there is still much work to be done in understanding the filtration process, it is felt that these recommendations will help ensure the desired performance of drainage geosynthetics.

L. David Suits
New York State
Department of Transportation
Albany, New York; symposium chairman and editor.

Contents

Pore Size Characterization and Permeability

Gregory R. Fischer,[1] Robert D. Holtz,[2] and Barry R. Christopher[3]

EVALUATING GEOTEXTILE PORE STRUCTURE

REFERENCE: Fischer, G. R., Holtz, R. D., and Christopher, B. R., "**Characteristics of Geotextile Pore Structure,**" Recent Developments in Geotextile Filters and Prefabricated Drainage Geocomposites, ASTM STP 1281, Shobha K. Bhatia and L. David Suits, Eds., American Society for Testing and Materials, 1996.

ABSTRACT: There are many test methods available to determine the pore sizes of geotextile filters. Often overlooked is the fact that each method provides a different interpretation of a geotextile's pore structure. A survey of the available test methods, indicates that four categories of pores can be measured. Pore characteristics are identified by one of the following methodologies: sieving, theoretical, volumetric, and numerical. A critical review of the data produced by these methods shows that the actual pore structure as related to flow-through behavior can only be determined by the bubble point method, which provides a volumetric pore size. This test identifies the constriction size of each pore channel in a geotextile, where retention and clogging are most critical. The bubble point test method is advantageous because it provides for the complete pore size distribution of the geotextile, can be performed more efficiently than sieving methods, and provides an accurate estimate of the permeability of the geotextile.

KEYWORDS: bubble point, clogging, drainage, filter, geotextile, permeability, pore sizes, pore size distribution, retention

INTRODUCTION

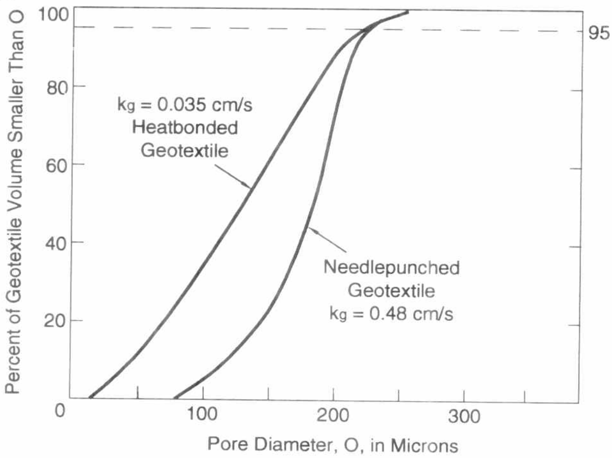
Most geotextile filter design methods, especially for soil retention, are based on relationships developed between the pore size(s) of the geotextile and grain size(s) of the soil. Although these design methods generally have been satisfactory, they are based on only a characteristic larger end pore size of the geotextile. A more complete description of the pore structure may lead to an improved filter design. In the United States, designers typically use the apparent opening size (AOS) as this characteristic pore size. The AOS is evaluated by dry sieving glass beads and the test to determine its value has been standardized as ASTM Standard Test Method for Determining Apparent Opening Size of a Geotextile (D 4751).

[1]Principal Engineer, Shannon & Wilson, Inc., 400 N. 34th Street, Suite 100, Seattle, WA 98103.

[2]Professor, Department of Civil Engineering, University of Washington, Seattle, WA 98195.

[3]Consultant, 210 Boxelder Lane, Roswell, GA 30076.

The AOS is a practical measure of the near-largest apparent pore diameter in the geotextile. Using terminology similar to grain size distributions, it is commonly expressed as O_{95} (based on retaining 95 percent of a given size bead). Other design methods have used different characteristic pore sizes, such as O_{90}, O_{98}, $O_{90,w}$, O_f or filtration opening size (FOS), based on similar principles of a near-largest pore size; however, different laboratory methods are used to obtain each of these characteristic pore sizes. Although some researchers have advocated smaller pore sizes for design, as shown in Christopher and Fischer (1992), in the past it has been difficult to accurately and repeatedly measure smaller pore sizes of geotextiles. Unfortunately, this difficulty in no way precludes the importance of these smaller pore sizes. For example, Fig. 1 shows pore size distributions (PSDs) for two geotextiles. Although the O_{95} pore sizes are similar, the different PSDs influenced their permeability and may influence their filtration characteristics. Also, performance tests (e.g., Table 1) have found that geotextiles with similar FOS values may experience different degrees of clogging and quantities of soil piping, suggesting the dependence on total geotextile pore structure and not just a single, large pore size.



Note: Pore size distributions obtained by mercury intrusion porosimetry.

FIG. 1--PSDs and permeability measurements for two different geotextiles with similar O_{95} pore sizes (after Prapaharan et al., 1989).

TABLE 1--Filtration behavior of similar FOS geotextiles (after Bhatia et al., 1991).

