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GEOTEXTILE FILTER CRITERIA FOR TROPICAL RESIDUAL SOILS

CRITERES DES FILTRES GEOTEXTILES DANS LES SOLS RESIDUELS TROPICAUX

FILTERKRITERIEN FÜR GEOTEXTILIEN IN TROPISCHEN VERWITTERUNGSBÖDEN

Residual soils are the dominant soil group in the East Asian region. Until recently nothing was known of the long term performance of geotextile filters with these soil types. To evaluate the performance of geotextile filters with tropical residual soils a laboratory program was instigated utilising the two dominant residual soil types from Hong Kong - a completely decomposed granite (CDG) and a completely decomposed volcanic (CDV) soil. The results of the program demonstrate conclusively that geotextiles perform well as filters for these two soil types provided the geotextile is selected properly. the results also show that while several of the existing filter criteria predict the filtration limits (piping and permeability) with reasonable accuracy, others do not. A generalised filtration relationship is presented which is more applicable to well graded residual soils.

Residuale (ortsentstandene) Boeden sind die vorwiegende Bodengruppe in der Ostasischen Region. Bis kuerzlich war nicht viel bekannt ueber das langzeitliche Verhalten von Geotextilfiltern in diesen Bodentypen. Um die Eignigkeit von Geotextilfiltern fuer residual Boeden zu pruefen, eine Serie von Laboratoriumsversuchen wurde unternommen, an zwei typischen Boeden von Hong Kong: Ein total verwitterter Granit (CDG) und ein total verwitterter Boden vulkanischer (CDV) Herkunft. Die Ergebnisse dieser Forschungsuntersuchung haben klar bewiesen dass sich Geotextilien fuer diese Bodenarten als Filter bewaehren, vorausgesetzt dass sie richtig ausgewaehlt werden. Es hat sich auch gezeigt dass nicht alle der existierenden Filterkriterien die Filtrationsgrenzen (hydraulischer Grundbruch und Durchlaessigkeit) genuegend genau voraussagen. Eine verallgemeinerte Filtrationsbeziehung wird gegeben die sich besonders fuer gut gekoernte residuale Boeden eignet.

INTRODUCTION

Large scale development of the East Asian region has required the adoption of many novel engineering practices in order to maintain quality, low cost and speed of construction. This is especially the case with geotechnical structures where a very wet climate coupled with relatively permeable soils has resulted in the extensive use of drainage (both surface and subsurface) as a cost-effective means of maintaining the integrity of structures.

Most of the soils in the East Asian region have been formed by the insitu weathering (by water) of the parent rock. These soil types so formed are termed residual soils. For these soils the extent of decomposition varies with depth from the ground surface. Brand(1) notes that this wide variation in the degree of weathering results in extensive variations in soil particle size distribution both within an individual soil profile and from site to site.

Tropical residual soils exhibit different properties and behave differently in many cases to soils which are commonly found in temperate regions and on which much of the 'classical' geotechnical design methods have been established. As such, new design guidelines have had to be adopted which recognise the intrinsic properties of these residual soils.

The use of geotextiles as filters for tropical residual soils has increased markedly over the last five years. The reasons for this are numerous, but mainly because of their relative economy, consistent properties and general ease of installation. However, while the use of geotextile filters has increased, concerns have been expressed about their performance in filtering tropical residual soils as no research work has been carried out to establish performance and selection criteria for geotextile filters with these soils. In instances where selection criteria were used, these were inevitably based on existing European or North American methods whose soil types were different (and so might exhibit different filtration characteristics) to tropical residual soils.

RESIDUAL SOILS OF HONG KONG

Hong Kong, a British dependency, on the Southern coast of the Peoples Republic of China has experienced phenomenal development during the last ten years. Its relatively small land area, coupled with hilly terrain, neccessitates the widespread use of cuts and fills to provide the required foundations for most civil structures. Hong Kong's heavy Summer rainfall, coupled with the need for extensive earthworks, results in the extensive use of subsurface drainage as a means of maintaining the stability and integrity of a variety of geotechnical structures. As the performance of many of these geotechnical structures is critical (loss of life could be expected if failure of the structure occurred) considerable care is taken in the design and construction of these structures and in the selection of materials.

