Laboratory Study of Vertical Drains for a Ground Improvement Project in Taipei

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ABSTRACT: This study was performed to evaluate the general specifications of the vertical drain for a ground improvement project in the Taipei MRT system. Concerning the in-situ condition, the major performance-related properties reviewed in this paper are clogging resistance of filter geotextiles and the flow rate of the drains. Six types of vertical drain were collected for the testing program and a clayey soil sample was obtained for the performance test. The flow rate of drains was determined under the controllable hydrostatic confinement condition. It was found that the flow rate was to be influenced by the period and the level of confining pressure applied. 3-days is the minimum testing period recommended to meet these specifications. Findings are provided for further consideration of this typical project. To ensure the flow rates of the various drains are acceptable for the job, the required flow capacity calculated from the consolidation process was also studied and analyzed in this paper.

1 INTRODUCTION

Use of sand drains to decrease the time necessary for consolidation of preloaded saturated soft soils has been known since Moran(1926) and Porter(1936). The theoretical basis and analysis method for determining the variables associated with the requsted radial consolidation was formulated by Barron (1948) in the late 1940's. However, in application it was found later that the placement of large sized sand drains, with their compressing effect, could disturb the surrounding soil and significantly affect performance. Furthermore, the limited specification of sand used was also a hindrance to construction. Thus, the material for a strip-type artificial drain of much smaller size was developed for use, and gradually replaced sand drains. This kind of material was first made of paper. In the 1960s, with the development of the petrochemical industry, polythene, polyproplene, polyester and PVC plastic became the major components of artificial drains.

In terms of the drain material's characteristics, a filter is necessary to filtrate the soil grains and to allow water to enter the core. The core gathers the compressed water which is then channelled to the surface of drainage layers. Various analytical theories and designed methods were developed on the basis of these two characteristics. In recent years, the design theories and analysis models of the geotextile applied to filtrate have matured. Whether filtration and drainage can fully function in the drain filter layer has become a crucial factor to this technique. Thus, in the hope that the material selection can ideally reflect the performance and upgrade the reliability of vertical drain evaluation and analysis models, this research put emphasis on the study of related material behaviors for vertical drains.

2 BACKGROUND AND SCOPE OF STUDY

The purpose of this study was to evaluate and analyze the related properties of vertical drains. By utilizing the performance test, the vertical drainage capacity was also evaluated in order to better understand the stability of the vertical flow rate under the simulated in-situ confining condition. Soil adopted in this study was soft clayey soil. And, types of vertical drains were sampled with the symbols of L, K, F, C, M, and S. To set up the study plan and test program, preliminary review of the following considerations was required.

2.1 Filtration Function of the Geotextile to the Soil

Haliburton (1982), Christopher and Holtz (1985) along with many other researchers have pointed out that the piping resistance and clogging behavior should be taken into consideration for the functions of filtration and drainage with geotextiles. For piping resistance, the relationship of the "Apparent Opening Size" (AOS) with the soil granules was used for making schemes. To evaluate the clogging resistance, it was suggested that the performance behavior, the Gradient Ratio(GR), should be less than 3. The above two properties were the basic examination standards for material selection, and will be first reviewed and evaluated in this study.

2.2 Flow Rate Capacity

Following the entry of the pore water into the cores by way of the filter, the study focused on the flow rate capacity to ensure a smooth drainage channel in the cores. The factors influencing the flow rate capacity need to be summarized herein.

The typical shapes of cores are classified into stud, groove and mesh. However, because the factors involved are too complicated, the performance of the drainage channel cannot be evaluated by simple geometrical behavior. Additionally, the interacting effect of the tensile modulus further obscures the evaluation. Since the drainage channels are divided by core and confined within the filter, the drainage capacity is believed to be affected by the changes of the cross area under in-situ conditions. Factors included are shapes and compressibility of the core, tensile and creep behaviors of the filter, as well as other properties. Again, the interacting effects are too complicated to be evaluated by simple geometrical behavior. A performance test for monitoring the vertical drainage capacity was therefore properly designed for this study.

Bengt and Normand (1985) indicated that during the consolidation settlement period (more than 5% of thickness), the drain may be folded with the settlement and consequently the drainage capacity may be diminished or lost. Folding was simulated and evaluated in this performance test.

