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APPLICATION OF GEOTEXTILES IN EMBANKMENTS AND DAMS
UTILISATION DE GEOTEXTILES DANS LES DIGUES ET BARRAGES
ANWENDUNGEN VON GEOTEXTILIEN IM DEICHBAU UND DAMMBAU

This report presents the applications of geotextile filters and their properties for filtration in embankment and dam. The effects of geotextile filters have been proved through two cases, i. e. an earthdam and one polder dike. When the needlepunched nonwoven geotextile were used for the earthdam, their filtration properties are similar to those of granular filter, their efficacy were obtained in this project. When the woven geotextile were applied to the polder dike, with the specific grain-size distribution, the soil stratum itself gradually become a naturel filter so that the anti-seepage capacity of foundation soil was improved. Also, this paper describes in detail the experiments of two cases and the analyses of their results.

Diese Arbeit berichtet über die Anwendungen von Geotextil-Filtern und über ihre Filtereigenschaften in einem Erddamm und einem Küstendeich. Die Verwendung eines Nadelfilzvlieses im Erddamm zeigt, daß seine Filtereigenschaften jenen körniger Filter ähnlich sind und daß es sich für diese praktische Anwendung bewährte.
Beim Einsatz eines gewobenen Geotextils im Küstendeich mit spezieller Kornabstufung des Untergrundes kam es in der Bodenschicht zur Bildung eines natürlichen Bodenfilters, sodaß die Beständigkeit des Untergrundes gegen Durchsickerung verbessert wurde. Diese Arbeit beschreibt weiter im Detail die Untersuchungen an diesen beiden Bauwerken und die Analyse der Ergebnisse.

INTRODUCTION

It is well known that the failures of dams and dikes are mainly caused by water flow, external forces and the insufficient strength of earth mass, in which the seepage flow plays an important role in causing such failures, as is shown in Fig.1. To avoid the erosion and piping inside the earth mass by the action of seepage flow, Terzaghi proposed that a drainage filter constructed with different granulometric composition should be used as a protection for earth mass. Some good results have been obtained from this proposal in a number of construction works. Facts have proved that the geotextile filters are same as the granular filters in respect of drainage filters. The use of geotextile filters is good practice for the anti-seepage capacity of foundation soil.

This report gives a summary of action mechanism of seepage flow and wave and the filtration properties of the geotextile filters in dikes and dams.