Until very recently, geotextiles have not been officially recognised as being a suitable filter material for subsurface drainage applications in Hong Kong. The major reason being because there was no data available on the long term performance of geotextile filters with the soils of Hong Kong. Because of the need for high performance filters in Hong Kong it was decided to concentrate the research into the performance of geotextile filters with tropical residual soils using the residual soils prevalent in Hong Kong.

Two residual soil types cover much of Hong Kong. One type, which has been formed by the insitu weathering of granite parent rocks, is commonly referred to as completely decomposed granite (CDG). The second type, which has been formed by the insitu weathering of volcanic (ryolitic) parent rocks, is referred to as completely decomposed volcanic (CDV) soil. The properties of these two soils have been well researched, e.g. Brand(1), Lumb(2), Lumb(3).

The grading envelope for the CDG soils (see Figure 1) show these to be predominantly silty sand in texture and very well graded (with uniformity coefficients approximating 500). The grading envelope for the CDV soils (see Figure 1) show these to be very well graded also (uniformity coefficients also approximating 500), however, they tend to have a larger silt fraction than CDG soils.

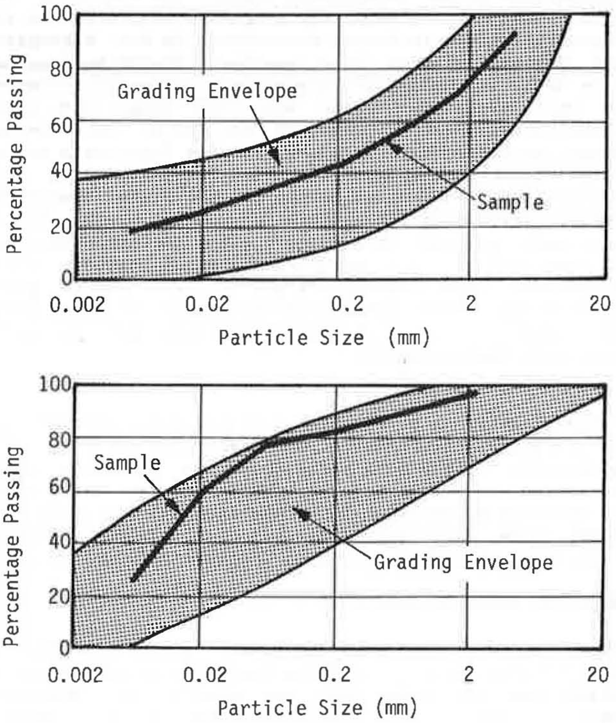


Figure 1: Grading Envelopes for CDG (Top) and CDV (Bottom) Soils With the Respective Sample Gradings.

Lumb(4) notes that the average insitu coefficient of permeability of CDG soil ranges between $3x10^{-7}$ and $4x10^{-5}$m/sec while CDV soil ranges between $2x10^{-9}$ and $4x10^{-7}$m/sec. Other sources however, have revealed permeability results outside of these ranges. Lumb also notes that it is possible for laboratory permeability tests to yield coefficients of permeability up to two orders of magnitude lower than comparable field permeability tests.

FILTRATION PERFORMANCE REQUIREMENTS AND GEOTEXTILE FILTER CRITERIA

The performance of the geotextile filter when placed adjacent to the base soil (soil to be filtered) depends on the interaction of many factors, the major ones being base soil particle size distribution, base soil structure, base soil chemistry, the size of pores in the geotextile, and the water permeability of the geotextile. While the actual mechanics of soil-geotextile filtration are quite complex the overall performance criteria governing geotextile filters (and granular filters for that matter) are quite simple. To achieve optimal filter performance two overall criteria must be met:

1. Following an initial period of instability which occurs during the formation of the soil filter zone adjacent to the geotextile the permeability of the system should remain relatively constant with time.

2. Following an initial period of soil piping which may occur during the formation of the soil filter zone no further insitu soil should be piped out of the filter system.

These two performance criteria are shown diagrammatically in Figure 2. If the permeability performance criterion is not adhered to then the movement of water through the filter system may be critically impeded. If the piping performance criterion is not adhered to then the filter system may allow continual piping of soil which may lead to failure of the structure. In practice, to ensure both criteria are met, close attention must be given to specific properties of the geotextile filter. The two geotextile properties which have a dominant effect on filtration performance are pore size (normally described in terms of an apparent opening size) and water permeability. The pore size indicates the ability of the geotextile to prevent soil particles of a particular size from migrating through the geotextile. Geotextile permeability indicates the ability of the geotextile to pass seepage water when it is placed adjacent a particular base soil.

