CHEN, R.-H., National Taiwan University, Taiwan
CHEN, C.-N., Ret-Ser Engineering Agency, Taiwan

PERMEABILITY CHARACTERISTICS OF PREFABRICATED VERTICAL DRAINS

CHARACTERISTIQUES DE PERMEABILITE DE DRAINS VERTICAUX PREFABRIQUES

DURCHLÄSSIGKEITSEIGENSCHAFTEN VON VORGEFERTIGTEN VERTIKALDRÄNS

The permeability characteristics of five prefab vertical drains were studied for future selection in the reclamation projects. The tests include tensile strength and elongation test, filter permeability test, filter pore size distribution test, and longitudinal permeability tests of drain with and without soil confinement. The results of filter permeability test confirmed that those filters with higher portions of larger pores have higher permeability. In addition, drain materials with thicker and harder cores also have higher permeability. However, the elongation of filter reduced the longitudinal permeability. The study also recommends a retention criteria for thin nonwoven fabrics.

Es wurden die hydraulischen Eigenschaften von 5 vorgefertigten Vertikaldränagetypen untersucht. Diese Prüfungen enthalten Zugfestigkeitsprüfung, Durchlässigkeitsprüfung und Prüfung der Öffnungsweite des Filtermaterials sowie Durchlässigkeitsprüfungen in Längsrichtung, mit und ohne Bodeneinfluß. Es zeigte sich, daß grobporige Filter eine höhere Durchlässigkeit besitzen. Weiters zeigen Dräns mit dicken und hohen Kurven eine höhere Durchlässigkeit. Die Dehnung des Filters reduziert die Transmissivität. Die Studie empfiehlt auch ein Filtertkriterium für dünne Vliese.

1. INTRODUCTION

In recent years, the prefab vertical drains have been used in many soil improvement projects because of its economy, easy for transportation and construction, and time-saving. However, there are many brands of prefab drains on the market and their permeability characteristics are various because of the differences in the method of production, material properties, geometries, and soil conditions. In order to provide information for future selection of the prefab drains used in the reclamation projects, five drains were selected and studied in the laboratory. They were selected in the consideration of their structures (shapes, geometries, and compositions) of both filters and cores. Furthermore, these drains must have been used before. They are Alidrain, Castle Board, Geodrain (white), Geodrain (paper), and Mebradrain.

2. TESTING PROGRAM

Generally speaking, the three most significant factors which affect the permeability characteristics of the prefab drains are the filter, the core, and the soil condition. Hence a testing program was set up to find out the permeability characteristics effected by the material composition, the method of production, the pore size distribution of the filter, and the tensile strength and elongation of the drain. According to above, the testing program includes: the pore size distribution and the permeability tests for the filter, the longitudinal permeability tests of drain with and without soil confinement, and the tensile strength and elongation test.

2.1 Longitudinal Permeability Test with Soil Confinement

To simulate the drains embeded in the ground, the drain specimen was confined and consolidated by remolded soil contained in the cell (Fig. 1). The soil obtained from Taipei basin was classified as CL by the Unified Soil Classification System. The grain size distribution of soil in shown in Fig. 8. The unit weight of the soil is 1.80–1.90 Mg/m³. There are four levels of confining pressures: 20, 100, 200, and 300 kPa.

After 100% primary consolidation of soil, the longitudinal permeability test was run under constant pressure head. The coefficient of longitudinal permeability k_l can be calculated by equation (1).

$$k_l = \frac{QL}{AH} \tag{1}$$

where
A = original cross section area of the drain, m²
H = water pressure head difference, m
L = length of the test specimen, m
Q = average volume of discharge, m³/s

2.2 Longitudinal Permeability Test Without Soil Confinement

The longitudinal permeability test with soil confinement is time-consuming in preparation of sample and consolidation of soil. In order to save time, the test under no soil confinment is performed. However, the test results will be compared with those under soil confinement so that the effect of soil can be understood. In this test; the specimen was wrapped by rubber membrane instead of soil. The testing procedures follow those of 2.1.

