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"On the Need for a Better Test Method Than Dry or Wet Sieving to Obtain the Characteristic Opening Size for Geotextile Filter Design Purposes"

by

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Background

The need for retaining the upstream soil particles on the openings of a geotextile filter (but not excessively clogging it) was first observed by Bob Barrett of Carthage Mills Co. in the 1960's. Using intuitive knowledge he co-opted Charles Calhoun of the U.S. Army Corps of Engineers to devise a test method for geotextile design purposes. As the test evolved over time, and is now embodied as ASTM D4751, the method successively exposes a specimen to sequentially larger uniform-sized glass beads using a Ro-Tap sieve shaker searching for the bead size at which less than 5% passes through the test specimen. This is called the O_{95} of the geotextile being evaluated in units of millimeters. It is customarily converted to the nearest U.S. sieve size value, e.g., #40, #70, #100, etc. and is then called the apparent opening size, or AOS. Figure 1 shows the general laboratory setup. The test and its resulting value of O_{95} is used in design in the USA and some other countries.

Figure 1 - Laboratory setup for dry glass bead sieving for the characteristic opening size of geotextile filter per ASTM D4751.

The AOS test just described is considered by the authors to be quite inaccurate, but simplicity of the test and its inertia seems to sustain its use in the United States. Some of the problems associated with the test are as follows:

- The test is conducted dry, whereas filtration and drainage always involve liquids.
- The glass beads can easily get trapped in the geotextile itself (particularly in thick nonwovens) and not pass through at all.
- Electrostatic charges often result with the finer glass beads clinging to the inside of the sieve (even with the application of an anti-static spray on the geotextile) and not participating in the test at all.
- The test allows glass beads to pass through larger size openings that may or may not correspond to the opening size traveled through.
- Yarns in some geotextiles easily move with respect to one another (as they tend to do in woven slit-film geotextiles), thereby allowing the beads to pass through an enlarged void not representative of the complete geotextile test specimen.
- The test is directed only at the 5% size (equivalent to the 95% passing size), which allows for determination of the O_{95} size. The remainder of the pore sizes are not defined.

Beyond the dry sieving method just described, however, there are many other possible test methods for measuring pore size as Table 1indicates.

Table 1 - Significant Features of Different Pore Size Measurement Methods
(Fischer, 1994, mod.)

Test	Relative Sample Size	Finer Pore Sizes Measured	Type of Pore Measured	Provide PSD for Compressed Geotextiles	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
Hydrodyamic 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 constructions	No	Slow	High
Image Analysis	Small	Yes	Pore dimension	Yes	Slow	High
Capillary flow porometry	Small	Yes	Pore surface tension	Yes	Moderate	High

The second and third listed methods in Table 1 are wet sieving methods. Some associated comments in regard to these tests follow:

- In Canada (CGSB-148.1) and France, a frame containing the geotextile specimen has well-graded glass beads placed on it and is repeatedly submerged in water. The bead fraction that passes is calculated and a O_{95} equivalent particle size is obtained.
- In Germany, the setup is similar but a water spray is used. The soil fraction that passes as well as an effective opening diameter is calculated.
- The ISO 12956 test is also a wet sieving test and (being an ISO test method) is a major factor in its worldwide implementation.

In addition to above mentioned sieving methods there are also more sophisticated measurement techniques emerging, including capillary flow, mercury intrusion, and image analysis. Figure 2 illustrates that the differences in pore size measurement of eight of these methods are quite pronounced. This divergence has significant design implications.

