Geotextile Filter Criteria and Soil Particle Bridging

N. W. M. John
Q.M.W., University of London, UK

P. D. J. Watson
Kingston University, Surrey, UK

ABSTRACT: A set of geotextile filter design criteria has been developed by examining soil particle bridges on the surface of non-compressible geotextiles. The soil particles were represented by discs in two-dimensional models and by spheres in three-dimensional models. The models examined the relationship between uniformity coefficient, particle size and pore size, and resulted in two overlapping phenomena being observed. At uniformity coefficients less than 2.0, bridge formation is dependant upon particle interlock and packing, whilst at uniformity coefficients greater than 2.0, large particles act as catalysts for bridge formation. These phenomena resulted in the specification of an upper O_{90}/d_{90} ratio. Further analysis revealed that certain particles did not usefully contribute to bridge formation, which resulted in the specification of a lower O_{90}/d_{90} ratio. Both these concepts have been incorporated on a final design chart, which is then compared to other published filter design criteria.

1 INTRODUCTION

A review of available geotextile filter criteria reveals that the criteria consist of the following general format (Bertacchi and Cazzufi, 1984):

$$O_n < \lambda d_n \qquad (1)$$

where O_n is the significant geotextile pore opening size, λ is the constant or variable parameter dependant on the surrounding conditions and d_n is the base soil particle size.

Consequently, all the criteria attempt to relate a geotextile pore opening size to a base soil particle size. This approach seems logical, since it is necessary for soil particles to bridge the geotextile pores in order that a filter can be established in the soil. However, only limited research has been carried out into bridge formation at the soil-geotextile interface.

In particular, tests were carried out by Faure et al. (1986) using Schneebeli, or wooden straws, which were required to bridge model pore sizes. This line of thought was however not pursued. Therefore, a series of tests involving larger than life scale models, was devised to examine the formation of soil particle bridges on the surface of non-compressible woven and non-woven geotextiles.

2 TWO-DIMENSIONAL MODELS

An idealised soil particle can be represented by a sphere in a three-dimensional model, which translates to a disc in two dimensions. Similarly, the idealised circular pore in a three-dimensional model is represented by a slot in the two-dimensional model.

2.1 The apparatus

The apparatus consisted of two acrylic plates held apart from each other by strips of thin metal sheet. These strips allowed the spacing between the two plates to be tightly controlled. The discs were free to move within this space to form bridge networks. An adjustable base plate enabled the modelling of different geotextile pore openings.

The soil particles were represented by various sizes of discs, in the form of commercially available steel washers. By mixing the discs in different proportions it was possible to obtain model soils with uniformity coefficients ranging from 1.0 to 8.5.

2.2 Test results

Tests were carried out by filling the apparatus with the model soil. They were repeated with progressively larger O_{90} pore openings until it became impossible for a soil bridge to form. The limiting O_{90}/d_{90} ratios are summarised in Table 1 and illustrated graphically in Fig. 1.

Table 1 Collapse ratios from two-dimensional model tests

Uniformity Coefficient C_u	Particle Size d_{90}	Maximum Bridge Width O_{90}	Collapse Ratio O_{90}/d_{90}
1.00	36.7mm	154mm	4.20
1.40	36.7mm	114mm	3.11
1.70	60.0mm	150mm	2.50
2.10	36.7mm	88mm	2.40
3.60	36.7mm	85mm	2.32
8.35	100.0mm	222mm	2.22

