A Method of Measuring Pore Size in Nonwoven Needle Geotextiles

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ABSTRACT: At present, there are various methods of determining the pore size distribution of needled nonwoven geofabrics. None of them has allowed for the features that the needled nonwoven geofabrics are thin stereo netted geotextiles with high porosity. Pores run multidirectional and are irregular in forms. The method introduced in this paper can meet these features better. Some new results obtained and analysed are reported. It provides a new laboratory test method for further improvement of filtration design criteria.

1. INTRODUCTION

The quantities of needled nonwoven geofabrics used in civil engineering form a fairly high percentage among the geotextile materials. They are mainly used in filtration and drainage engineering. At present, most of the existing filtration criteria with needled nonwoven geofabrics are basically extended from the filtration theory based on spherical-shaped grained materials, in which the porosity of the needled nonwoven geofabrics is a key parameter. These are discussed in detail in the "Second Chinese conference on geosynthetics" and "The fourth international conference on geotextile, geofilm, and related products". At present, the porosity feature is denoted by the opening size O, corresponding to a cumulative frequency on the pore size distribution curve.

The equivalent opening size Eos corresponds to the surface opening that is the maximum size of grains that can go through the geofabrics. The effective opening size Oe refers to the typical opening size for which the geofabrics can keep the most part of the material staying on it. From these definitions, to define the porosity features, one should, in the first stage, use a method to measure the various sizes of the openings, calculate the frequencies, and plot the opening size distribution curves. In the second stage, measure the various grain sizes for the selected standard materials and the cumulative frequencies, plot the grain size distribution curves, and divide them into some grain size groups. In the third stage, with a number of geofabric samples, use the standard grain material in certain range of grain groups for testing. If most grains of one group do not pass through the geofabrics (90%-98% of mass) then Oe can be represented by the grain size of this grain group which equals the opening size distribution curve of the geofabrics (its cumulative frequency is also about 90%- 98%). Also, the maximum size of the standard material (or the average size of certain grain group) which can get through the geofabrics can be taken for Eos that equals the opening size of certain cumulative frequency on the opening size distribution curve. Oe or Eos of nonwoven needle geofabrics is the data commonly used in filtration design.

For determination of opening size distribution curve and Oe or Eos of the geofabrics, there are direct and indirect methods. At present, the main method used is vibrational dry sieving method. It is the method of using a standard grain material, and testing the easiness of getting through the geofabrics. Because all the grains of same size cannot get through the geofabrics, some of them stay on or in the geofabrics.

The existing commonly used filtration design criteria of nonwoven needle geofabrics have some drawbacks. For example, some kinds of needled nonwoven geofabrics which do not meet these criteria work well in filtration, no matter in the laboratory experiments or in field projects (Cao & Wang, 1990; Xu & Wang, 1992).

The opening size distribution curve of nonwoven needle geofabrics and the selection of their porosity features are very important in the establishment of the filtration design criterion, because in the opening of the needled nonwoven geofabrics are surrounded by fibres of irregular shape and the pore channels spread in various directions and geometries as shown in Photo 1. In addition, the effect of static electrical attraction, etc. during the test should also be considered. Therefore the direct or indirect methods which assume that the pores of the geofabrics are isolated from each other, and

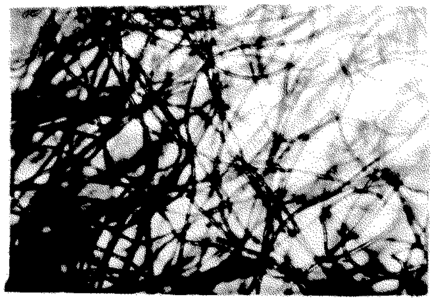

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Photo 1 Geofabric

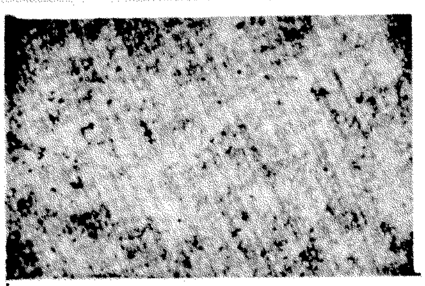

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Photo 2 Geofabric

the channels of the pores are straightforward from top to bottom are not suitable for measuring the opening size (denoted by equivalent size). Specially, the sieving method using standard grain material to determine the opening size distribution curves and Oe or Eos has serious weakness. For the reasons, image processing techniques is examined for measuring the porosity features. In the system a light beam irradiates the geofabrics on the under-side, and a microscope with an attached camera takes the image on the other side which is formed by parts of the light beam transmitted through the openings of the geofabrics. The microscope is needed to amplify the opening image. The image signal is coded by an A/D converter and fed into a micro-computer for analysis. The typical image is shown in Photo 2. The small light spots are the needle openings. It can be seen that the size and the density of the opening relate to the transparency of the geofabrics. Besides, the thickness of the geofabrics would be nonuniform, because the geofabrics is squeezed or stretched during the laying process. In the high density area, the spots connect each other forming a large bright area.