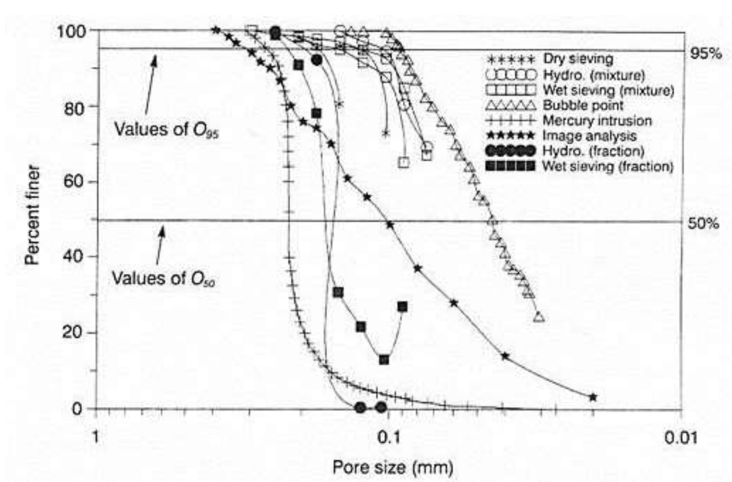


Figure 2 - Pore size distribution using various testing methods (after Bhatia and Smith, 1996).

Geotextile Filter Design Methods

The simplest of the many geotextile filter design procedures determines the percentage of site-specific soil passing the No. 200 sieve, whose openings are 0.074 mm, and compares it to the laboratory measured 0_{95} of the candidate filter. According to AASHTO the following is recommended:

- For soil with ≤ 50% passing the No. 200 sieve: $0_{95} < 0.60$ mm—i.e., a required AOS of the geotextile ≥ No. 30 sieve.
- For soil > 50% passing the No. 200 sieve: $0_{95} < 0.30$ mm—i.e., a required AOS of the geotextile ≥ No. 50 sieve

To extend this concept further, a number of direct comparisons of different geotextile-opening sizes (0_{95}, 0_{50} or 0_{15}) has been made in ratio form to various soil particle sizes to be retained (d_{90}, d_{85}, d_{50} or d_{15}); see Christopher and Fischer, 1992. The numeric value of the ratio depends upon the geotextile type, the soil type, the flow regime, etc. For example, Carroll (1983) recommends the following:

$$0_{95} < (2 \ or \ 3) \ d_{85}$$

where d_{85} is the soil particle size in mm, for which 85% of the total soil is finer.

In contrast to the above mentioned simplified methods, a more comprehensive approach toward soil retention criteria is given for both steady-state and dynamic flow conditions (Luettich, et al., 1992). To utilize their graphs one must first characterize the upstream soil, e.g., perform a grain-size distribution, along with Atterberg limits and dispersivity properties for the fine fraction. Numeric examples using the method are given in Koerner (2012), among others.

In all of these methods, and many more as given in Table 2, the resulting design-required opening size is heavily dependent on a properly simulated laboratory measured value of the same opening size.

Table 2 - Existing Geotextile Retention Criteria (Christopher and Fisher, 1992, mod.)