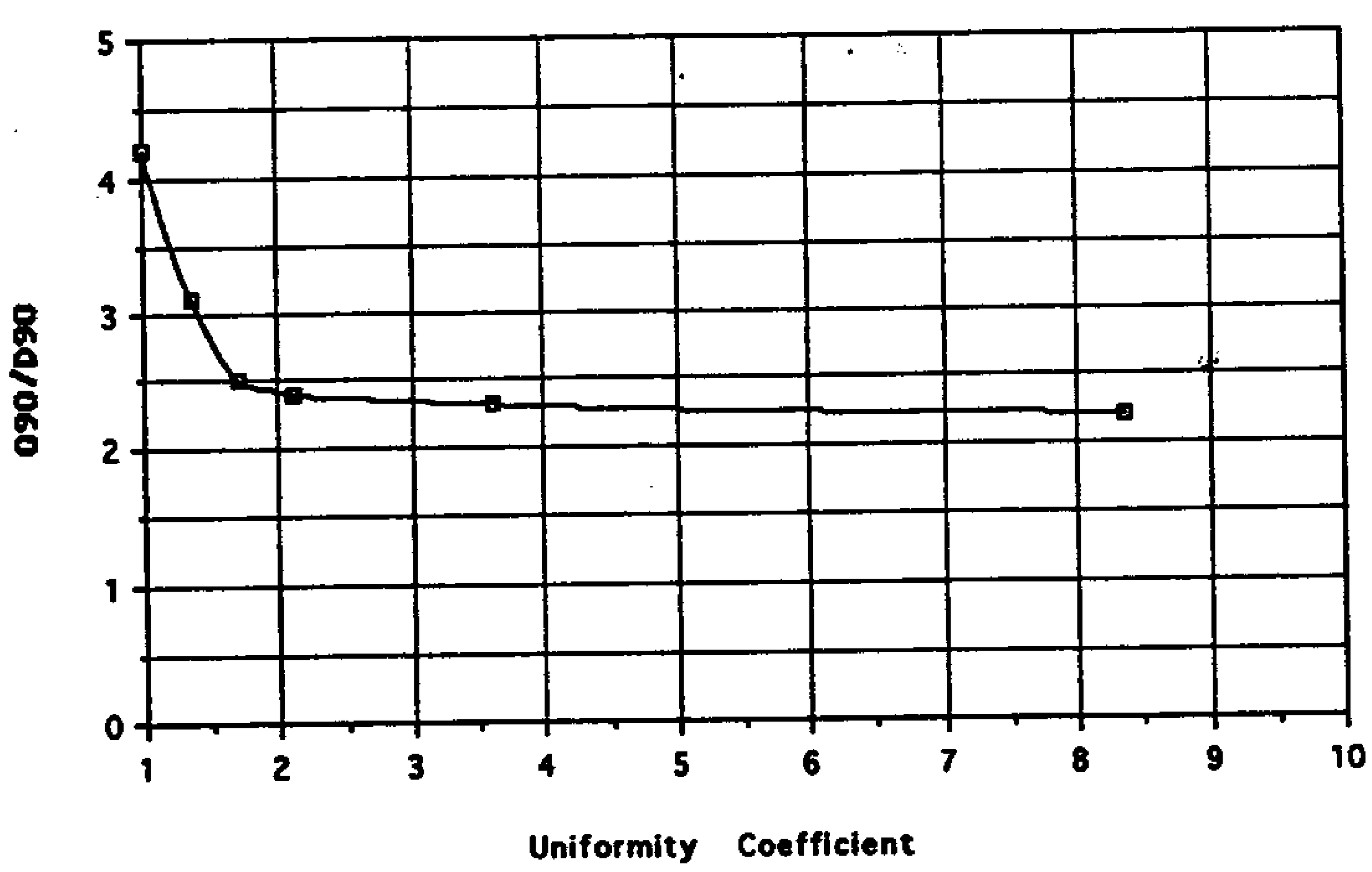

Fig. 1 Graph of final results from all two-dimensional tests

3 THREE-DIMENSIONAL MODELS

More realistic three-dimensional models were used to verify the results from the two-dimensional tests. The apparatus was constructed from acrylic sheet to form an open box with a removable base plate. A circular opening in the base plate represented the O_{90} pore.

Tests were performed by filling the box with various mixtures of spheres representing model soils. Repeating the test with progressively larger pore openings identified the limiting O_{90}/d_{90} ratios for bridge formation. These are summarised in Table 1, which compares these results to those predicted by Fig. 1.

Table 2 Comparison of three-dimensional collapse ratios to predicted ratios from two-dimensional tests

Uniformity Coefficient C_u	Predicted Collapse Ratio O_{90}/d_{90}	Actual Collapse Ratio O_{90}/d_{90}
1.00	4.20	4.26
1.70	2.50	2.43
2.11	2.40	2.32
3.21	2.30	2.21
8.24	2.20	2.12

From Table 2, the actual collapse ratios are within 1.4% to 3.9% of the predicted values. The above results therefore confirmed that the relationship determined from the two-dimensional tests (see Fig. 1) was equally valid for three-dimensional tests.

During these series of tests it was noted that there was more soil loss than with comparable two-dimensional tests. This was particularly noticeable with the smaller sized soil fraction of each soil mixture, with large losses occurring just before failure. These losses appeared to reflect the loss of fines that can occur in a real soil/geotextile system.

4 OBSERVED PHENOMENA

4.1 Development of a lower limit

The relationship shown in Fig. 1 gives the maximum O_{90} size for soil particle retention on a geotextile filter. A geomembrane however, clearly meets this criterion, even though it could not possibly function as a filter. Similarly, a geotextile might also meet this criterion even though it subsequently fails due to clogging.