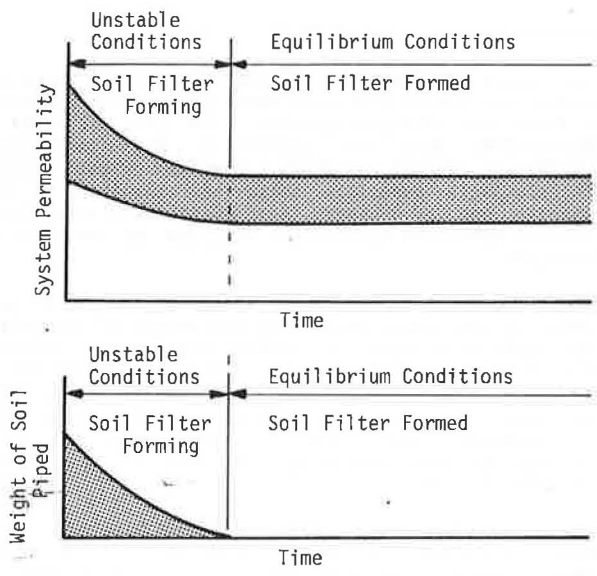


Figure 2: Overall Requirements for Optimal Filter Performance.

In order to meet the two filtration performance requirements shown in Figure 2 geotextile filter criteria have been developed by a number of authors. A selection of the most commonly used filter criteria are listed below.

1. Calhoun(5) - Piping Limit $O_{95} \leq D_{85}$ (1)

2. Lawson(6) - Permeability Limit $O_{90} \geq D_{15}$ (2)

3. Ogink(7) - Piping Limit - wovens $O_{90} \leq D_{90}$ (3)

 - nonwovens $O_{90} \leq 1.8D_{90}$ (4)

4. Schober and Teindl(8) - Piping Limit $O_{90} \leq B\ D_{50}$ (5)

where O_{90}, O_{95} are the apparent opening sizes of the geotextile, D_{90}, D_{85}, D_{50}, D_{15} are the particular soil fraction sizes in each relationship, and B is a variable which depends on base soil uniformity coefficient, type of geotextile, and safety factor employed.

It is observed that the existing geotextile filter criteria shown above exhibit a common format, viz:

$$O_a = C\ D_n \qquad (6)$$

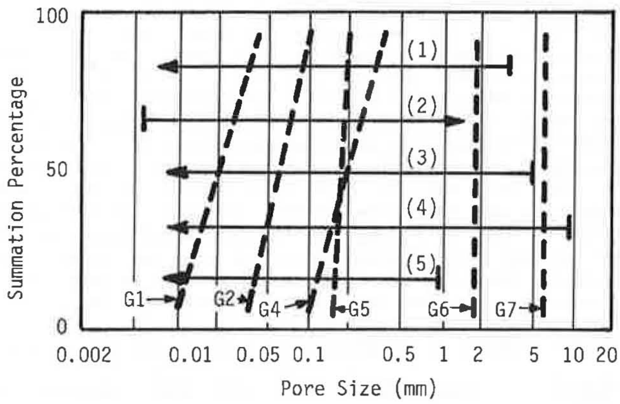
where O_a is the apparent opening size of the geotextile, D_n is the base soil particle diameter below which lie n% of soil particles, and C is a coefficient dependent on the particular soil fraction D_n, the grading of the base soil and the hydraulic conditions prevailing.

To provide detailed geotextile filter relationships for a particular base soil three separate values of the variable C exist. One value (the minima) will establish the permeability limit for the geotextile filter (values of C smaller than this will result in a geotextile which is less permeable than the base soil). The second value (which is larger than the minima) will establish the point where controlled initial soil piping begins (smaller values of C will provide a geotextile which allows stable water flows with no soil piping, while larger values of C will provide a geotextile which allows stable water flows with some initial soil piping). The third value (the maxima) will determine the piping limit for the geotextile filter (values of C greater than this maxima will result in a geotextile which allows continual uncontrolled piping of the base soil). Existing geotextile filter criteria tend to concentrate on only two of the above values of C - the permeability limit (minima) and the piping limit (maxima).