2.3 Permeability Test of Filter Material

This test is probably the most important one among the five tests. Firstly, the drain was saturated in the de-aired water in the cell (Fig. 1), then a constant pressure head is applied. After the rate of discharge (must be within $0.2 \times 10^{-3} \sim 8.0 \times 10^{-3}$ m³/s) was stable, the data were taken. The permeability of the filter k_n is obtained from equation (2)

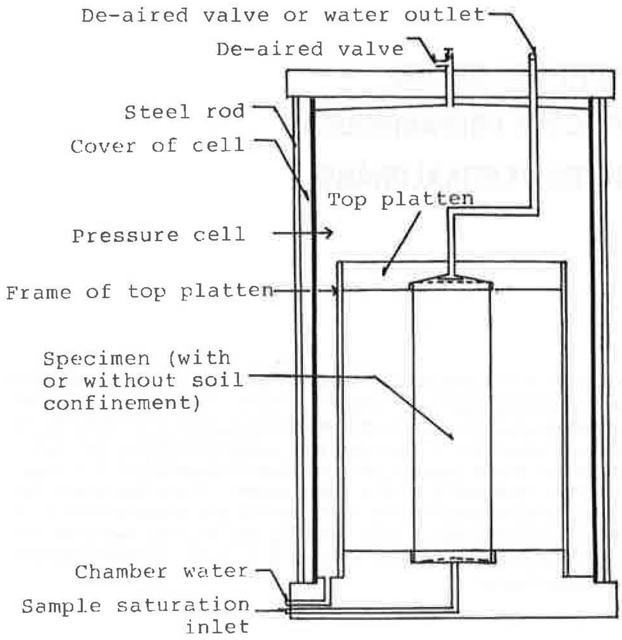

Fig. 1 The Cell of Permeability Test

$$k_l \cdot A \cdot H \cdot \left(\frac{k_n \cdot W}{k_l \cdot A \cdot T}\right)^{1/2} = Q \cdot \coth \left[L \left(\frac{k_n \cdot W}{k_l \cdot A \cdot T}\right)^{1/2} \right] \quad (2)$$

where
- A = effective cross section area of the drain, m
- H = the pressure head difference between testing chamber and exit of vertical drain, m
- L = effective length of vertical drain specimen, m
- Q = discharge velocity, m^3/s
- k_l = the longitudinal permeability of vertical drain material at 10 kPa confining pressure determined by the longitudinal permeability test, m^3/s
- T = thickness of filter layer, m
- W = effective width of filter layer, m

2.4 Mercury Intrusion Test

The pore size distribution of the filter has direct and significant influence on the permeability of the filter. This test is run with a mercury intrusion porosimetry. The diameters of the pores can be calculated by equation (3) (1):

$$P \cdot r = 2T \cdot \cos\theta \quad (3)$$

where
- P = absolute pressure, k Pa
- r = the diameter of the pore, m
- T = surface tension, kN/m
- θ = the contact angle of mercury and the material, degree

2.5 Tensile Strength and Elongation Test

The drain wll undergo tensile stress during installation and by the lateral pressure of the soil. It is thus necessary to understand the stress-strain relationship of the drain material so that the effects of installation speed and consolidation rate of soil can be considered. The specimen was tested along its longitudinal direction under a rate of 305±10mm/min to obtain its average tensite strength and elongation.

3. PORE SIZE DISTRIBUTION OF FILTER MATERIAL

The selected filters are different in composition which includes the material itself and the method used to strengthen the filter. Consequently, their performances are expected to be quite different. However, the most significant factor dominating the drainage capability is probably the pore size distribution of the filter. Unfortunately, the testing method for determination of pore size has not been standardized so far. The EOS (equivalent opening size) method has its own limitation in measuring small pores due to the electrostatic forces effect (2). Hence, the mercury intrusion test was applied on the measurement of pore size.

It needs to mention here that the filters had been studied by the macroscopy before running the intrusion test. The twenty magnification (20X) photo of the filter of Alidrain (Photo 1) shows many white spots. Same white spots can be seen for Castle Board, white Geodrain, and Mebradrain, but these photos are not shown. The white spots are the pores that the light can pass through. The only photo which does not have clear white spots is the photo of paper Geodrain.