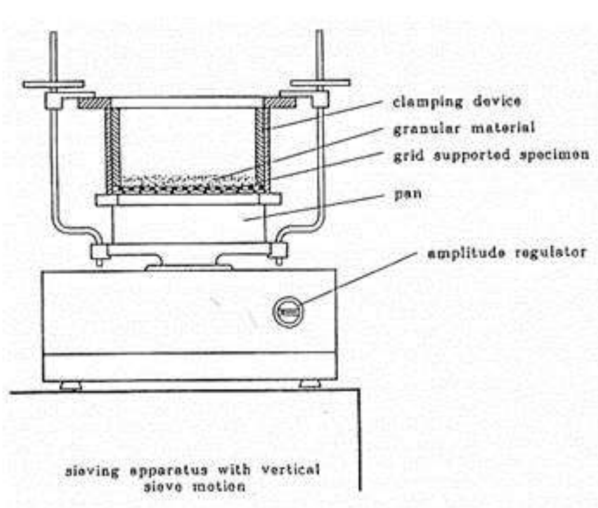
Source	Criterion	Remarks
AASHTO Task Force #25 (1986)	50% ≤ 0.074 mm, O_{95} > 0.59 mm 50% ≤ 0.074 mm, O_{95} > 0.30 mm	no limitations on geotextile type or soil type
Calhoun (1972)	$O_{95}/D_{85} \leq 1$ $O_{95} \leq 0.2$ mm	Wovens, soils with ≤ 50% passing No. 200 sieve Wovens, cohesive soils
Zitscher (1974)	$O_{50}/D_{50} \leq 1.7$- 2.7 $O_{50}/D_{50} \leq 2.5$ to 3.7	Wovens, soils with CU ≤ 2, D_{50} = 0.1 to 0.2 mm Nonwovens, cohesive soil
Ogink (1975)	$O_{90}D_{90} \leq 1$ $O_{90}/D_{90} \leq 1.8$	Wovens Nonwovens
Sweetland (1977)	$O_{15}D_{85} \leq 1$ $O_{15}D_{85} \leq 1$	Nonwovens, soils with CU = 1.5 Nonwovens, soils with CU = 4.0
Rankilor (1981)	$O_{50}/D_{85} \leq 1$ $O_{15}/D_{15} \leq 1$	Nonwovens, soils with $0.2 \leq D_{85} \leq 0.25$ mm Nonwovens, soils with D_{85} > 0.25 mm
Schober & Teindl (1979) (with no factor of safety)	$O_{90}/D_{50} \leq 2.5$-4.5 $O_{90}/D_{50} \leq 4.5$-7.5	Wovens and thin nonwovens, dependent on CU Thick nonwovens, dependent on CU, silt and sand soils
Giroud (1982)	$O_{95}/D_{50} \leq$ (9-18)/CU	Dependent on soil CU and density Assumes fines in soil migrate for large CU values
Carroll (1982)	$O_{95}/D_{85} \leq 2$-3	Wovens and nonwovens
FHwA via Christopher and Holtz (1989)	$O_{95}/D_{85} \leq 1$-2 $O_{95}/D_{15} \leq 1$ or $O_{50}/D_{85} \leq 0.5$	Dependent on soil type and CU Dynamic, pulsating and cyclic flow if soil can move beneath geotextile
French Committee on Geotextiles and Geomembranes (1986)	$O_f/D_{85} \leq 0.38$-1.25	Dependent on soil type, compaction, hydraulic and application conditions
Fischer, et al. (1990)	$O_{50}/D_{85} \leq 0.8$ $O_{50}/D_{15} \leq 1.8$-7.0 $O_{50}/D_{50} \leq 0.8$-2.0	Based on geotextile pore size distribution, dependent on CU of soil
Luettich, et al. (1992)	design charts	Based on geotextile void size, soil size and type, hydraulic conditions and other factors

where O_x = geotextile opening size corresponding to “X” particle size based on dry glass bean sieving
O_f = filtration opening size based on hydrodynamic sieving
D_y = soil particle size corresponding to “Y” percent passing
CU = coefficient of uniformity = D_{60}/D_{10}

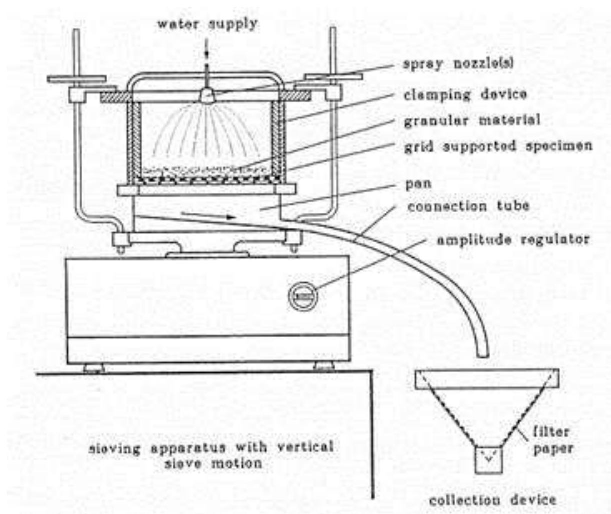
Statistical Variations of Opening Size for Bead Sieving Methods

Dierickx and Myles (1996) provided the first insight into the statistical variation of the three sieving-related opening size test methods. The test methods are shown diagramically in Figure 3. They used five different materials (see Table 3) and involved numerous worldwide laboratories to perform comparative testing.