Ideally a minimum O_{90} size should be specified. This lower limit is often expressed indirectly by relating the permeability of the geotextile to the permeability of the soil (John 1987).

A more logical approach is to consider the requirements of a filter. The relationship in Fig. 1 positively seeks to retain enough large size particles to form a natural filter at the soil/geotextile interface. In a similar manner, the lower limit should positively aim to lose sufficient fine particles to ensure adequate permeability and resistance to clogging. This forms the basis for a concept of positive wash through.

Analysis of the results from the model tests revealed that those soil particles below a certain size would be of 'no significant use' in a bridge formation. These particles were defined as being:

$$\text{Smallest particle size} = 0.228\ O_{90}\ \text{Pore size} \qquad (2)$$

As the loss of such particles does not hinder the bridging process, they are the target size for the concept of positive wash through. The lower limit for O_{90} is therefore specified as 0.228 times the collapse ratio values given in Table 1, and results in a new geotextile filter design criterion as shown in Fig. 2.

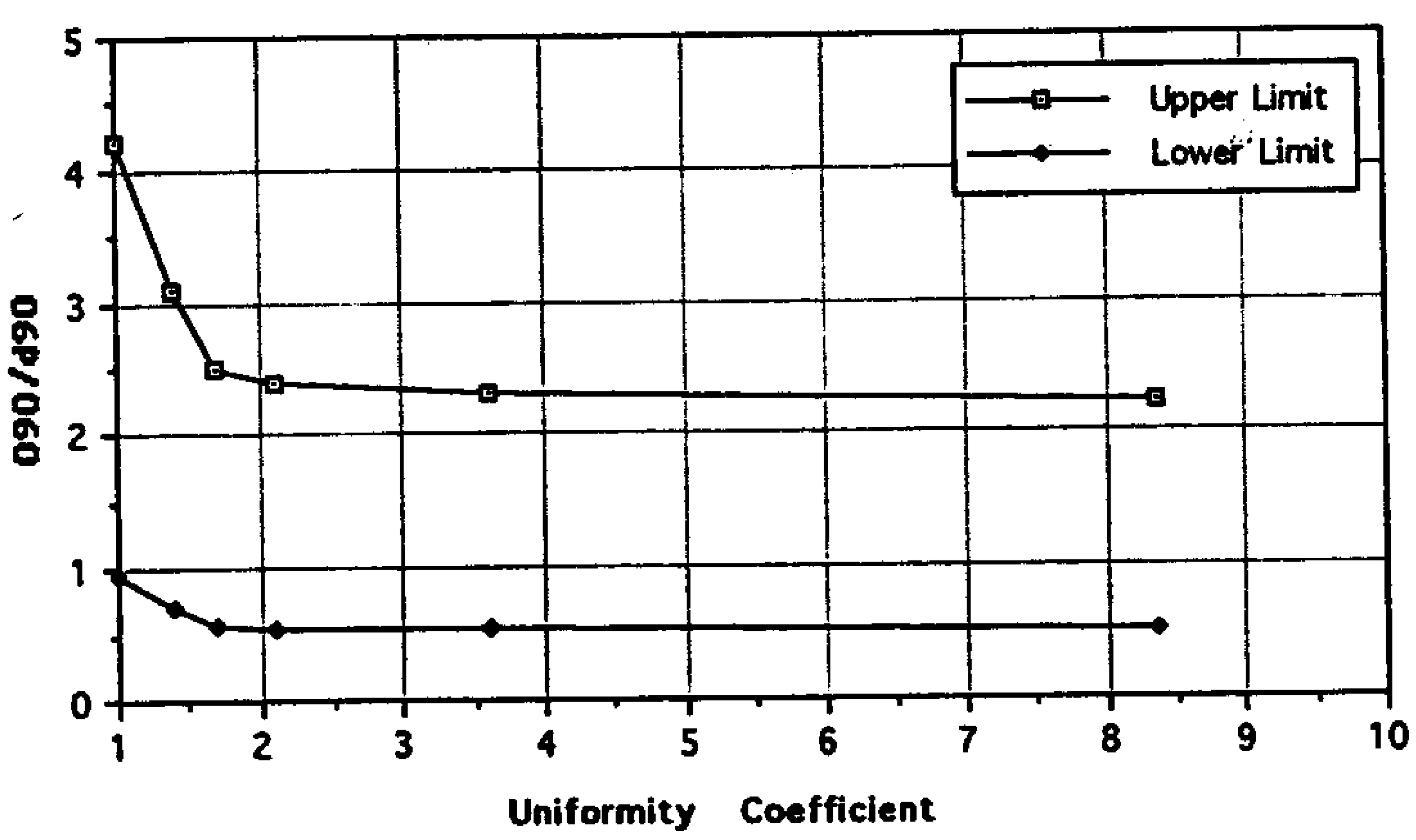

Fig. 2 Filter design criteria for non-compressible geotextiles with unidirectional flow