From Photo 1, it can be seen that the pores have various sizes and they are distributed randomly or concentrately. This phenomenon were found not only in various brands of filters but also in the same brand of filter.

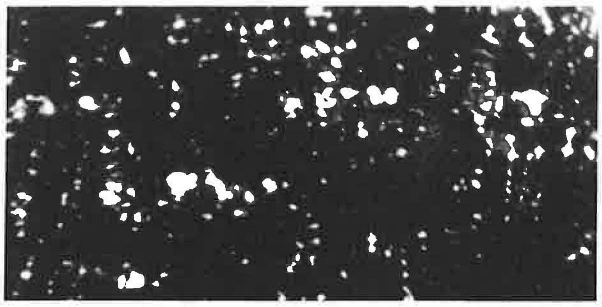

Photo 1. The 20X Photo of the Filter of Alidrain

The pore size distributions of five filters measured by the mercury intrusion test are presented in Fig. 2. For paper Geodrain, the curve is not so smooth as those of other filters, but shows step-wise distribution. This is probably due to break-down of strengthening material by the high pressure of mercury intrusion. The histograms of each drain are shown in Fig. 3. Mebradrain has the highest percentage of larger pores (0.1mm); Alidrain has about 50% of the pore sizes close to 0.05mm; Castle Board has more larger pores than Alidrain and most of the pore sizes are within 0.062 – 0.116 mm; while white Geodrain has uniform distribution of pore size.

4. STRESS-STRAIN RELATIONSHIP OF DRAIN

The stress-strain behavior of prefab drains are effected by their structures. The cores of each drain will be described first. Alidrain has alternate heights of many small studs on the surface of the core. Castle Board has solid castle-shaped core and high resistance to lateral soil pressure. The contact portion of the filter and the core of two Geodrains are thin lines. The core of Mebradrain is also castle-shaped but thinner than that of Castle Board. Typical stress-strain curves are presented in Fig. 4. The first peak point of the curve is the failure point of the filter material and the second peak point represents the failure point of the core. Note that Castle Board has only one peak point and highest strength because its filter and core are glued together.

All the first failure points of the tensile strength and elongation tests are presented in Fig. 5. It can be seen that, in general, Castle Board has the highest tensile strength while white Geodrain has the lowest strength, and those of Mebradrain, Alidrain, and paper Geodrain are in between. For the elongation of drains, Alidrain and Mebradrain are larger than those of three other drains. These behaviors certainly have some connection with the composition of the drains. For example, Alidrain is composed of polyester fibers. Mebradrain is comprised of 100% polypropylene. Two Geodrains are composed of cellulose fibers and are easily to be teared off by fingers due to their thin thickness (Table 1).