The above phenomena could significantly block the drainage water from entering the cores, build up pore water pressure, and thus lead to the failure of earth work. This is known as the well resistance effect (Barron, 1948). Six types of drains were properly selected from six different manufacturers to cover the material characteristics and variations. Basically, the drain sizes are the same (the width is 10cm± 10%, and the thickness ranged from 3mm to 6mm), except for the core section shapes and the filter geotextile materials. The general properties are provided in Table 1. The related test equipment and methods are briefly described as below.

Table 1. General properties of drains.

Drain	Size	Material		Tensile strength, kg (Extension Ratio,%)	
	Width (Thickness)	Core (Section)	Filter	Core	Filter
L	95.4 (3.2)	PVC (Groove)	Papery nonwoven	370 (30)	21 (11)
K	93.2 (3.5)	PVC (Groove)	Papery nonwoven	377 (29)	20 (12)
F	99.6 (6.1)	Polythere (Stud)	Polyproplene*	263 (51)	69 (77)
C	99.4 (5.2)	Polyester (Mesh)	Polyester*	207 (68)	92 (27)
M	99.1 (3.6)	Polythere (Groove)	Polyester*	251 (23)	101 (86)
S	99.5 (4.4)	Polythere (Stud)	Polyester*	257 (46)	98 (94)

*Heat-bonded.

3 TEST PROGRAM AND METHOD

3.1 Hydraulic Properties of Filter Geotextiles

Filter geotextile's hydraulic properties including permeability, piping resistance and clogging resistance potential were evaluated. For permeability and piping resistance, the test procedures were arranged to follow the methods of ASTM 4491-87 and ASTM 4751-87 accordingly. The details referring to those standards are not covered herein. For clogging resistance potential, which is known as the most important factor that influences filtration/drainage performance of the soil system, the Gradient Ratio Test (GR Test) was adopted in this study. ASTM 5101 method was implemented for the test procedures and related details. Soil used in the test program was obtained from one particular site of the Taipei MRT project which is subject to the vertical drain treatment.

3.2 Flow Rate Capacity Test

To better understand how lateral earth pressure may influence the in situ drains, the performance test was designed to study the stability of vertical drainage capacities. For engaging the confining pressure to apply on the vertical drain, the rubber membrane was directly installed and covered the drains in a specially designed triaxial cell. In this situation, special consideration on the clamp details was given to avoid the leakage problem around the wedges of band-shaped specimen. The typical unit details are given in Fig.1. During testing, 0.75kg/cm^2, 1.5kg/cm^2 and 3.0kg/cm^2 were selected as confining pressures; this is to simulate the in-situ depth of overburdening to 7.5m, 15m, and 30m accordingly.

It was considered that under the confining pressure effect, the geotextile may be crowded into core drainage channels due to the creep strain. If this occurs, the drainage capacity will gradually drop, which results in the malfunctioning of the vertical drain. Based on this consideration, several trials were made to select the proper testing period. A long-term period of 144 hours was then selected for each set of controlled conditions during the entire test program.

In addition, as consolidation settlement of the soil mass proceeds, the drains are subject to, and must accommodate the axial shortening. Christopher and Koerner(1988) have summarized the various possible foldings for this shortening behavior. In this study, local bending, U- and V- shaped foldings were simulated for specimen installation and testing. The units manufactured for shaping the foldings were designed based on a 10% settlement of the soil layer. Details of these arrangements are also given in Fig.1. To simulate the in-situ flow conditions, water was supplied from the bottom of the device to produce an upward flow during testing.