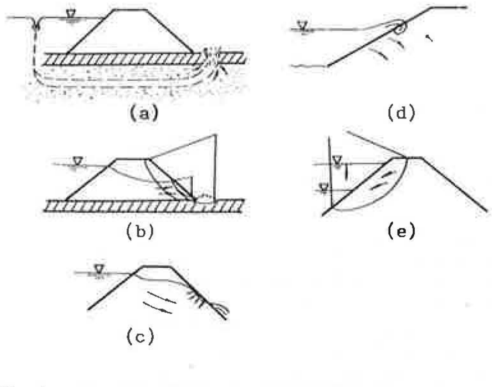


Fig.1 Failure types of embankment and dam

1. ACTION MECHANISM OF SEEPAGE FLOW AND WAVE

The research into the effects of seepage flow and wave on dike and dam is normally terminated in the analyses of stabilities. When the upstream water level is in a stable state, the field of steady seepage appears downward, the escape may occur on downstream slope due to water pressure from downward seepage flow, which in turn will make the stabilities in danger. When the upstream water level is falling, the unsteady seepage is formed inside the dike or dam. At the moment when the upstream water level begins falling, subsequently the equilibrium of steady seepage field is broken and the regulation of pore water pressure is performed so as to reach a new equilibrium. The regulation of equilibrium continues with the upstream water level falling. At the initial stage of upstream water level falling, the dissipation rate of pore water pressure might correspond to the falling speed of upstream water level, therefore, the falling of phreatic lines is simultaneous with that of upstream water level and its distribution of seepage field is same as the steady seepage field. When the upstream water level is down to a certain degree and the dissipation rate of pore water pressure is not corresponding to the falling speed of upstream water level, the value of pore water pressure near the upstream will be higher than that of upstream water level. At this time, the seepage field is divided into two parts: adjacent flow to the upstream zone is upward and the other is still downward, so that the phreatic surface becomes convex and the watershed is formed(Fig.2)(1). The distribution of seepage field is undergoing a transition from downward flow into upward flow in the adjacent upstream zone. This transition is shortened with the rapid falling of upstream water level, the watershed is further close to the upstream slope with the significant difference of height between phreatic surface and upstream water level. Since the continuous falling of upstream water level, the area, in which the value of pore water pressure is above the upstream water surface, is gradually expanded and the watershed is shifted to the downstream. In view of the variations of unsteady seepage field at the falling of upstream water level, the dynamic pressure of upward seepage is fairly hazardous to the stability of upstream slope. When two different flows are formed with the phreatic surface above the upstream water level. The unstability becomes more serious with the celerated falling of upstream water level. Needless to say, the sudden drawdown of upstream water level will be most hazardous. It is possible to get the armour overthrown and broken due to the uplift when the upstream water level rapidly falls.

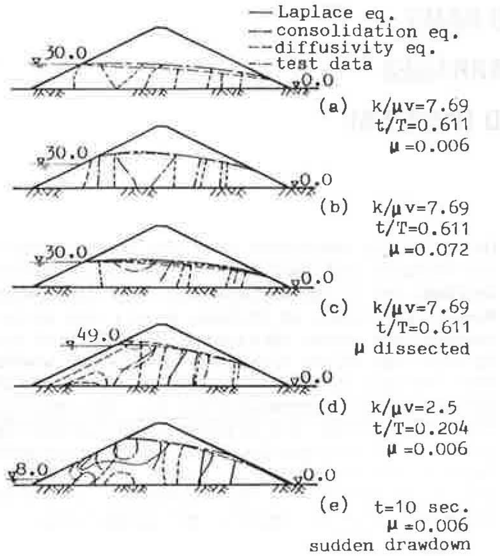


Fig.2 Distribution of unsteady seepage field

When waves are breaking against the dike or dam slope, the water mass will give an impact to the slope in a jet-flow state to form a water flow against the shore, which circulates with alternative uprises and falls. The fluctuation of wave current occurs on the entire slope under the action of waves, the slope should be well protected against the erosion caused by this fluctuation, or otherwise the slope will be destroyed by erosion. While waves are broken, the maximum pressure exists on the point of the slope where is under the impact of jet-flow, and the wave pressure decreases progressively at this point along the upside and low side of the slope. Through the gaps between the armour and filter layer and the soil pores, the wave pressure is transfered from the surface to the interior. However, the value of wave pressure is continously decreasing during the transfer, it is possible to get the armour upset and destroyed due to the internal uplift pressure, this is because of the phase differences between the distributions of wave pressures in different layers when the water flow against the shore falls back along the slope surface. In addition, it is possible to wash away the soil particles through the gaps of the armour layer to make the slope revetment collapsed and finally destroyed by erosion fluctuating seepage flow.

2. GEOTEXTILE PROPERTIES FOR FILTRATION

As is known to all that the function of filters is not only to prevent the foundation soil from continous erosion by the water flow, but also to ensure the free drainage so as to enhance the anti-erosion capacity of foundation soil. In the same way, the geotextile may be used as drainage filters, their filtration properties vary with the hydraulic conditions and the types of the fabrics selected.

For unidirectional flow, when the water flow passes through the foundation soil/filter, a part of fine grains is migrated from foundation soil, washed away with water flow, so that the water becomes muddy. If water slowly becomes clear after a time, it means that the loss of fine grains from foundation soil has stopped; the equilibrium of grains has been met and the geotextile have been acted as filter. On the contrary, if the water still remains muddy, it shows that the loss of fine grains from foundation soil continues and the geotextile is not in function as filter. For the alternating flow, the fluctuating pressure borne on the slope is directly transfered to the soil protected by geotextile. The pressure at wave crest is absolutely contrary to that at wave trough. During wave trough, the slope is borne negative pressure, the grains from foundation soil are possible to be sucked into the filter, but not permitted to escape from the above layer, during wave crest, the slope is borne by positive pressure, the grains sucked into the filter can be pushed back to the foundation soil by wave pressure. Therefore, it is necessary to provide a specified thickness for filter to damp alternating forces. It is much more important to ensure the soil against deformation under fluctuating pressure.