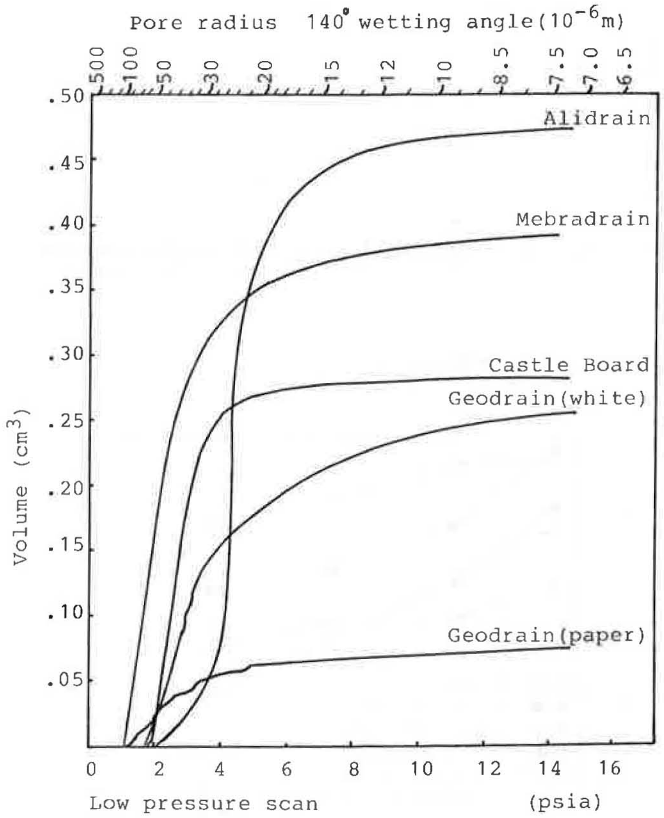

Fig. 2 Pore Size Distributions of Filters Measured by Mercury Intrusion Porosimetry

5. LONGITUDINAL PERMIABILITY OF DRAIN

The result of longitudinal permeability test is shown in Figs. 6 & 7. In general, the permeability decreases as the confining pressure increases (Fig. 6) under no soil condition. This phenomenon is not so obvious in the condition with soil confinment (Fig. 7). In addition, comparison of Figs. 6 and 7 show that the longitudinal permeability will reduce when the drains are under soil confinement except for Castle Board. This is probably because the filter and the core of Castle Board are glued together and hence the amount of elongation is small. Consequently, the reduction in the area for discharge is less. The other possibility might be due to the high stiffness of the core and hence it is hard to be compressed by confining pressure.

On the contrary, Alidrain has many studs of two different heights on the core. Since the contact area of the filter and the core is not so much that large deformation of the filter may easily produce under confining pressure. Hence, Alidrain has the lowest longitudinal permeability among the five drains.