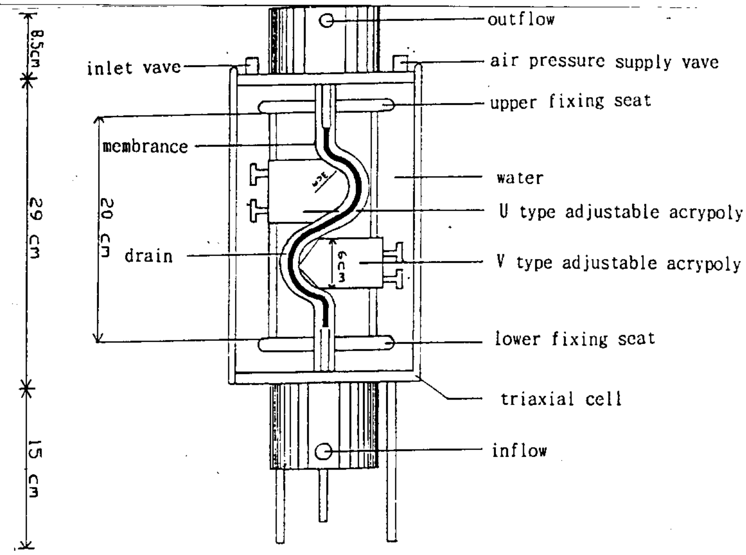


Fig. 1 Test apparatus for flow rate capacity

4 RESULTS ANALYSIS AND DISCUSSION

4.1 Hydraulic Properties

In this part of the study, the clogging resistance potential of the geotextile resulting from the particular in-situ soils along with the vertical drainage capacity of the simulated underground confining conditions are to be analyzed and discussed. To evaluate the clogging resistance of filter geotextiles, the filtration and drainage functions were considered by means of basic criteria. As mentioned, the GR<3 was used as the limiting of factor to judge the clogging phenomena from the results given in Fig.2. Results indicated that all GR values exhibited met the "<3" requirement under a lower gradient (i=1.0). In this part, because the cohesive soil particles could not be moved easily toward the geotextile, it