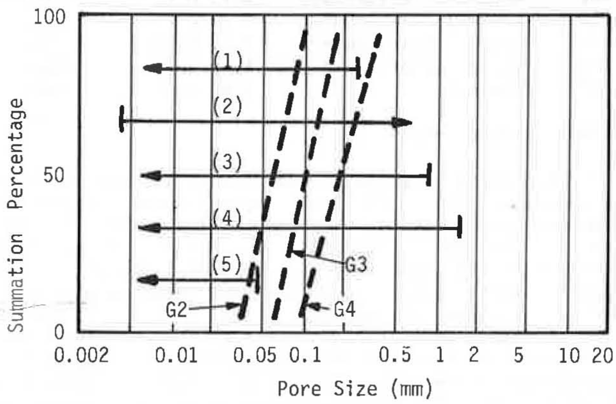
EVALUATION PROGRAM FOR GEOTEXTILE FILTERS

To evaluate the filtration performance of geotextiles with the two residual soil types of Hong Kong a sample of CDG was extracted from the Discovery Bay site on Lantao Island and a sample of CDV was extracted from the Kohima Barracks site near Clear Water Bay. A particle size distribution analysis (both sieve and hydrometer-with dispersant agent) was carried out on the two soil samples. The particle size distributions of the two samples are shown in Figure 1. The CDG sample conforms well with the mean grading range for CDG soils while the CDV sample exhibits a greater degree of decomposition than the average CDV material.

The five existing geotextile filter criteria (Equations (1) to (5)) were used in conjunction with the sample particle size distributions to determine 'appropriate' geotextile filter limits. The filter limits predicted by the five different filter criteria are shown in Figure 3. For the CDG sample (Figure 3a) the prediction of the piping limit using Equations (1) and (3) show close agreement with each other, however, the prediction of the piping limit using Equations (4) and (5) differ markedly. For the CDV sample (Figure 3b) there is a great variation in the predicted piping limit using the different geotextile filter criteria. It is clear that one aspect of any study of geotextile filter performance with these two soil types should involve the accurate determination of appropriate piping and permeability limits.



a) CDG Soil Sample.



b) CDV Soil Sample.

Figure 3: Geotextile Filter Criteria Limits and Pore Size Distributions of Geotextiles Used in CDG and CDV Evaluation Propgram.

To evaluate both the long term filtration performance of geotextiles and the applicability of existing geotextile filter criteria a laboratory program was instigated using permeameter tests to quantify the relevant performance parameters. The permeameters used were identical to those described by Rycroft and Dennis-Jones(9).

Six geotextiles and a geogrid covering a wide range of pore sizes and permeability were selected for the laboratory program. The relevant hydraulic properties of the geotextiles and geogrid are shown in Table 1. All geotextiles and the geogrid obey the minimum water permeability requirements for geotextile filters stipulated by Lawson(6).

Due to limitations on the quantity of permeameters available and the need to provide long term filter performance data (a permeameter would be confined to a single test for a long period of time) it was decided to concentrate primarily on the CDG soil sample while using the CDV soil sample to provide selected comparisons.

Five of the geotextiles shown in Table 1 (geotextiles G1, G2, G4, G5, and G6) and the geogrid G7 were selected for permeameter testing with the CDG soil sample. It was thought that as these six materials covered a wide spectrum of pore sizes, the permeameter results could be expected to establish not only the long term filtration capabilities of geotextiles, but also the relevant permeability and piping limits for CDG soils. The pore size distributions of the five geotextiles and geogrid are shown in Figure 3a superimposed on the filter limits predicted by the five existing geotextile filter criteria (Equations (1) to (5)). It is observed that geotextiles G1, G2, G4, and G5 fall within the filter limits predicted by all five filter criteria. Geotextile G6 falls outside the piping limit predicted by Equation (5) but within the limits predicted by the other four criteria. Geogrid G7 falls outside the piping limit predicted by all the criteria except Equation (4).

Table 1: Hydraulic Properties of Geotextiles and Geogrid.

PRODUCT CODE	CONSTRUCTION	PORE SIZE O_{90} mm	O_{50} mm	PERMEABILITY $L/m^2/sec^{\#}$
G1	Nonwoven, meltbonded	0.04	0.02	30
G2	Nonwoven, meltbonded	0.10	0.07	50
G3	Nonwoven, meltbonded	0.18	0.12	80
G4	Nonwoven, meltbonded	0.35	0.20	150
G5	Woven, monofilament	0.20	0.17	90
G6	Woven, monofilament	1.5	1.5	>500
G7	Geogrid	7.0	7.0	>>500

#100mm constant head.