As for the woven geotextile, since their thickness is very small, the filtration efficiency directly depends on the opening size of fabric and the grain size of foundation soil. If the opening size is bigger than the grain size of foundation soil, it is unstable; on the contrary, it is stable. When the specific grain-size distribution is available for foundation soil, only under specific hydraulic conditions the woven geotextile are capable of promoting the foundation soil itself to form a natural filter, as a result, the satisfactory filtration is made (Fig.3(a)). The filtration properties of nonwoven geotextile are dependent on the opening size, permeability and thickness of fabric. For the thermobonded nonwoven geotextile with a very small thickness, their filtration efficiency is similar to that of woven geotextile. Generally, the needle-punched geotextile are thicker than other fabrics, as we learned from the tests for geotextile filters that their filtration properties are similar to granular filters (Fig.3(b)). Because the porosity of needlepunched geotextiles is larger, even over 90%, their permeability ($k=10^{-3}-10^{-4}$ m/sec) is far more great than that of ordinary foundation soil. Even if their meshes are partially clogged by soil particles, their permeability only decreases by 4 times (Fig.4). It is apparent that the filtration properties of needlepunched nonwoven geotextiles can however meet the permeability requirement of filters.

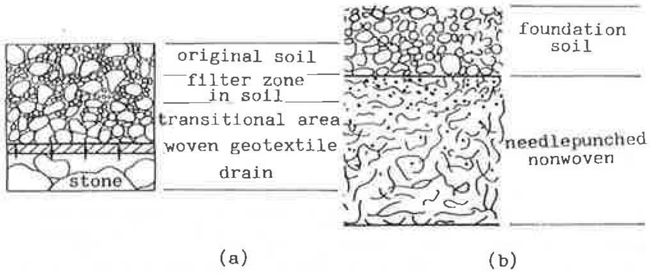


Fig.3 Filtration characteristic of geotextiles

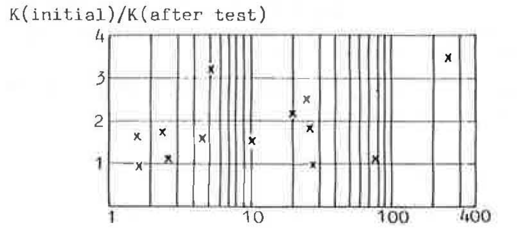


Fig.4 Clogging-uniformity coefficient relation

3. PRATICAL APPLICATIONS

3.1. Case One (2)

The Maizihe Reservoir is located on the Maizi River which is in the southwest of Luliang County in Yunnan province. Its major dam was completed in August 1955, it's a homogeneous earthdam with maximum height of 21.15 m and a length of 630 m. Since the major dam was built up on the Tertiary sandy loam and fine sand bed, the erosive effect of seepage flow on the foundation soil was serious, many times, collapses, falling pits were found on the upstream and downstream slopes, and swampinesses at dam toes. In 1983 a detailed investigations were made in order to take some remedial measures, in which the geotextile filters insteated of granular filters.

3.1.1. Laboratory tests and calculation analyses

(1) Seepage calculation

The seepage calculations by two-dimensional finite element method were carried out on Sections 0+390 and 0+460 of this earthdam in order to know the distribution of seepage field, the discharge and the exit gradient. We have discretized 218 elements and 138 nodes in accordance with the program of Automatic Dissection of Earthdam Seepage Calculation compiled by our research group. First, we verified the distribution of seepage field before the installation of geotextile filters, then, we predicted the distribution of seepage field at design water level after installation of geotextile filters, for detail refer to Fig.5. The calculation of seepage discharge was perfomed with central line method.