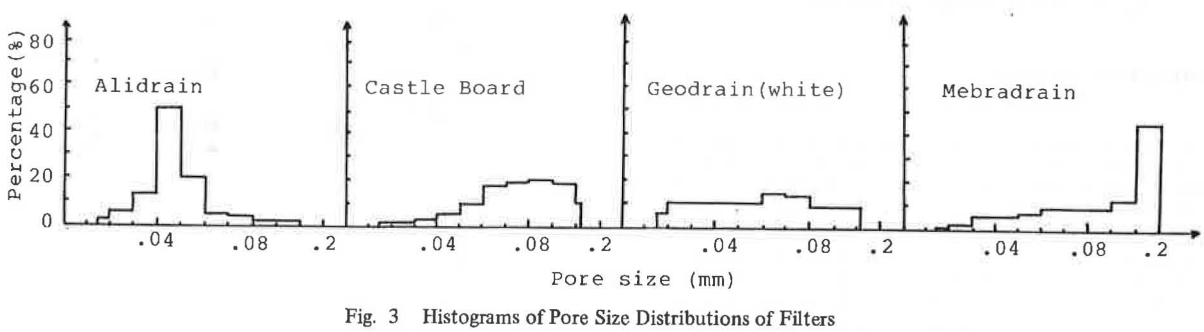

Fig. 3 Histograms of Pore Size Distributions of Filters

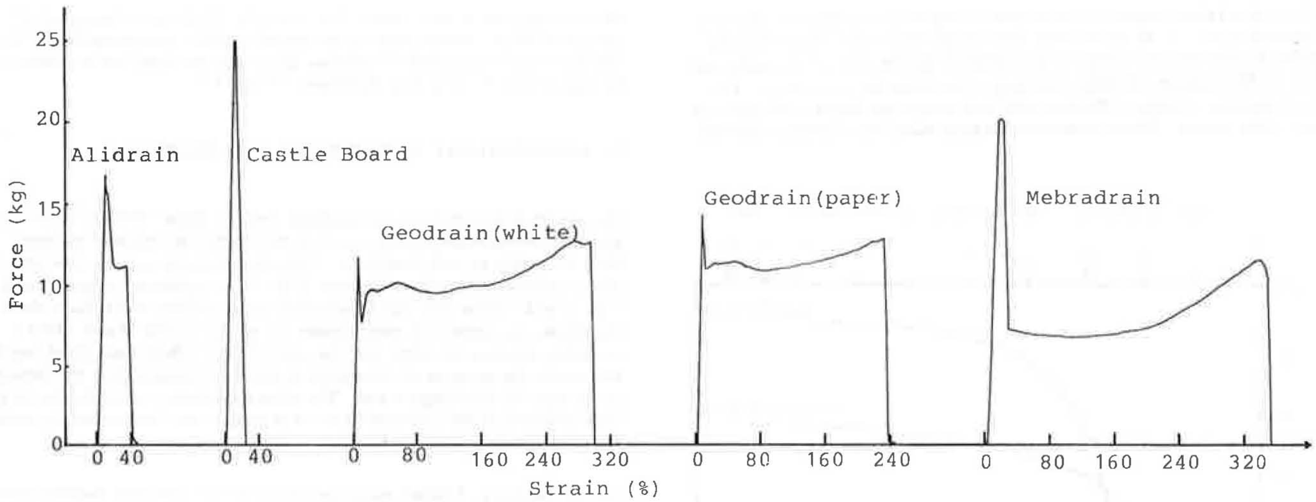

Fig. 4 Tensile Strength — Elongation Curves of Varous Drains

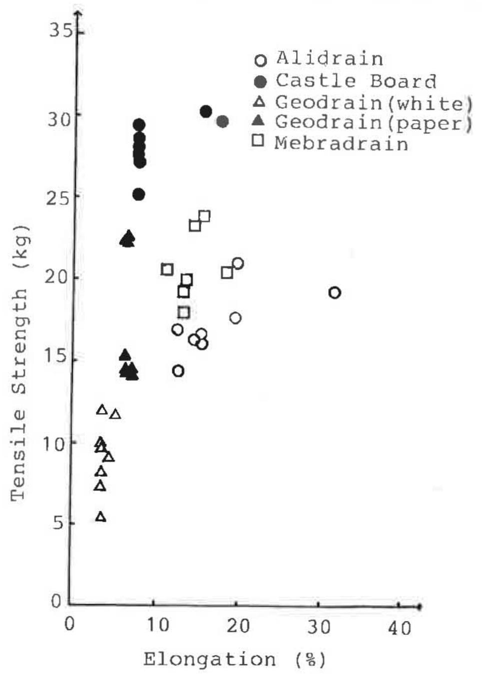

Fig. 5 Tensile Strengths of Various Filters

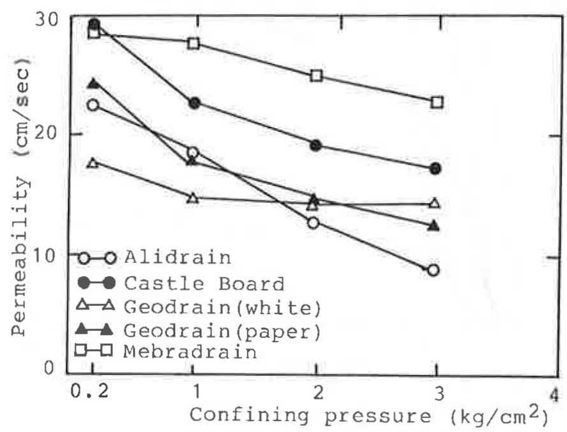

Fig. 6 Longitudinal Permeability-Confining Pressure Relationships of Drains without Soil Confinement

6. PERMIABILITY OF FILTER

The result of permeability test of filter material is shown in Table 1. Mebradrain has the highest coefficient of permeability but also the thickest filter. Paper Geodrain has the thinnest filter while the coefficient of permeability is the smallest. However, two Geodrains have the same thickness of filters, but the coefficient of permeability are different by as much as five times. It is therefore concluded that the thickness of the filter is not a dominating factor for the permeability of the filter. On the other hand, the effect of pore size distribution on the coefficient of permeability is obvious as can be seen from Table 1. Those filters with higher portions of larger pores have higher permeability. For example, Mebradrain has the highest portion of larger pores (45% larger than #140, also see Fig. 3) and hence the highest coefficient of permeability.