For comparative purposes it was decided to choose three geotextiles (G2, G3, G4) which would, hopefully, demonstrate good filter performance with the CDV soil sample. The pore size distributions of these three geotextiles are shown in Figure 3b superimposed on the filter limits predicted by the five existing geotextile filter criteria (Equations (1) to (5)). It is observed that all three geotextiles lie beyond the piping limit predicted by Equation (5). The apparent opening size of geotextile G4 lies at the piping limit predicted by Equation (1). All three geotextiles lie well within the limits predicted by Equations (2), (3) and (4).

Once the geotextiles had been selected they were placed in the permeameters with the appropriate soil sample and a constant hydraulic gradient was applied across the system. The permeability of the geotextile - soil sample system was recorded at various time intervals and on completion of each test the total weight of soil piped through the geotextile was also recorded. The duration of the tests varied from 25 to 700 days depending on the performance of the geotextile filter. A summary of the results obtained are shown in Table 2.

DISCUSSION OF RESULTS

For the CDG soil tests, geotextiles G1, G2, G4, G5, and G6 all attained equilibrium system permeability after an initial period of time. Four of these tests (one each with geotextile G1, G2, G4, and G5) were continued for over 600 days with no significant change in system permeability once equilibrium conditions had been established. The change in system permeability with time for CDG soils and geotextiles G1, G2, G4, G5 and G6 conformed to a well defined region (or envelope). This envelope is shown in Figure 4 with the actual system permeability versus time results for CDG with geotextiles G1, G2 and G5 superimposed for demonstration purposes. It is observed that the system permeabilities reduce with time up until between 100 and 200 days, and thence remain constant with time. All five geotextiles tested attained equilibrium system permeabilities between $1x10^{-7}$ and $6x10^{-7}$ m/sec. These equilibrium system permeabilities are generally within the range of permeabilities quoted for CDG soils (Lumb(4)). Thus it may be assumed that when these five geotextiles are used as filters for CDG soils the permeability of the CDG soil itself controls the permeability of the soil-geotextile system (the properties of the five geotextiles have no effect on overall system permeability).

Table 2: Summary of Filtration Results for the Various Geotextiles and Geogrid With CDG and CDV Soil.

TEST	TEST DURATION days	EQUILIBRIUM SYSTEM PERMEABILITY $kx10^{-7}$ m/sec	SOIL PIPED g/m^2	O_{90}/D_{85}
G1-CDG	700	4	0	0.01
G1-CDG	270	2	0	0.01
G2-CDG	700	1.5	0	0.03
G2-CDG	350	1.5	0	0.03
G4-CDG	630	2	90	0.10
G4-CDG	240	3	30	0.10
G5-CDG	700	1.5	0	0.05
G6-CDG	540	1.5	2800	0.41
G6-CDG	200	3	2000	0.41
G7-CDG	65	-	cont.	1.89
G7-CDG	25	-	cont.	1.89
G7-CDG	120	-	cont.	1.89
G7-CDG	120	-	cont.	1.89
G2-CDV	250	10	0	0.33
G3-CDV	250	18	0	0.60
G4-CDV	250	14	500	1.17