Image processing has been successfully used in various areas, but application to testing of needled nonwoven geofabrics is rare. We use the sample geofabrics only 10x10 cm in size. The image size is even smaller. Because the image processing is fast and reliable, we can take a number of images on one sample, and use a number of samples for the test. The computer calculates the statistical data of the geofabrics, and prints them out in a relatively short time. The test results are more rapidly available than other methods. It is also non-destructive and non-contaminative. The geofabrics sample can be used for other measurements that makes the test results more uniform. Moreover, vertical and horizontal forces can be exerted on the samples to understand its influence on the size of opening areas. The comparison with the other methods will be made later.

2. OPERATION PRINCIPLE

The image processing procedure of pores of the needled nonwoven geofabrics is shown in Fig. 1. The light reflected from the mirror irradiates the geofabrics through the openings forming a spotted image captured by the camera. The image signal then is fed to the computer through an image interface and displayed on the screen. The image processing program does statistical analysis about the spots in the screen window, such as the number of spots, the average spot area, the distribution of the spot areas, etc. Because of the limited vision of the camera, one can do the same test many times on different areas of the geofabric sample. Then the results can be averaged for higher accuracy. The results can then be displayed or printed out.

In the image processing, the threshold techniques is used to sharpen the blurred boundaries caused by fibre structure. Ten threshold levels are selected with a pair of suitable minimum and maximum thresholds, as shown in Fig. 2, which is expressed in one dimension. The upper and lower bounds of thresholds should keep unchanged during testing different geofabric samples for comparison.

The magnification of the microscope is 8x5.3 mm. The image resolution is 512x512 pixels. So, the corresponding area of a pixel is 1.61743x10 mm. and the equivalent diameter is 0.01435 mm. It is 4.181 times smaller than the smallest sand grain which is 0.06 mm. It is convenient to calculate the area using the number of pixels.

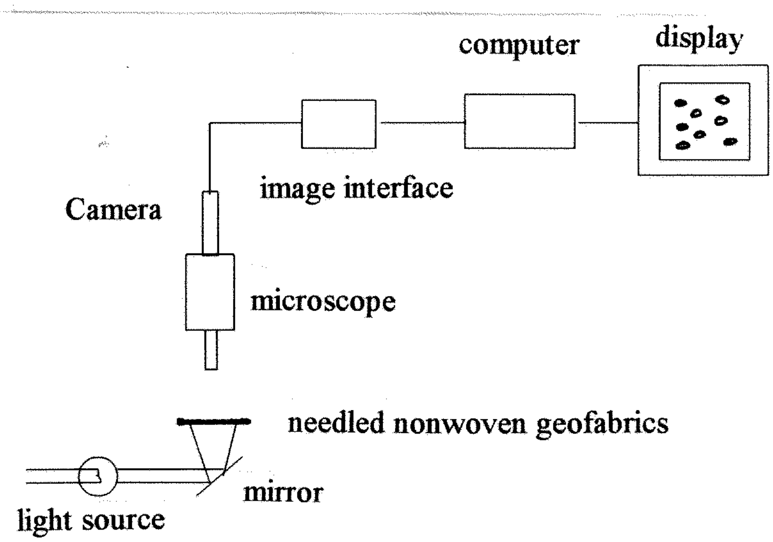

Fig. 1 Operation Principle

3. RESULT OF ANALYSIS

A series of tests was carried out for different needling times, different vertical forces and geofabrics of different specifications, and analyzed the results. The photograph of the image within the window for a selected level of threshold is shown in Photo 3. In the following, we will introduce the results of analysis of the test with no vertical forces exerted for the commonly used (400 g/m^2) needled nonwoven