Geotextile Identification	FOS (mm)	ψ (sec^{-1})	k_g (cm/s)	Pore Volume Clogged (%)	Soil Piped (g/cm^2)
C	0.103	1.40	0.39	0 - 80	0.05
F	0.105	1.97	0.20	30	0.03 - 0.10
K	0.110	0.80	0.03	5	0.20 - 0.27
N	0.105	1.33	0.38	25	0.05

To obtain the smaller pore sizes, which, as suggested previously, most likely influence filtration behavior, the complete PSD of a geotextile is required. In the last 15 years, significant effort has been focused on attaining the PSDs of geotextiles for filtration design (Wates, 1980; Wates and Wittstock, 1986; Miller et al., 1986; Fischer et al., 1990; Prapaharan et al., 1989; Elsharief, 1992; Miller and Tyomkin, 1994; Bhatia and Smith, 1994; and Fischer, 1994). The following sections discuss these methods and their meaning in terms of geotextile filter design.

PORE SIZE DETERMINATION

Whether a single pore size or PSD is used in design, the method of finding this size or distribution is critical. Many methods have been used for pore size determinations. Table 2 summarizes the significant features of each of the methods used to determine pore sizes, and includes the type of pore measured by each technique.

TABLE 2--Significant features of different pore size measurement methods (after Fischer, 1994).

Test	Relative Sample Size	Finer Pore Sizes Measured	Type of Pore Measured	Provide PSD for Compressed Geotextile	Relative Time of Test	Relative Cost
Dry sieving	Large	No	Index of pore size	No	Slow	Low
Wet sieving	Large	No	Index of pore size	No	Slow	Low
Hydrodynamic sieving	Large	No	Index of pore size	Yes	Slow	High
Suction	Large	Yes	Pore volume	Yes	Rapid	Moderate
MIP	Small	Yes	Pore volume	Yes	Rapid	Moderate
Liquid extrusion porosimetry	Small	Yes	Pore Volume	Yes	Rapid	High
Bubble point	Small	Yes	Area of pore constrictions	Yes	Rapid	Moderate
Minimum bubble pressure technique	Small	No	Number of pore constrictions	No	Slow	High
Image analysis	Small	Yes	Pore dimension	Yes	Slow	High
Theoretical	N/A	Yes	Pore dimension	Yes	Rapid	Moderate

Notes: N/A - not applicable.

As shown in Table 2, the available methods include dry sieving with soil (the Belgium and United Kingdom standard) or glass beads (ASTM D 4751), wet sieving (the Swiss and German standard), hydrodynamic sieving (the

Canadian, French and Italian method), the suction method (Dennis and Davies, 1984), mercury intrusion porosimetry [MIP] (Prapaharan et al., 1989, and Elsharief, 1992), capillary liquid extrusion porosimetry (Miller and Tyomkin, 1994), the bubble point method (Bhatia and Smith, 1994, and Fischer, 1994), the minimum bubble pressure technique (Miller et al., 1986), and image analysis (Wates, 1980; Rollin et al., 1982; Prapaharan et al., 1989; and Elsharief, 1992). In addition, theoretical modeling has been proposed as an alternative method to determine geotextile pore sizes (Masounave et al., 1980, and Faure et al., 1986 and 1990). The advantages and disadvantages of these methods have been previously mentioned (Wates, 1980; Miller et al., 1986; Faure et al., 1986; Dierickx and van der Sluys, 1990; Gourc and Faure, 1992; and Fischer, 1994). A thorough discussion of each of the above methods is provided in Fischer (1994).

CRITICAL REVIEW OF PORE MEASUREMENT METHODS

General

As shown in Table 2, there are 10 methods available to determine the pore sizes of geotextiles. Many of these methods are used in different geotextile filter design criteria. Unfortunately, there is inadequate understanding and interpretation of the data obtained from all these tests. Most designers assume that the PSD of a geotextile is a unique property of that geotextile, similar to the grain size distribution of a soil. As such, when designing for filtration applications, attention is given to the value of the pore size(s) of interest without regard to the method used to obtain this size or distribution. This results in filter design criteria and pore size data being randomly interchanged without matching the design criteria to the pore data. After evaluation of each test procedure and the resulting pore data obtained (Table 2, Column 4), it can be seen that each method provides pore sizes and distributions that are not necessarily a unique property of the geotextile, but instead depend on the method of measurement. This is a critical difference that is often overlooked when designing geosynthetic filters.

Pore Structure Terminology

So far the term "pore size" has been used generically to represent the void space between geotextile fibers; however, as shown in Table 2, the available test methods measure different parts of a void. Thus, it is important to define the terminology that represents the void space between geotextile fibers (Fig. 2).

The word "pore" is a generic term that has several meanings. By definition, a void is an opening between geotextile fibers. A pore channel is a continuous void through the geotextile, the path in which water or matter would follow in moving from one side of the geotextile to the other. A pore, then, is the size of the void at any location along this channel. As shown in Fig. 2, pores of various sizes make up one pore channel. Where the pore channel is constricted at its minimum opening the term "pore channel constriction" is defined (Kenney et al., 1985, and Gourc and Faure, 1992). Thus, the pore channel constriction (or pore constriction) is simply one pore along the channel. Pore space that is not involved in any pore channel is referred to as a dead-end pore.

In developing the concept of pore constriction, it is suggested that the shape of the pore channel will not influence filtration behavior, except where that channel has its least dimension (Kenney et al., 1985). Soil particles will either be retained or passed at this location. If the constriction is smaller than the equivalent particle diameter of interest, the particle will not pass and will either not enter the pore channel or become lodged in the geotextile at or some