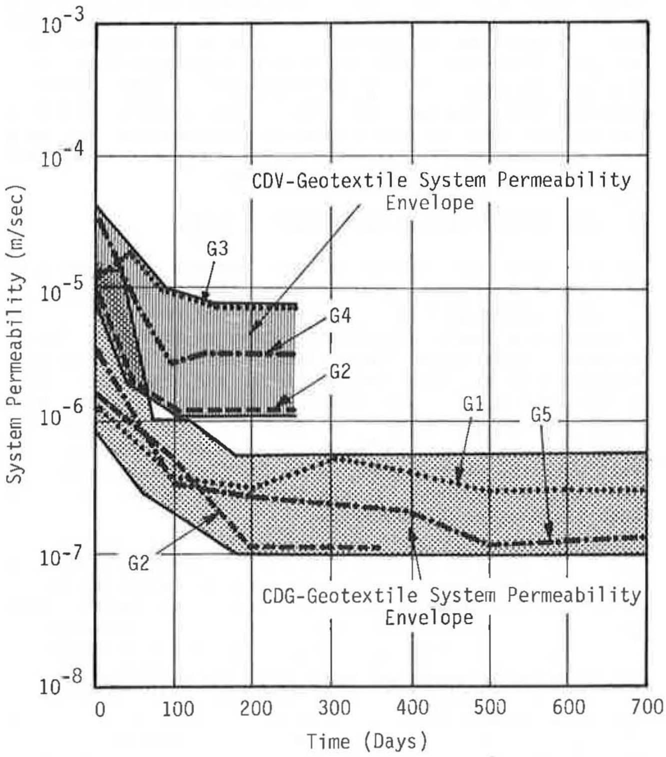


Figure 4: General Range of System Permeabilities Using Selected Geotextiles With CDG and CDV Soil Samples.

The relationship between system permeability and time for geotextiles G2, G3 and G4 with CDV soil (see Figure 4) also show an initial general reduction but after approximately 100 days equilibrium conditions are reached with the system permeability then remaining relatively constant with time. The equilibrium system permeabilities for the three geotextiles ranged between $1x10^{-6}$ and $8x10^{-6}$m/sec which is greater than the general permeability limits for CDV soils quoted by Lumb(4). This discrepancy in the permeability results is most likely due to the low density of the CDV soil samples in the permeameters (relative to normal insitu soil density).

The relationship between system permeability and time for the four tests carried out using geogrid G7 and the CDG soil sample is shown in Figure 5. In each case the permeameter had to be closed down after a period of time (between 25 and 120 days) because of continual uncontrolled soil loss through the filter. Comparison between the results obtained using geogrid G7 and the system permeability envelope for geotextiles G1, G2, G4, G5, and G6 shown in Figure 5 demonstrates the continual unstable hydraulic conditions within the permeameters containing geogrid G7. Only one of the tests appeared to reach an equilibrium system permeability but this had to be stopped after 120 days because of continual soil piping.

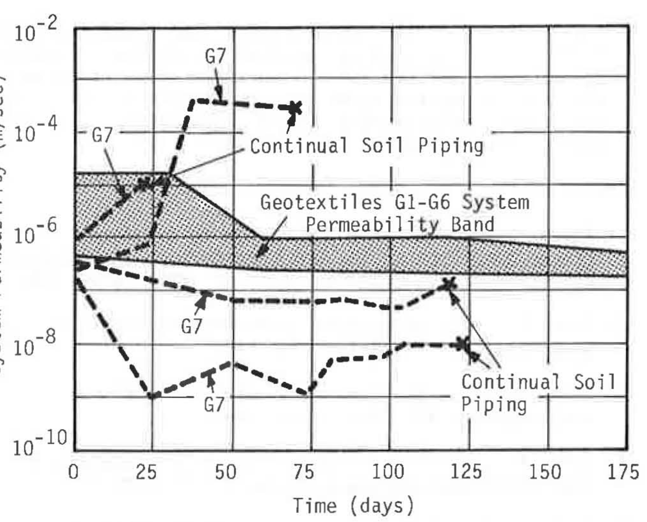


Figure 5: System Permeabilities for Geogrid G7 With CDG Compared With System Permeability Envelope Obtained Using Geotextiles G1-G6.

The piping characteristics of the CDG and CDV soil samples with the various geotextiles and geogrid are also shown in Table 2. It was noted that geotextiles G4 and G6 (with the CDG soil sample) and geotextile G4 (with the CDV soil sample) allowed initial soil piping to occur but this reduced to zero after a period of time. Geogrid G7 (with the CDG soil sample) however, allowed continual uncontrolled soil piping.

Comparison of the results obtained for G4-CDG and G5-CDG (Table 2) appear to demonstrate the importance of the higher percentile pore sizes (in geotextiles) in controlling the amount of soil piped through the geotextile. In the two G4-CDG tests 90 and 30 g/m^2 of soil piped through geotextile G4 while no soil piped through geotextile G5 in the G5-CDG test. From Table 1 it is observed that the O_{90} value of geotextile G4 is greater than that of geotextile G5 although their O_{50} values are very similar.