(2) Filtration tests

The filtration tests were carried out with nonwoven geotextiles. First, under the action of flow below to above, the geotextile filters were proved as well as the granular filters in regard to the improvement on anti-erosion capacity; then tests were performed with flow from above to below according to the maximum exit gradient(1.03) from the seepage calculation plus a specific safety factor. The time history for permeabilities of foundation soil/geotextile system was measured out. As is shown in Fig.6, three kinds of soils protected by geotextiles were respectively stable, in which, the sand loam took 9 days to become stable.

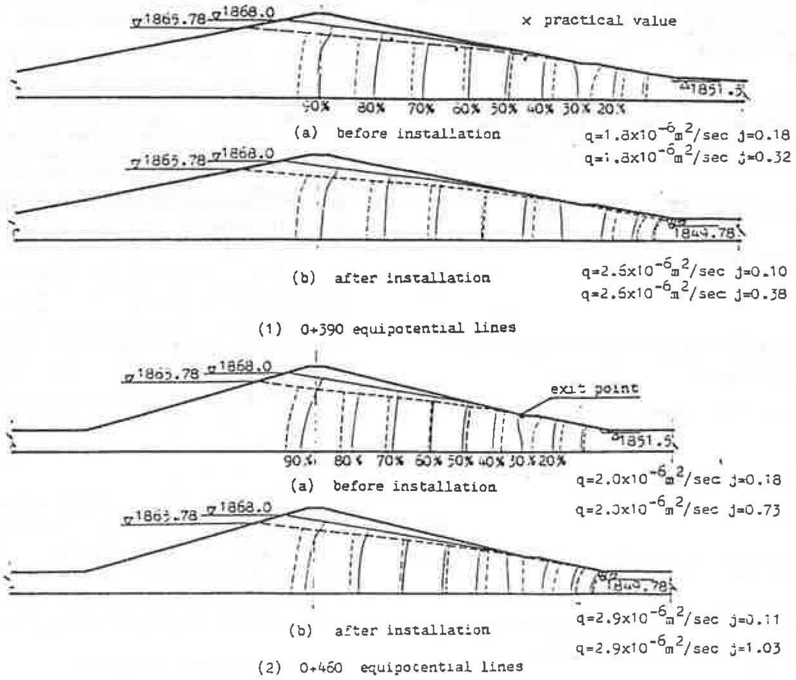


Fig.5 Distribution of seepage field

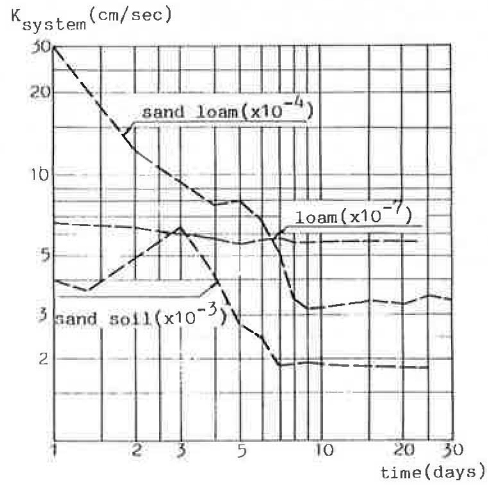


Fig.6 Time history of permeabilities for foundation soil/geotextile system

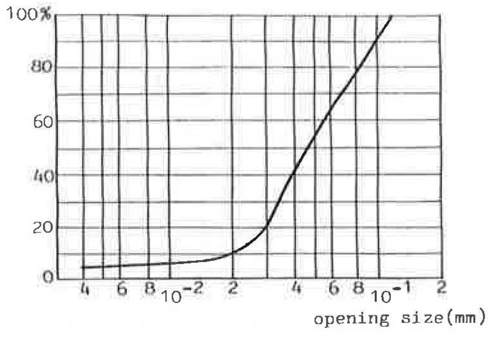


Fig.7 Opening size distribution of a geotextile

The criteria of the geotextile filters(5, 6) used in the Maizihe Reservoir were analysed according to the indices of physico-mechnics of soils in this Reservoir area. As is shown in Fig.7, the geotextile are only capable to meet the piping requirement (O_e/d_{85}=0.11/0.45=0.24) , but unable to meet the permeability requirement(O_e/d_{15}=0.11/ 0.12=0.92. However, since the porosity of nonwoven geotextiles is fairly large, their permeability coefficient is $2x10^{-3}$m/sec. For the drainage criterion with ratio of the permeabilities between geotextile and foundation soil, they will fully meet the permeability requirement of filters ($k_g/k_s > 30$).

(2) Strength analyses

When geotextiles are used as drainage filters, the thickness, opening size and permeability of fabrics are decisive factors, but their mechnical properties are less important. The geotextiles should be ensured from breaking or tearing during installation and in service. For the purpose of selecting proper geotextiles, it is recommendable to refer to the following formula.

Bursting analysis

On the assumption that the curved surface of geotextile under the uniform normal stress is same as that shown in Fig.8, the tensile stress T created by fabric should be in equilibrium with the difference between the top and bottom pressures of fabric.

$$P_1 ds_1 ds_2 = P_2 ds_1 ds_2 + 2T(ds_1 \sin \frac{d\beta}{2} + ds_2 \sin \frac{d\alpha}{2}) \qquad (1)$$