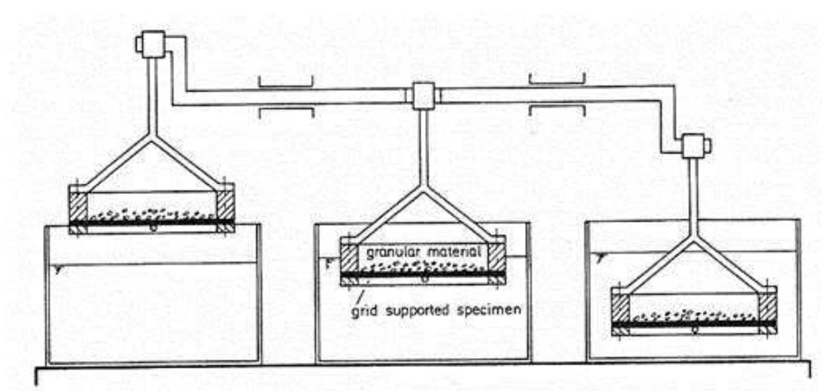
- For dry sieving - 5 laboratories participated.
- For wet sieving - 8 laboratories participated.
- For hydrodynamic sieving - 10 laboratories participated.



(a) Dry sieving



(b) Wet sieving



(c) Hydrodynamic sieving

Figure 3. Major test methods *based on sieving* used to obtain opening sizes of geotextile filters (ref. Dierickx and Myles, 1996).

Table 3 - Measured Mass and Thickness of the Geotextiles Used by Dierickx and Myles, 1996

Geotextile	Mass/Unit Area (g/m^2)	Thickness (mm)
1. Woven tape PP 130 g/m^2	118	0.50
2. Woven monofilament PE/PP 250 g/m^2	229	0.74
3. Heat bonded PP 140 g/m^2	139	0.46
4. Needle punched PE 150 g/m^2	142	1.30
5. Needle punched PE 300 g/m^2	292	2.30

Their conclusion was that "the most reliable results of the characteristic opening size are obtained with the wet sieving procedure". As a result of their findings this method was used in Europe and has been adopted as ISO 12956. However, their advice did not sway the ongoing use of dry sieving in the USA and to this day ASTM D4751 is used exclusively.

Regarding the statistical variation of ASTM D4751, a interlaboratory study of the test method was performed in 1999. Three sets (five test specimens each) were randomly drawn from four materials, two woven and two nonwovens. They were tested for apparent opening size in each of five laboratories. The design of the experiment and an analysis of the data are given in an ASTM Research Report. It is not generally available (for unknown reasons) and the test method does not have an accompanying precision and bias statement.

The above said, a more recent perspective on dry sieving can be gained via proficiency test data generated by the Geosynthetic Accreditation Institute's-Laboratory Accreditation Program, or GAI-LAP. As with other standardized tests, geotextile samples were sent to participating laboratories and statistical data is currently available. The samples sent for evaluation via ASTM D4751 had properties listed in Table 4.

Table 4 - Measured Mass and Thickness of the Geotextiles Evaluated

Geotextiles	Mass/unit area (g/m^2)	Thickness (mm)
1. Woven PP type (silt film)	124	0.51
2. Woven PP monofilament	210	0.72
3. Nonwoven PP needlepunched	101	1.31
4. Nonwoven PP heat bonded	181	0.47

Samples were sent to twenty-two laboratories with the statistical results for the 0_{95} values shown in Table 5.