Interpolation of the results shown in Table 2 indicate that for the CDG soil sample a ratio of $O_{90}/D_{85} \leq 1$ (or alternatively $O_{90}/D_{50} \leq 10$) is required to prevent continual loss of soil through the geotextile filter. Moreover, a ratio of $O_{90}/D_{85} \leq 0.05$ (or alternatively $O_{90}/D_{50} \leq 0.6$) is required for the CDG soil sample to ensure no soil at all is piped through the geotextile. Because of the small number of tests carried out using the CDV soil sample it was not possible to determine the maximum allowable O_{90}/D_{85} ratio required to prevent continual uncontrolled piping of soil through the geotextile. It was possible, however, to approximate the limit of zero soil piping which was $O_{90}/D_{85} \leq 0.6$ (or alternatively $O_{90}/D_{50} \leq 12$).

The CDG soil tests failed to determine the permeability (lower) limit for geotextiles as even the geotextile with the finest pores (geotextile G1) performed well as a filter with the CDG soil. Because of the limited number of tests carried out with the CDV soil sample it was also impossible to establish the permeability limit for this soil.

COMPARISON OF RESULTS WITH EXISTING FILTER CRITERIA

As stated above, the piping limit (the onset of continual uncontrolled piping) for CDG soil occurs at a ratio of $O_{90}/D_{85} = 1$ (or alternatively $O_{90}/D_{50} = 10$). While it was impossible to establish the permeability limit for CDG soils (even the geotextile with the finest pores performed well) it would appear prudent that the ratio corresponding with geotextile G1 (the finest geotextile tested) be used as the permeability limit until such times as the real permeability limit can be determined. Thus it is proposed at this stage to establish the permeability limit for CDG soils at $O_{90}/D_{85} = 0.008$ (or alternatively $O_{90}/D_{50} = 0.08$).

Comparison of these results with the predictions using existing geotextile filter criteria (Equations (1) to (5) and Figure 3a) show that Equation (1) agrees well with the piping limit obtained in the test program, however, Equations (3) and (4) overestimate the actual piping limit while Equation (5) underestimates it. One reason for the poor agreement between the results obtained in the test program and those predicted using Equation (5) may be because of the extensive extrapolation required to obtain the filter criteria coefficient B in Equation (5) as Schober and Teindl(8) only provide values of B up to a base soil uniformity coefficient of 5 (both soil types tested had uniformity coefficients approximating 500).

Because of the relatively small number of filtration tests carried out using the CDV soil it is only possible to make general comparisons between those results obtained from the test program and the filter limits predicted by the five existing geotextile filter criteria (Equations (1) to (5) and Figure 3b). It appears that Equation (1) is suitable for predicting (conservatively) the piping limit for CDV soils. Equations (3) and (4) appear to overestimate the piping limit while Equation (5) grossly underestimates it. It is impossible to determine the accuracy of Equation (2).

DEVELOPMENT OF APPLICABLE FILTER CRITERIA

Due to the inability of existing geotextile filter criteria to predict the filter limits (piping and permeability) of the residual soils tested (with the possible exception of Equation (1)) it was proposed to develop alternative geotextile filter criteria especially for these soil types. To develop a geotextile filter - residual soil relationship Equation (6) was used as a basis, viz:

$$O_{90} = C\ D_n \qquad (7)$$

where O_{90} is the apparent opening size of the geotextile filter, C and D_n are the same as described in Equation (6). To utilise Equation (7) values of the coefficient C must be determined for different percentile values of n.

The relationship between C and n for CDG soil is shown in Figure 6. In providing comprehensive relationships between C and n it is possible to distinguish four regions which depict different filtration characteristics. In Figure 6 Region 1 is where it is possible for the permeability of the geotextile to be less than that of the base soil. Region 2 is where zero soil is piped through the filter and the permeability of the soil-geotextile system attains equilibrium. Region 3 is where an initial amount of soil is piped through the filter and the permeability of the soil-geotextile system attains equilibrium. Region 4 is where continual uncontrolled soil piping occurs through the geotextile. The permeability (lower) limit occurs at the juncture between Regions 1 and 2. The piping (upper) limit occurs at the juncture between Regions 3 and 4. Selection of geotextile filters which fall within Regions 2 and 3 will ensure good long term filter performance.