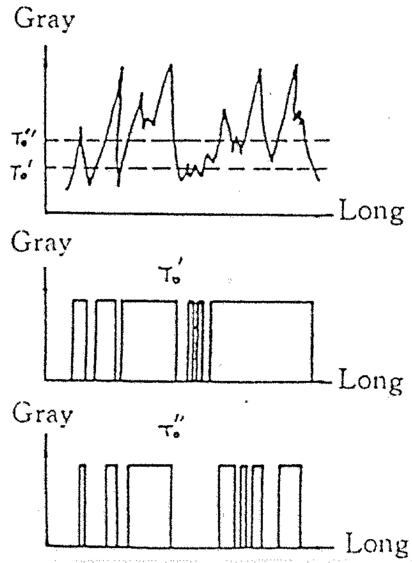

Fig. 2 The effect of lower threshold expressed in one dimension

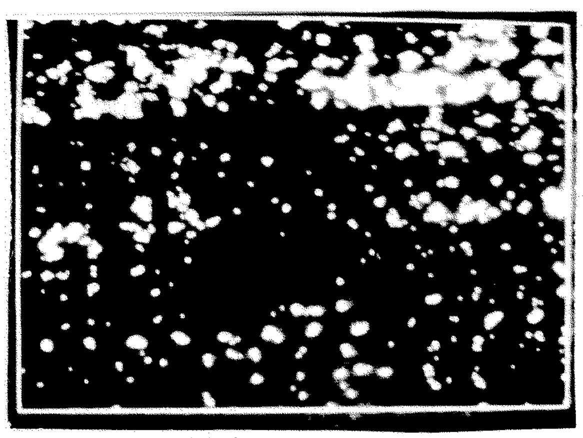

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Photo 3 Geofabric

geofabrics manufactured by three factories (labelled number 1, 2 and 3), and the needled nonwoven reinforced geofabrics (Labelled reinforced, Wang & Wang, 1993) with specification of 700 g/m^2. The results are shown in Tables 1 to 4 for the four kinds of geofabrics. The light transmitting rate as a function of threshold level is shown in Fig. 3. The threshold levels are divided into ten ranks. The transmittance is denoted by the ratio of the spots' area to the window area.

From Fig. 3, we see that the light transmitting rate of the geofabrics No. 3 attenuates rapidly with the increasing threshold level. This is because the colour of the geofabrics is dark blue. The light can only get straight through the needle openings. The influence of the threshold level on other areas is small. On the other side, the curves of geofabrics No. 1 and 2 basically coincide with each other. It is shown that for the geofabrics of same specifications, the opening size distributions are almost the same, even though they come from different factories. This also indicates that the discrepancy of this test method is small. But the reinforced geofabrics, because of its larger mass per unit area and the distribution of the light transmittance rate is relatively small, attenuates rapidly. This also reflects the penetration coefficient which is an order smaller.

The spot area at certain threshold and the percentage of the

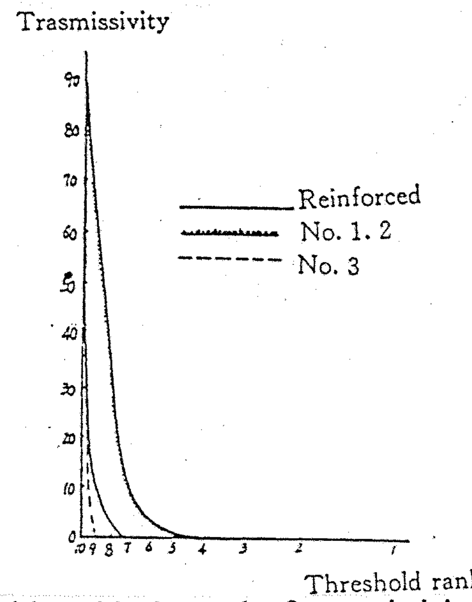

Fig. 3 Semi-logarithmic graph of transmissivity as a function of the threshold rand

area which is smaller than the previous one, is listed in table 5. In practice, the number of threshold levels we select in the test was far more than in the table in which we list some of them for explanation. The data listed is a good representation. The distribution curve of the spot area is shown in Fig. 4. If the opening size corresponding to 95% of Spot area is taken for the equivalent opening size of the geofabrics, the result for the reinforced geofabrics O_{95}=0.045 mm, for geofabrics of No. 1 O_{95}= 0.084 mm, and for No. 2 O_{95}= 0.077mm. This is very close to the result for dry sieving method, in which $O_{95,\ d}$<0.05 mm for the reinforced geofabrics, $O_{95,\ d}$= 0.90 mm for No. 1 and $O_{95,\ d}$=0.07 mm for No. 2. But the values of percentage is 5 percent different. This may relate to the static electrical effects and the blockage of part of grains in the pores of the fibres in dry sieving method. For geofabrics No. 3, the equivalent opening (size of the apparent maximum opening) is Omax = 0.175mm for the select threshold. This is a slightly bigger than O_{95}= 0.150 mm for dry sieving method.