did not lead to significant clogging. In view of this consideration, even with the extremely low value of the GR presented by sample S, a judgement is hard to make. However, with a higher hydraulic gradient (i=5.0 and 10.0), samples of C, M, and S may be defined as being clogged. For long-term considerations, sample M may be selected for use because its GR values could be gradually reduced during the testing period. By reviewing GR values and the potential to change over the elapsed time, the selection can also be made for samples L and K. However, the judgement is still not certain and long-term testing may be required of sample F to ensure that the filter system in the soil can be developed and performs to the lower gradient ratio.

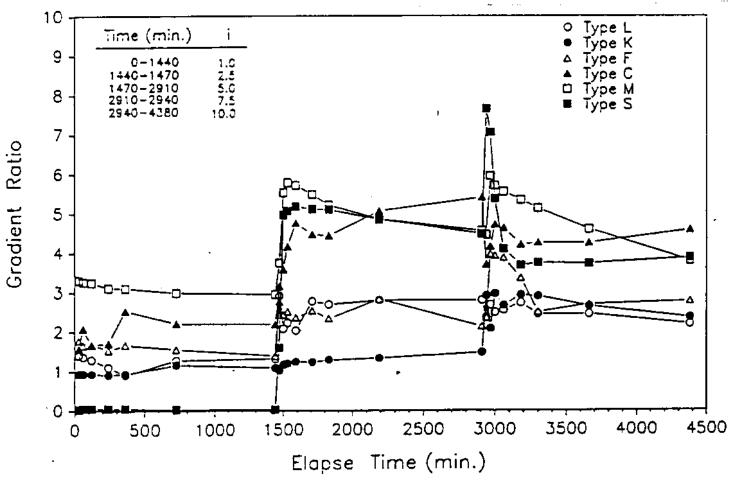
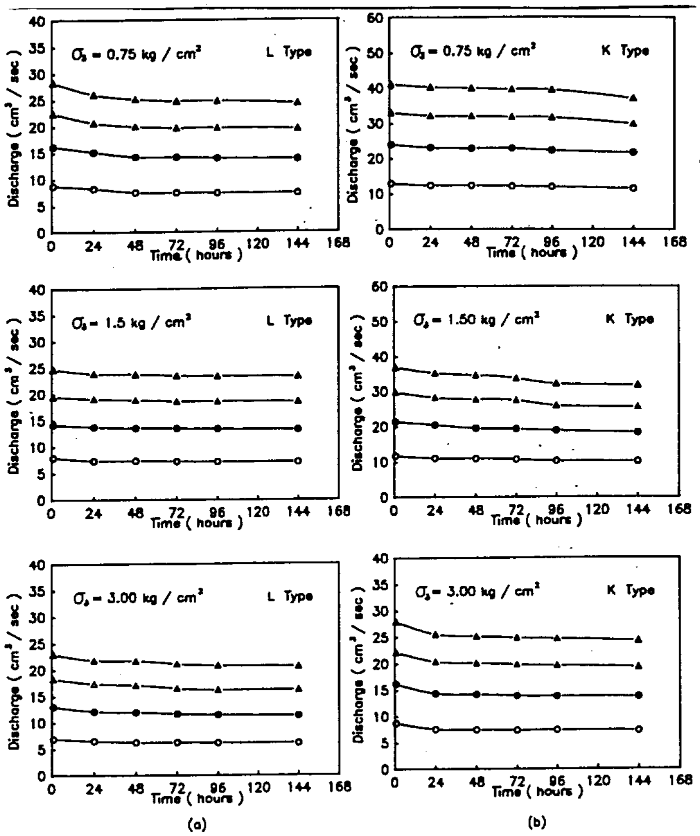
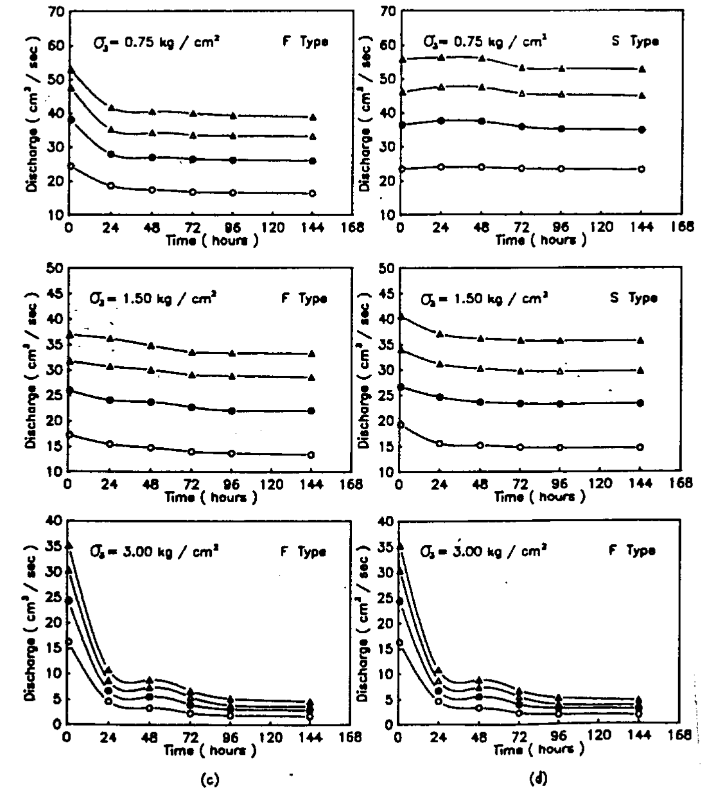