From eq.(1) it can obtained that

$$T= \frac{P_1 - P_2}{\frac{1}{R1} + \frac{2}{R2}} \qquad (2)$$

Where: P_1 and P_2 top and bottom pressure respectively

R_1 and R_2 curvaty radii

On the assumption that the curved surface is axially symmetric, and P_2=0

$$T= \frac{b}{8} (\frac{b}{2h} + \frac{2h}{b}) P_1 \qquad (3)$$

$$T= E_1 \varepsilon \qquad (4)$$

$$1+ \varepsilon = \frac{1}{2}(\frac{b}{2h} + \frac{2h}{b}) \arcsin \frac{1}{\frac{1}{2}(\frac{b}{2h} + \frac{2h}{b})} \qquad (5)$$

Where: E_1 = modulus of deformation at round hole bursting

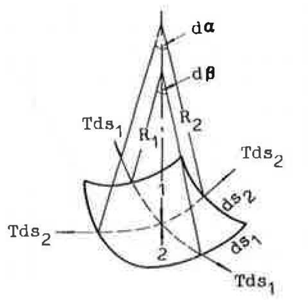
b = diameter of round hole (0.4 d) (4)

d = diameter of stone

= relative elongation

h = flexibility

Remember the above formulas are just an approximate solution.



1 — $P_1 ds_1 ds_2$ 2 — $P_2 ds_1 ds_2$

Fig.8 Tensil stress analysis in bursting

Puncturing analysis

As a result of the occurence of the elongation at curvature due to normal stress(P1) borne by fabrics, the stress(T) is created in fabrics. Therefore, the puncture resistance required for fabrics should be at least equal to the contact force between fabrics and stones. The contact force(P_c) is approximately expressed as follows:

$$P_c = \frac{(0.2d)^2 + h^2}{hd} P_1 f \qquad (6)$$

Where: d= average diameter of stones

f= contact area, depending on shapes of stones (It is recommendable for gravel or coble to take the ball crown surface area, and for crushed rocks it is better to take the cone surface.)

For the downstream drainage drains at the Maizihe Reservoir, it is filled by sand gravels of 5-80 mm, with height of 2.3 m. The required bursting strength of geotextile is 37 kg and the puncturing strength 20 kg, these value are by far lower than the bursting strength(469.3kg) and puncturing strength(190kg) of fabrics used in the site.

3.1.2. Installation and effects

In 1984, along the upstream slope 7630 m^2 of nonwoven geotextile was installated, and 1460m^2 placed on the downstream drains. Again in 1985, another 14770m^2 was installation along the upstream slope. The armour layer for the upstream slope is the mortarless stones below elevation 1862.5m the precast concrete blocks above elevation 1862.5m. The weight of single block depends on wind speed in the Maizihe Reservoir area. The maximum wind speed recorded in this area in 23m/sec, so that its weight is estimated to be 28 kg.