Table 5 - Statistical Results for Characteristic Opening Size (O_{95}) from GAI-LAP Proficiency Test Program for Various Geotextiles

Geotextile	Mean Value (mm)	Standard Deviation (mm)	Coef. of Variation (%)
1. Woven silt film tape	0.289	0.039	14
2. Woven monofilament	0.317	0.025	8
3. Nonwoven needlepunched	0.257	0.027	10
4. Nonwoven heat bonded	0.129	0.09	69

Note: Past GAI-LAP proficiency test results have given different trends in C_v-values but invariably they are large in the context of their use and applicability in filter design.

Clearly seen is that the woven monofilament fabric has the lowest C_v-value but even its variation has significant implications when used in design. For example, if a designer uses plus or minus two standard deviations around the mean value, the resulting opening size varies within a rather large range; i.e.,

$$0.317 \pm 0.050 = 0.267 \text{ to } 0.367 \text{ mm}$$

Also note that the other geotextiles evaluated in Table 5 have even higher values as the coefficient of variation data indicates, e.g., at 69% the results from the above type of calculation are well beyond utilization.

The above status regarding dry sieving is somewhat improved using wet sieving. Data from Dierickz and Myles (1996) indicates the relative situation insofar as a comparison of 0_{90}-values. For example, wet sieving indicates quite large scatter in evaluating woven slit film and lightweight nonwoven geotextiles. This scatter is increased using hydrodynamic sieving with even woven monofilament geotextiles showing large variations. Again, the implications of using even wet sieving methods leaves a design required value with a relatively large spread of choices.

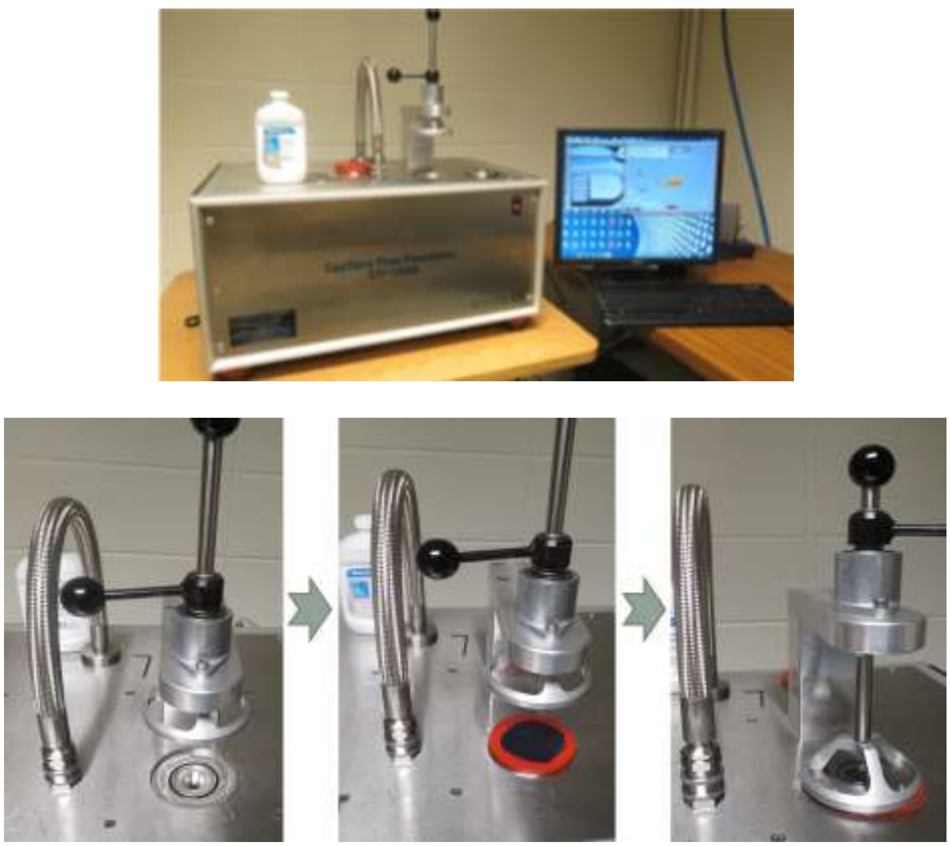
Capillary Flow Testing per ASTM D6767

A very different test from the three sieving methods discussed so far is the capillary flow test for determining pore size distributions of geotextile filters. It is covered in the recently approved ASTM D6767 test method. The test has the distinct advantage of determining the entire pore size distribution of the geotextile filter and not just a single value. Thus it can be used in conjunction with any of the design methods listed in Table 2.