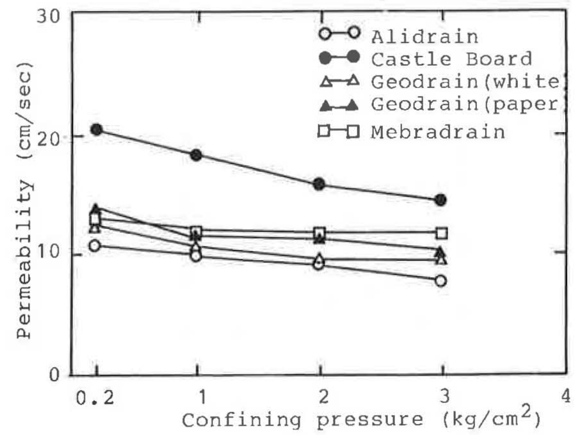

Fig. 7 Longitudinal Permeability-Confining Pressure Relationships of Drains with Soil Confinement

Table 1. Pore Size Distribution, Thickness, and Permeability Filters

Brand		Alidrain	Castle Board	White Geodrain	Paper Geodrain	Mebradrain
Thickness (mm)		0.334	0.424	0.22	0.22	0.549
Mercury	plus #140	1	9	9	*	45
% retained	#140∿#200	5	54	27	*	28
by weight	minus #200	94	37	64	*	27
Coefficient of permeability (m/s)		1.54×10^{-6}	9.80×10^{-6}	1.40×10^{-6}	2.71×10^{-7}	2.39×10^{-5}

* Not applicable by mercury intrusion method

7. FILTER-SOIL INTERACTION

In order to evaluate the permeability characteristics of the drains accurately, several factors need to be considered, e.g., the electro-chemical forces of the geotetile filter, chemical properties of fibrous structure compound and soil composition (3). However, the retaining ability of the soil surrounding the geotextile is too complicated to be determined. Hence, the rules-of-thumb were proposed.

(a) $\frac{O_{90}}{d_{50}} < 1.7 \sim 3$ by Schober and Teindl (4)

(b) $\frac{O_{95}}{d_{85}} < 2 \sim 3$ by Calhoun (5)

where On corresponding to n percent opening size for filter material, d coresponding to particle diameter as determined by sieve analysis for soil. It is of interest to check the above two criteria by using the data obtained from the pore size distributions of filters and soil (Fig. 8). The result is presented in Table 2.

It seems that criterian (a) is too conservative for the five drains studied, especially for Calstle Board. On the other hand, the criteria proposed by Calhoun seems to be more close to the data. However, in Authors' opinion, Calhoun's criteria seems to be more suitable for filters with large portions of larger pores. Since the mercury intrusion method can determine the smaller sizes more accurately, the following two criteria are proposed based on this study:

Table 2. Relationship between Pore Sizes of Filters and Soil Grain Size

Criteria	Alidrain	Castle Board	White Geodrain	Mebradrain
$\frac{O_{90}}{d_{50}} < 1.7 \sim 3$	4.6∿6.0	7.0∿9.0	3.0∿4.0	5.8∿7.6
$\frac{O_{95}}{d_{85}} < 2 \sim 3$	0.9∿1.4	1.4∿2.1	0.7∿1.0	1.2∿1.7
$\frac{O_{90}}{d_{85}} < 1.2 \sim 1.8$	1.2∿1.8	1.8∿2.7	0.8∿1.2	1.5∿2.3
$\frac{O_{50}}{d_{50}} < 10 \sim 12$	6.1∿8.2	10.1∿13.5	8.1∿10.8	12.2∿16.3

$$\frac{O_{90}}{d_{85}} < 1.2 \sim 1.8 \quad \text{and} \quad \frac{O_{50}}{d_{50}} < 10 \sim 12$$

The ratio O_{50}/d_{50} ensures that seepage forces within the filter are reasonably small. The reason to choose the upper bound of O_{50}/d_{50} to be 12.0 instead of 13.5 and 16.3 for those of Castledrain and Mebradrain, respectively, is that fines were found in the cores of these two drains after test. Smaller upper bound can prevent fines from entering the core. In addition, the reason to choose O_{90} is beaause the slope of the curve changes much near O_{90} and it can be measured more accurately by the mercury intrusion method. Besides, white paper Geodrain has too small coefficient of permeability, hence the ratio of O_{90}/d_{85} is chosen based on the performance of the other four drains.