The swamp area(35m long, 20m wide) at this dam toe dried up and the outflow downstream drains was clear one week after installation of geotextile filters. It is obvious that the effects of drainage and filtration for geotextile filters are fairly ideal. The measured unit seepage discharge was 1.8 x $10^{-5}m^2$/sec, a little higher than the calculationresults. The cause for this may be the supply from diffracted seepage. The storage level is now at 1867.7 m, only 0.3 m below the design level(1868.0 m),no abnormal phenomena have been found since then.

3.2. Case Two(3)

The ash dam for the ash yard of Shanghai Ash Removal Project is situated in the south of Fengxian County at Shanghai, It is on the northern beach of Hangzhou Bay. Its design section is shown in Fig.9. This region belongs to the monsoon belt in East Asia, typhoon attacks are often in summer and autumn while cold waves appear from time to time in winter and spring. Around the year wind waves are predominant, the wave parameters are shown in Table 1.

3.2.1. Seepage calculation

The seepage calculations by two-dimensional finite element method were performed on the longitudinal section of ash dam in order to have a good understanding of the distribution of seepage field during execution and in service. The analysis was conducted at two selected combinations of most unfavourable water level and in accordance with the program of Automatic Discretization of Earth Dam Seepage Calculations compiled by our research group, the results are expressed in Fig.9. It is known from Fig.9 that the seepage fields at two combinations of water level are extremely different; respectively their exit points are at elevations 2.52m and 3.085m; the maximum exit gradients are 0.43 and 0.96 ; and the unit seepage discharge are $7.5x10^{-7}m^2$/sec and $5.3x10^{-6}m^2$/sec.

3.2.2. Filtration tests

With regard to the loss of ash by the action of seepage and wave to the stability of filter, the following tests were performed:

Granular filter tests;

Tests for woven geotextile for the protection of granular filter;

Filtration tests with ash/granular filter/woven geotextile system, as is shown in Fig.10 ;

Wave tests.

These tests shown that the sizes range of granular filter should be from 0.25 to 3 mm; their average diameter of pores is D_o=0.12 mm, D_o/D_{15}=0.12mm/0.026mm=4.62 and the thickness of filter is 200 mm. The woven geotextile (O_e=0.28 mm, permeability coefficient=$2.5x10^{-4}m^2$/sec) was selected, it can prevent from the ash loss. The original design option was altered in such a way that one filter layer of medium sand was substituted for two filter layers