The test procedure is based on the principle that a wetting liquid (e.g., mineral oil) is held in the continuous pores of the geotextile test specimen by capillary attraction and surface tension. Furthermore, the minimum pressure required to force liquid from these pores is a function of the pore diameter. By comparing the gas flow rates of both a wet and dry geotextile at the same pressures, the percentage of fluid passing through the pores larger than or equal to a specific size may be calculated from the pressure-versus-size relationship. By increasing pressure in small steps, it is possible to determine the flow contribution of very small pore size increments by comparing differences. Two such devices are shown in Figure 4.

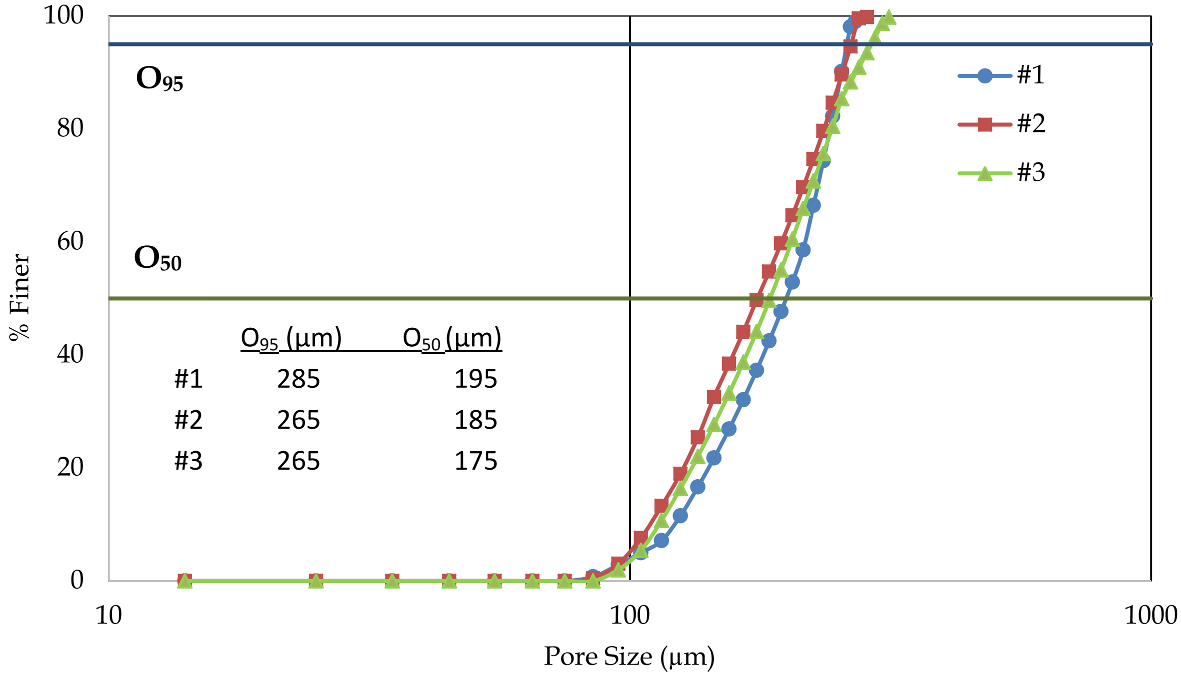
Figure 5 illustrates some results of capillary flow test evaluation of 67 geotextile test specimens. The repeatability is fairly consistent and the authors (Bhatia and Smith, 1996) highly recommend this particular method. More recent information on the test and its behavior is available in Kiffle, et al. (2014).