Fig. 2 GR Test results

In reviewing the results of flow rate testing, the analysis was made in two ways. The first approach was focused on the flow rate changes during the testing period. The results are shown graphically in Fig.3. The following approach was considered for the effect of confining pressure on the changes of flow rate. For evaluating purposes, results are represented in a formal way, as shown in Fig.4. It is considered that with the onset of confining pressure, vertical drains may be deformed and result in a reduction of flow rate. For the first approach, the reduction can obviously be found on samples F and S in Fig.3. For other drains, the flow rate changes with time elapsed are not significant.





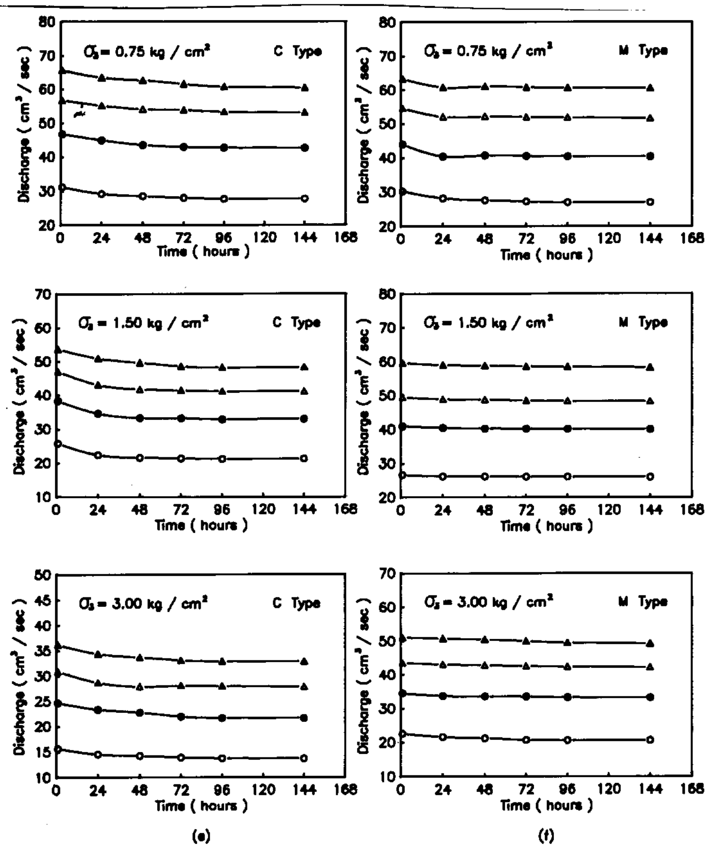


Fig. 3 Relationship of flow rate and time
(Heads, ○ : 10cm, ● : 20cm, △ : 30cm, ▲ : 40cm)

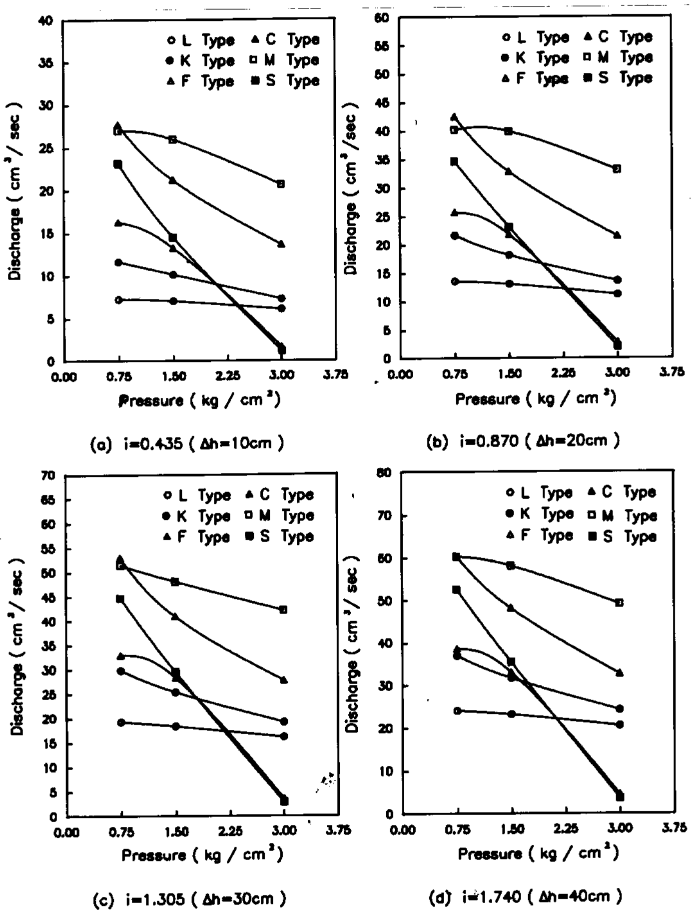


Fig. 4 Relationship between flow rate capacity and confining pressure for drains with different hydraulic heads

Generally speaking, flow rate for all tested drains remained fairly stable after a 72-hour testing period. This indicates that the creep effect on the drain deformation is negligible over a long period of confining pressure. However, to obtain the flow rate for design considerations, a testing period of at least 72 hours is required.

4.2 Required Flow Rate

Before reviewing the flow rate from Fig.4, a number of attempts for predicting the required flow rate are reviewed. Notable among these are Jamiolkowski et al. (1985), Holtz, et al. (1986), Cazzuffi (1986), and Lawrence and Koerner (1988). In their analysis, it is assumed that each vertical drain is a free drainage path and is therefore capable of removing the required amount of expelled water. In their prediction, the particular projects were the known basis for calculation. However, they used a simplified procedure, instead of determining the required flow rate and time dependent factor.

For this part of the study, the equations of Barron(1948) and Newman(1931) were adopted for evaluating the consolidation properties.

The following set of conditions which were applied to predict the required flow rate, were taken from an actual project in Taipei:

Clayey silt soil(CL-ML) having Cv=0.00423 m^2/day and Ch=0.00311 m^2/day; 30.0 m deep with vertical drains 2.0m center to center; and consolidation settlement calculated as 2.5m. Total volume of water squeezed out of soil mass due to 2.5m consolidation can be obtained.