From Fig. 4, we can also see that although the number of openings which size is bigger than 95% their areas are large

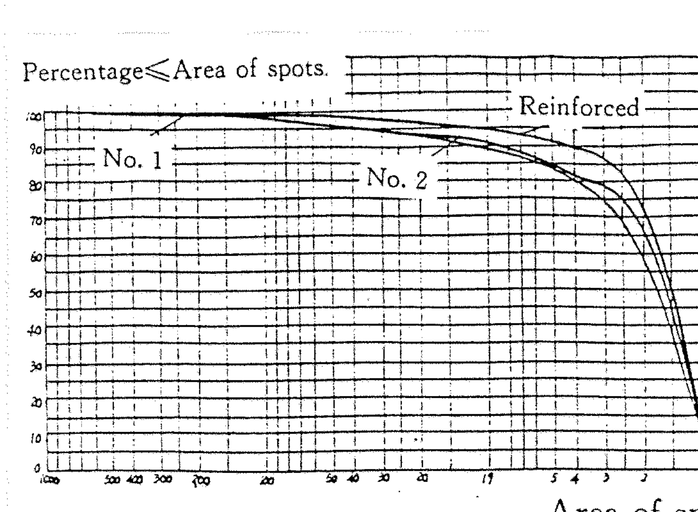

Fig. 4 The distribution curve of the spot area

Table 1: Reinforced

Rank	10	9	8	7	6	5	4	3	2	1
Sport number	672	266	85	31	10	6	2	1	1	1
Area of Spots	34098	1167	214	62	24	9	4	2	1	1
Area of Window	80571	80571	80571	80571	80571	80571	80571	80571	80571	80571
Transmissivity	42. 32044	8. 17167	1. 44841	0. 26560	0. 07695	0. 02979	0. 0117	0. 00497	0. 00248	0. 00124

Table 2: No. 1

Rank	10	9	8	7	6	5	4	3	2	1
Sport number	81	293	587	483	220	71	21	9	2	1
Area of Spots	52366	28523	13460	4377	1403	448	157	48	11	1
Area of Window	48471	48471	48471	48471	48471	48471	48471	48471	48471	48471
Transmissivity	87. 40484	58. 84550	27. 76918	9. 03014	3. 01830	0. 92426	0. 32391	0. 09903	0. 002269	0. 00206

Table 3: No. 2

Rank	10	9	8	7	6	5	4	3	2	1
Sport number	79	249	381	300	154	62	18	4	5	1
Area of Spots	41617	293364	15735	4705	1513	425	104	30	8	1
Area of Window	48471	48471	48471	48471	48471	48471	48471	48471	48471	48471
Transmissivity	85. 85959	60. 58055	32. 4672	9. 70684	3. 12145	0. 87681	0. 21456	4. 06189	0. 01650	0. 00206

Table 4: No. 3

Rank	10	9	8	7	6	5	4	3	2	1
Sport number	4	4	3	2	2	2	2	2	1	1
Area of Spots	44483	182	79	49	25	19	11	8	1	1
Area of Window	53001	53001	53001	53001	53001	53001	53001	53001	53001	53001
Transmissivity	83. 92001	0. 34339	0. 14905	0. 09245	0. 04717	0. 03585	0. 02075	0. 01509	0. 00189	0. 00189

Table 5: Statistics of spots

Reinforced	Area of spots	342	153	105	42	17	10	6	4	3	2	1
	Percentage≤Area of spots	99. 55	99. 25	98. 96	98. 07	96. 28	94. 79	93. 15	90. 03	86. 90	73. 21	0
No. 1	Area of spots	559	205	100	34	21	12	6	4	3	2	1
	Percentage≤Area of spots	99. 32	98. 63	97. 61	94. 88	92. 83	90. 10	85. 67	81. 23	75. 09	60. 07	0
No. 2	Area of spots	347	100	60	29	12	10	6	4	3	2	1
	Percentage≤Area of spots	99. 60	98. 39	96. 79	94. 78	91. 97	90. 76	86. 35	81. 15	79. 52	67. 87	0

and distribution is wide. This is also different from the result using vibration dry sieving method. It indicates that those big openings with wide distribution and small number (which relates to fibre net broken by needles) could not be reflected by the standard grain sieving method. But in our new method this can be easily done. On the other hand, the porosity of the needled nonwoven geofabrics is generally over 90 %. With this method, the total spot area tested is 86% area of the window for analysis. This shows that a part of openings are covered by the fibre nets, the effect of which on the performance of penetration and filtration still remains to be studied.

4. CONCLUSION

In order to objectively reflect the condition of the silting and erosion of the soil body protected by the needled nonwoven geofabrics, the key parameter is the opening size distribution of the needled nonwoven geofabrics and suitable selection of the porosity details. At present, the direct and indirect test methods all have their drawbacks. They are not suitable for needled nonwoven geofabrics as they are constructed of thin stereo netted fibres in the irregular shapes and the pores spread through in various directions. This prevents understanding of their penetration and filtration performances. The test method introduced in this paper is more suitable for needled nonwoven geofabrics according to the preliminary analysis of the results. Besides, it is more suitable than the hypothesis with spherical particles.

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