(a) TRI, Austin, Texas in-house device

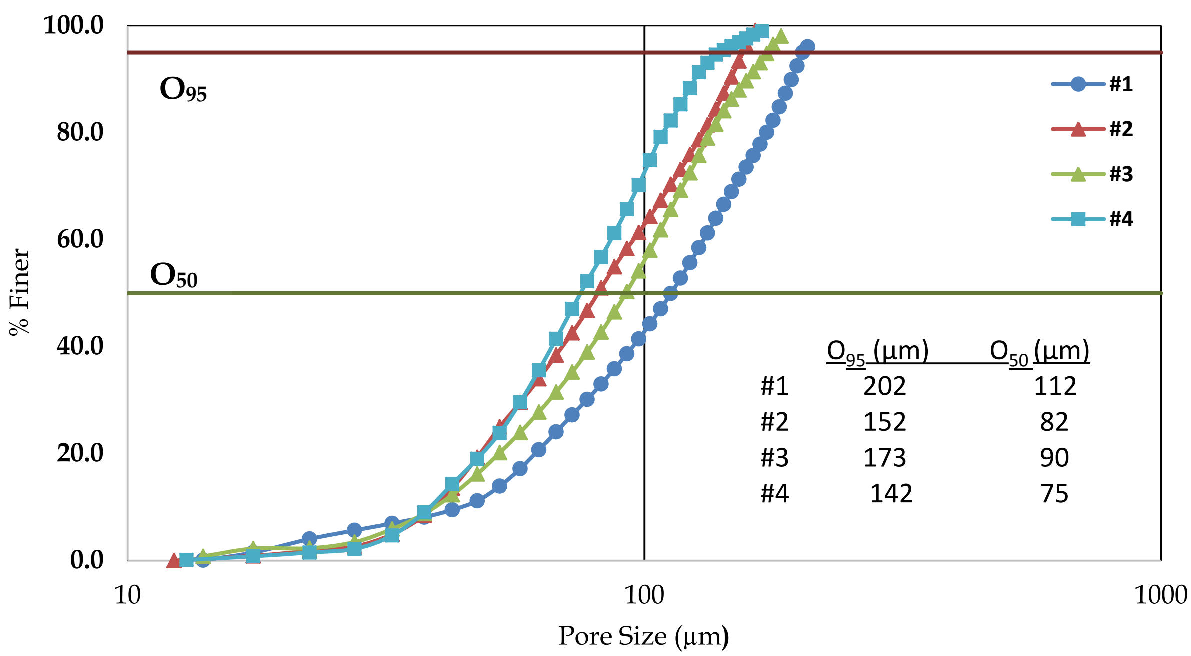


(b) PMI, Ithaca, New York commercial device

Figure 4 - Various capillary flow porometry devices.



(a) repeatability results for a woven geotextile (Mass/Unit Area =410g/m^2, thickness=1.10mm)



(b) repeatability results for a nonwoven geotextile (Mass/Unit Area =195g/m^2, thickness=1.40mm).

Figure 5 - Typical capillary flow test results for geotextiles (ref. Kiffle, et al. 2014).

Summary and Recommendation

Readily seen in Table 5 is that the statistical variation of O_{95}-values obtained using the dry sieving method per ASTM D4751 challenges its utilization for any of the design methods shown in Table 2. Stated differently, it is felt that dry sieving should not be used and another test method should be selected. The obvious alternative is another sieving method; the options being either wet or hydrodynamic sieving. However, they also have quite large statistical variations.

Of the large number of alternative tests to sieving methods, it appears to the authors that the capillary flow method warrants serious consideration. The method provides (i) for complete pore size characterization (thus can be used in any design method), (ii) is based on sound theoretical principles, (iii) papers are available in the technical literature, and (iv) it has been standardized at this point in time. In-house evaluations of the method by GSI are ongoing.

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