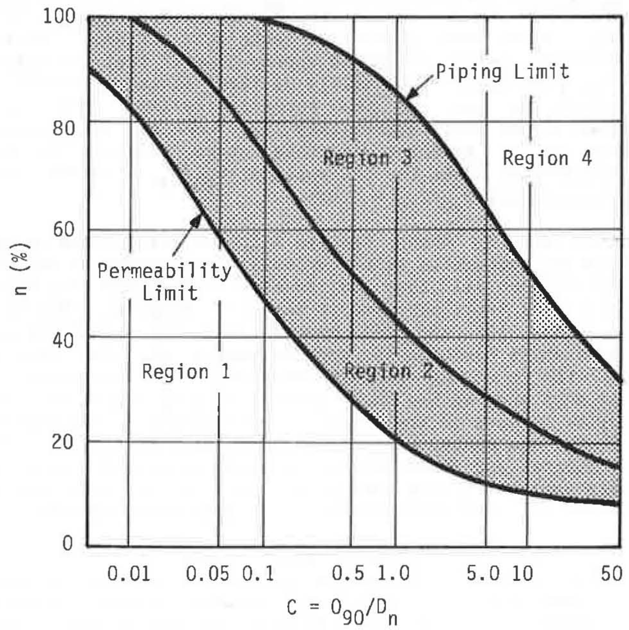


Figure 6: Values of C for Different Base Soil Particle Percentiles n for CDG Soils.

Because of the small number of tests carried out using the CDV soil it is impossible to determine in detail the relationships between C and n for this soil type. Comparison of the results obtained from the three tests using CDV soil and the filter relationships determined for the CDG soil (Figure 6) show that the relationships between C and n for CDG soils can also be applied to CDV soils. In actual fact the relationships shown in Figure 6 give conservative results when used in conjunction with CDV soils.

CONCLUSIONS

1. While the actual mechanics of base soil - geotextile filtration is quite complex the overall filtration performance requirements are quite simple. To achieve optimal filter performance the permeability of the geotextile - base soil system must reach equilibrium and the base soil must be prevented from being continually piped through the filter.

2. All of the geotextiles evaluated showed good long term filter performance with both CDG and CDV soils with test durations up to 700 days (almost 2 years). The geogrid, which was used as an extreme test (although it fell within the piping limit predicted by one of the existing geotextile filter criteria), allowed continual uncontrolled piping of soil and as such could not be considered as a filter for residual soils.

3. In general, it was found that existing geotextile filter criteria did not predict the filter limits (piping and permeability) for the CDG and CDV soils at all well - the exception being the filter criteria developed by Calhoun(5) for the piping limit. Consequently, it was desirable to develop alternative geotextile filter criteria specifically for well graded residual soils.

4. A generalised filter relationship was used as the basis for developing geotextile filter criteria specifically for CDG and CDV soils. Prediction of both the piping and the permeability limits are made using the one relationship with substitution of the appropriate filtration coefficients.

REFERENCES

(1) Brand, E.W., 'Analysis and Design in Residual Soils', Proceedings Engineering and Construction in Tropical and Residual Soils, ASCE, Honolulu, 1982, pp89-143.

(2) Lumb, P., 'The Properties of Decomposed Granite', Geotechnique, 12, 1962, pp226-243.

(3) Lumb, P., 'The Residual Soils of Hong Kong', Geotechnique, 15, 1965, pp180-194.

(4) Lumb, P., 'Slope Failures in Hong Kong', Quarterly Journal of Engineering Geology, Vol.8, pp31-65.

(5) Calhoun, C., 'Development of Design Criteria and Acceptance Specifications for Plastic Filter Cloth', US Army Waterway Experiment Station, Vicksburg, 1972.

(6) Lawson, C.R., 'Filter Criteria for Geotextiles: Relevance and Use', Journal Geotechnical Engineering Division, ASCE, Vol.108, GT10, 1982, pp1300-1317.

(7) Ogink, H.J.M., 'Investigations on the Hydraulic Characteristics of Synthetic Fabrics', Delft Hydraulics Laboratory, Publication No.146, 1975.

(8) Schober, W. and Teindl, H., 'Filter-Criteria for Geotextiles', Proceedings Seventh European Conference on Soil Mechanics and Foundation Engineering, Brighton, Vol.2, 1979, pp121-129.

(9) Rycroft, D. and Dennis-Jones, P., 'Geotextile Filtration Performance and Current Filter Criteria', Proceedings Second International Conference on Geotextiles, Las Vegas, Vol.1, 1982, pp67-72.