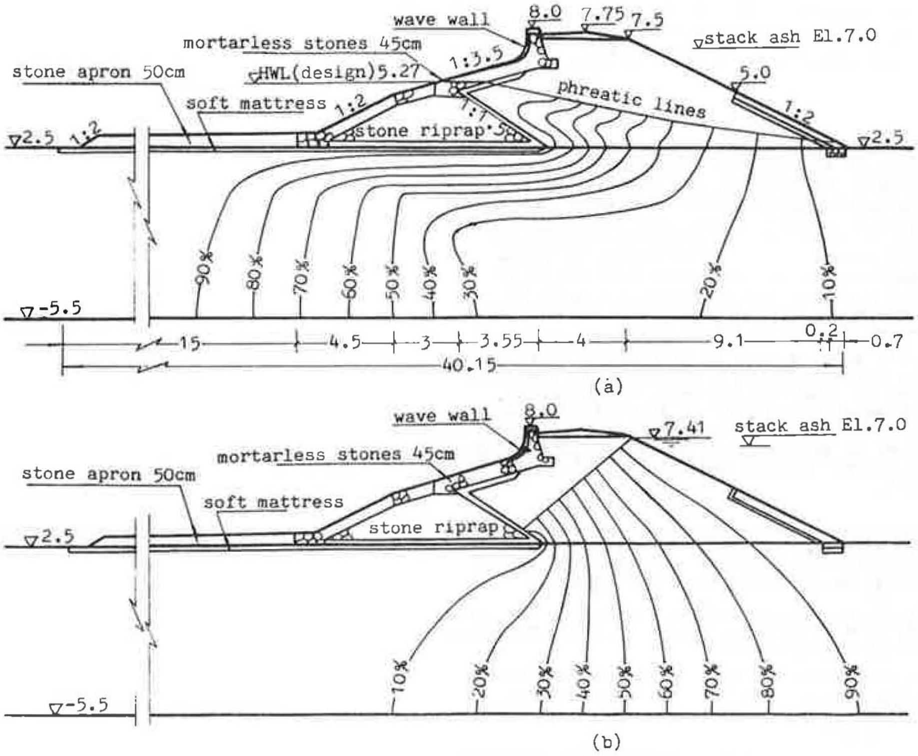


Fig.9 Design section of the ash dam

Table 1 Wave parameters in font of ash dam

Wave direction	Frequency	Water depth (m)	Wave height (m)	Wave length (m)	Wave velocity (m/sec)
SW-WSW	V_p=10% h_p=10%	2.27	1.15	16.0	
		2.77	1.13	17.0	
E-ESE		2.27	1.68	28.0	4.72
		2.77	2.02	31.0	5.21
SE-SSE		2.27	1.68	26.3	4.72
		2.77	2.02	29.0	5.21
SW-WSW	V_p=5% h_p=5%	2.40	1.62	18.2	
		2.90	1.59	19.5	
E-ESE		2.40	1.78	30.0	4.85
		2.90	2.13	32.5	5.33
SE-SSE		2.40	1.76	28.3	4.85
		2.90	2.10	31.0	5.33

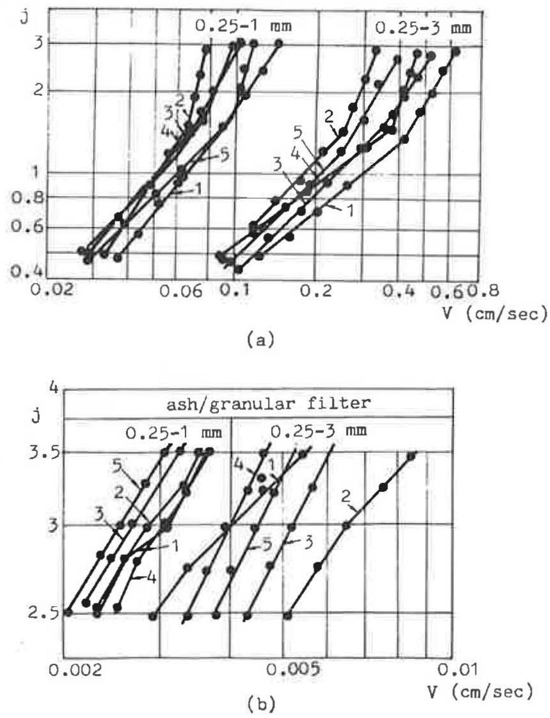


Fig.10 Results of filtration tests

of sand gravel. The integral model test for this new option was verified by 500 waves in a wave tank, no soil or sand grains were sucked out from this filter. It demonstrated that the efficiency of selected filter layer was excellent.

CONCLUSION

In China, although the research and application for geotextiles are just at the initial stage and the research works would be further intensified, the engineering projects and domains of geotextile applications have been steadily expanded. Through the researches into the substitution of geotextile drainage filters for the granular filters and the engineering practices, it is quite enough to state that the use of geotextiles in embankment and dam is of great reality. The applications of geotextile will be understood and mastered by more and more people engaging in hydraulic engineering in the course of time.

At present, the applications of geotextile still requires some necessary laboratory tests according to practical conditions in sites in order to determine the physical, mechanical and hydraulic properties of geotextiles. For the control of permeability, the bursting and puncturing strengths and ageing of geotextiles, it is, in particular, necessary to be verified through laboratory tests and the observations in situ.

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