4.2 Bridge formation

In an attempt to define the retention criterion shown in Fig. 2, further analysis was carried out. Initial considerations revealed a problem for a soil with a uniformity coefficient of 1.00. In this case, all the soil particle sizes are identical, such that a ratio value of 4.20 would be obtained regardless of whether the ratio was expressed as O_{90}/d_{90}, O_{90}/d_{50} or O_{90}/d_{10}. This raised the question of whether the decrease in O_{90}/d_{90} with uniformity coefficient was simply due to the choice of d_{90} for this figure.

The results presented in Fig. 2 were therefore re-analysed to find what soil particle size (d_n) could be used to hold the ratio O_{90}/d_n constant at 4.20, as the uniformity coefficient varied (see Table 3). In Table 3, the conversion of d_{90} particle sizes to other d_n values required the assumption that the particle size distribution was linear, and that d_n was taken to equal d_{50} for a uniformity coefficient of 1.0.

Table 3 Particle size values corresponding to a ratio value of 4.20

Uniformity Coefficient C_u	Ratio Value O_{90}/d_{90}	Particle Size d_n
1.00	4.20	d_{50}
1.40	3.11	d_{45}
1.70	2.50	d_{41}
2.10	2.40	d_{52}
3.60	2.32	d_{67}
8.35	2.22	d_{75}

In Table 3, a reduction in d_n indicates a loss of bridging capacity, whereas an increase in d_n indicates enhanced bridging capacity. For uniformity coefficients between 1 and 2 d_n falls. This is attributed to the inherent stability of perfectly uniform spheres that pack into a perfectly symmetrical arrangement. As the uniformity coefficient increases this steadily introduces a variation in particle size that starts to disrupt this packing effect.

In the second region of Table 3, where the uniformity coefficient exceeds 2.0, the d_n value increases. This can be attributed to a catalyst effect where a large size particle, such as a d_{80} or d_{90}, comes to rest near the pore and induces the bridge. As the uniformity coefficient increases, the diameter of these large size particles becomes a greater multiple of the average particle diameter d_{50}, resulting in an increase in the span of the bridge formation.

5 FILTER CRITERIA

As the filter design criteria shown in Fig. 2 makes use of the concept of positive retention, it was decided to make a comparison of this criteria to other positive retention criteria, for instance those of Giroud (1982), John (1987) and Schober and Teindl (1979).

Table 4 Positive retention criteria expressed as O_{90}/d_{90} limits

C'_u	Design Upper	Design Lower	Giroud Dense	Giroud Loose	John	Schober & Teindl
1.00	4.21	0.96	2.47	1.05	2.10	2.41
2.00	2.41	0.55	2.65	1.21	1.63	2.16
3.00	2.37	0.54	2.61	1.28	1.48	1.85
4.00	2.31	0.53	1.53	0.76	1.35	1.46
5.00	2.28	0.52	1.04	0.53	1.28	1.15
8.00	2.23	0.51	0.44	0.22	1.13	0.63
10.00	2.19	0.50	0.30	0.15	1.00	0.43

Direct comparison is complicated by the fact that differing standard pore and particle sizes are used. It is therefore necessary to assume a linear particle size distribution to convert from one particle size to another. Similarly, the different pore sizes can be converted by assuming a basic linear relationship. Details of the converted criteria are given in Table 4.

The O_{90}/d_{90} ratio values given in Table 4 show that the upper limits for all of the other positive retention criteria vary considerably, but in most cases lie between the upper and lower limits of the new design criteria. These values might suggest that the design criteria, as shown in Fig. 2, are superior to the other alternative criteria.

6 CONCLUSION

Criteria for filter design are shown in Fig. 2 for use with non-compressible geotextiles in unidirectional flow conditions. The upper limit criterion is based on the concept of positive retention, whilst the lower limit is based on the proposed concept of positive wash through.

The study of soil particle bridge formation shows that at uniformity coefficients between 1.0 and 2.0, bridging is dependant upon soil particle interlock and packing. At uniformity coefficients greater than 2.0, bridge formation is then dependant upon larger soil particles acting as catalysts.

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