$Q=\pi\ (2)^2 \div 4 \times 2.5=7.854\ m^3$

The degree of consolidation with elapsed time is given in Fig.5(a). Therefore, total volume of water squeezed out of soil mass is obtained and also shown in Fig.5(a). Following Fig.5(a), the rate of water flow is given Fig. 5(b).

In this figure, the minimum flow rate is indicated and therefore, the suggested flow rate with 3.0 of safety factor is obtained.

minimum flow rate = 0.085, m^3/day
= 0.98, say 1.0 cm^3/sec
Safety factor = 3.0
Suggested flow rate = 1.0 x 3.0
= 3.0 cm^3/sec

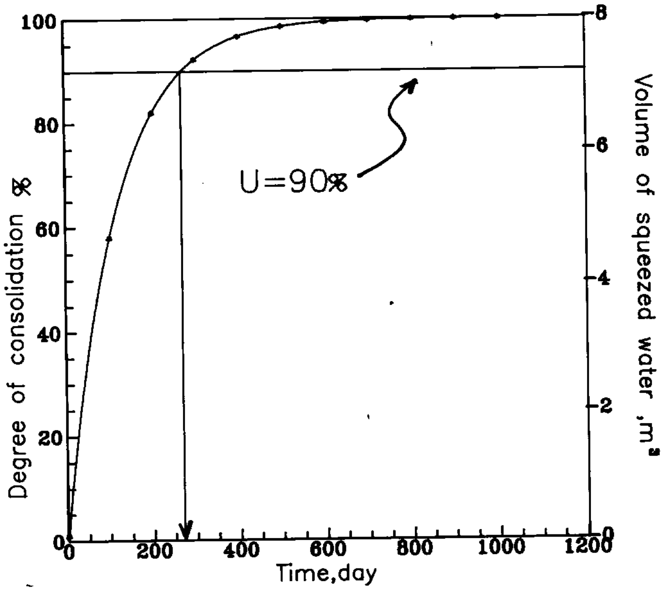
According to the suggested flow rate in this particular case, the properly selected vertical drains can be determined from Fig. 4, they are, L, K, C, and M types.

It must be considered that the drain must provide the required flow rate at the maximum applied normal stress to which it will be subjected in this study, types F and S drains were not suggested for this project. By combining this finding with the clogging resistance consideration for filter geotextiles, only L and K types of drains are recommended for use.

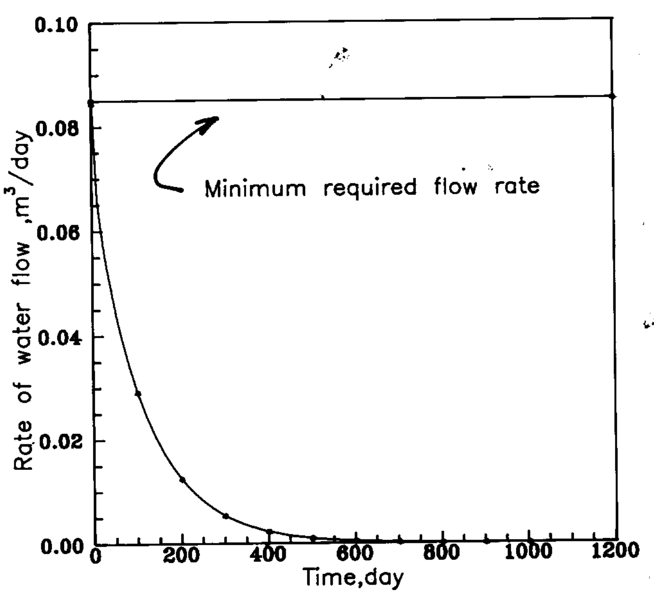
5 CONCLUSION

Based on the results analyzed above, the findings can be concluded as below.

1.A flow rate of at least 3 days is necessary to remain stable, and can therefore be used to judge the material selection.
2.A GR test is recommended to evaluate the clogging potential of filter geotextiles.
3.For design considerations, determining the minimum and the suggested flow rate are recommended.
4.When judging the material selection GR test and the flow rate need to be properly combined.



(a)



(b)

Fig. 5 (a) Prediction of consolidation behaiors, (b) Determination of minimum required flow rate

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