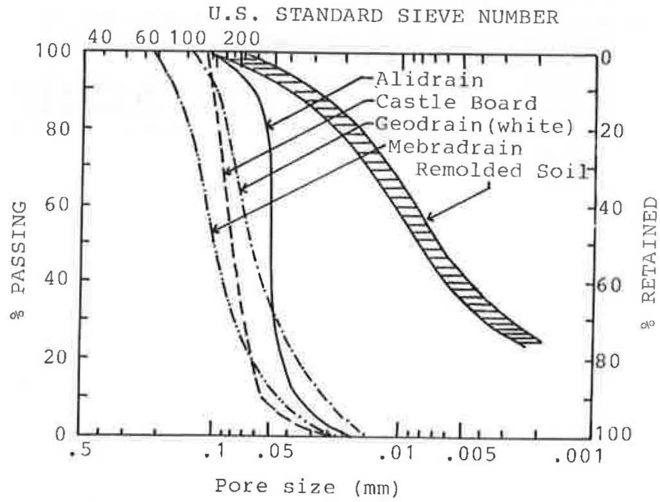

Fig. 8 Pore Size Distributions of a Soil and Various Drains

CONCLUSIONS

The study of the permeability characteristics of five representative prefab vertical drains was performed. The test program was set up in consideration of various performance, they are longitudinal permeability test, permeability of filter tests with and without soil confinement, tensile strength-elongation test, and mercury intrusion test for the filter pore size distribution. The conclusions from the test results are summarized as follow :

1. The permeability of filter is significantly effected by the pore size distribution of the filter. Those filters which have large portions of larger pores have higher permeability.
2. Thick and hard cores have good resistance to confining pressure and hence higher coefficient of permeability.
3. Large elongation of drains reduces the longitudinal permeability.
4. A criterion based on the ratios of O_{90}/d_{85} and O_{50}/d_{50} is proposed.
5. The longitudinal permeability of vertical drain decreases as the confining pressure increases whether there is soil confinement or not.

ACKNOWLEDGEMENTS

The Authors would like to express their thanks to Mr. J.S. Yang of RSEA, who initiated this project, and provided valuable information during this study. Special thanks are also extented to Profs. W.L. Cheng and C.L. Hwang at National Taiwan Institute of Technology, Moh and Associates, Inc., and Mr. Y.C. Ho of RSEA for their unselfish assistance and encouragement during this research. The research funding is provided by Ret-Ser Engineering Agency. Mr. K.Y. Tse read the manuscript. Mr. M.H.

Lok drew the figures.

REFERENCES

(1) Sridharan, A., Altschaeffl, A.G., and Diamond, S., "Pore Size Distribution Studies", Soil Mechanics and Foundations Division, ASCE, Vol. 97, SM5, May, 1971, pp. 771-787.
(2) Gerry, B.S. and Ray, G.P., "Equivalent Opening Size of Geotextiles", Geotechnical Testing Journal, GTJODJ, Vol. 6, No. 2, June, 1983, pp. 53-63.
(3) Kellner, L., Bally, R.T., and Matter, S., "Some Aspects Concerning Retaining Capacity of Geotextiles", 2nd. Int. Conf. on Geotextiles, Las Vegas, U.S.A., pp. 85-90.
(4) Schober, W., and Teindl, H., "Filter Criteria for Geotextiles", In Design Parameters in Geotechnical Engineering, BGS, London, England, Vol. 2, 1979, pp. 121-129.
(5) Calhoun, C.C., Development of Design Criteria and Acceptance Specifications for Plastic Filter Cloth, U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS, Tech. Rept. S–72–7, June 1972, pp. 6-55.