Filter Criteria of Woven Geotextiles for Protective Works

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ABSTRACT: This paper theoretically discussed and analyzed the engineering practice of the application of geotextile filters to the protective works applied mainly by forces of wave and water flow, such as riverside, tide barrier, and apron of sluice, etc. through field investigation. The new design criteria of geotextile filters for protective works have been drawn up. Especially, the design index $O_{90} \leqslant 10d_{90}$ compared with $O_{90} \leqslant (1 \sim 2)d_{90}$ conventionally used shows a great breakthrough in the design work, and provides a scientific basis for enabling the geotextiles with larger opening size can be popularized.

1 GENERAL DESCRIPTION

The protective function of geotextiles refers to preventing slope or foundation from slide, erosion and unstability under the action of seepage force, wave force or scouring by water flow. In most of protective works, such as bank protection, scouring control of gate foundation, slope protection of tide barrier, and emergency measures in flood control, etc. As the duration of application of force under high water pressure is generally short and intermittent, the seepage line in protected soil would not be raised so much even if there exists action of water flow, so that the slope of bank pretection of river is subjected mainly to wave force above the lowest level, and scouring force of flow below the lowest level, the slope protection of tide barrier is subjected to wave force, and the scouring control for gate foundation is subjected to the scouring force of water flow. The criteria of geotextile filter commonly used are:

$$O_{90} \leqslant Ad_{90} \quad (1)$$

$$k_g \geqslant \lambda k_s \quad (2)$$

Where O_{90} is the equivalent opening size of geotextile, d_{90} is 90 percent particle diameter of protected soil, A is the dimensionless parameter of soil conservation, $A=1 \sim 2$, k_g is the coefficient of permeability of geotextile, k_s is the coefficient of permeability of protected soil, λ is the constant of permeability.

Although the above criteria are on the ground of theory and practice, the most of which are drawn up in accordance with the design criteria, experience and laboratory test data of the granular material. They should be worth discussed for protective works mainly subjected to the action of wave force and water flow.

2 FIELD TESTS OF SCOURING

The field tests of scouring were taken place on the bank protection of Liaohe river, the slope protection of sea dykes at Changshanshi bay, Xingcheng county, and tide barrier of Dawa Delta, Panjin city, to study on the operation condition of woven geotextile in application to these protective works.

The test method is as follows: Put the protected soil into 1.0×1.0×0.1m wooden box with certain density, and covered with woven geotextile, the concrete cover is put on the surface of it, while the others are without concrete cover. Then put the samples on river bank or dyke slope to stand up for scouring by flow and waves. Through a certain period, take out samples to check their unit weight, water content, and particle size distribution, before and after scouring. The test results are listed in Tables 1 and 2.

From Table 1 it shows that:

(a) Weight of soil after scouring is greater than that before scouring.

(b) Contents of silt and clay increased after scouring. It is probably because the opening size of geotextile is greater than the particle diameter of soil, and the suspended sediment of the river rushed into the box when the geotextile is lashed by flow or waves (In the tested section of river: sediment concentration 3.0~6.0kg/m³, mid—value of particle diametar 0.025 ~ 0.026mm). It is shown that the opening size of geotextile may be selected a little bigger for the rivers with higher sediment concenatration.

Table 1 Results of scouring test of woven geotextiles for bank protection of Liaohe river

Material	Soil	Before /After scouring	Weight (kg)	Grain composition(%)				Analysis of filter criteria
				>0.1	0.1~0.05	0.05~0.005	<0.005	
Protected soil	Fine	Before	13.10		14	54	32	$d_{90}=0.065mm$
	Course	Before	13.29		72	22	6	$d_{90}=0.075mm$
Woven geotextile (Liaoyang)	Fine—1	After	15.34		15	51	34	$O_{90}=0.70mm$
	Fine—2	After	15.91					Fine soil: $O_{90}=10.8d_{90}$
	Course—1	After	15.10	3	56	32	9	Course soil: $O_{90}=9.3d_{90}$
	Course—2	After	12.99					
Woven geotextile (xinmin)	Fine—1	After	14.56		18	52	30	$O_{90}=0.72mm$
	Fine—2	After	14.22					Fine soil: $O_{90}=11.1d_{90}$
	Course—1	After	14.46	1	59	33	7	Course soil: $O_{90}=9.6d_{90}$
	Course—2	After	13.60					

Table 2 Results of scouring test of geotextiles for tide barrier [a]

Kind and size of geotextile	Equivalent opening size O_{90}(mm)	Location of test	Dry weight of sample			Analysis of filter criteria
			Before test (kg)	After test (kg)	Decrease (%)	
Woven geotextile 14×14	0.7	Xingcheng	29.5 31.3	26.2 27.8	11.2 11.1	$d_{90}=0.078mm$ $O_{90}=9.0d_{90}$
		Delta	86.2 86.2	80.6 83.2	6.0 3.5	$d_{90}=0.076mm$ $O_{90}=9.2d_{90}$

[a] The concrete plates of 0.6×0.6×0.07m were put on the geotextile for test field at Delta (4 pieces on each box).

It is shown from Table 2 that the geotextiles with or without concrete cover will have much effect on scouring. The protected soil will be scoured by tide waves despite which kind of geotextile is used without cover. When the woven geotextile with bigger opening size is used without cover, the weight of lost soil may be up to 10% or more. Under the condition of geotextile with concrete cover the weight of protected soil increased or decreased by 3.5~6.0% only before and after scouring, which meets the requirement of filter.

The cover and weights put on the surface of geotextile are indispensable in pratective works, which is of great importance to:

(a) Keep closely contact between geotextile and protected soil. letting the geotextile to restrain the soil particles and increase the cohesive force. On the other hand, it will decrease the fluctuating velocity along the surface of protected soil as a result of the water flow or waves acting through geotextile mattress. It is necessaty to keep closely contact between geotextile filter and the protected soil during the construction of protective works.

(b) Dissipate a large amount of energy around the covering material before the water flow or waves act on the filter of geotextile mattress.

(c) Decrease the area supporting directly the water flow or waves.

(d) Prevent geotextile from aging.

3 ANALYSIS OF ENGINEERING PRACTICE

3.1 Bank protection of river

It is the first time to use geotextile for bank protection of Liaohe river in Liaoning province in 1982. Since the formula $O_{90}\leqslant 10d_{90}$ was given out, the woven geotextiles have been popularized in bank protection of rivers of Liaoning province, including 70 or more dangerous sections of dykes. According to statistics, the total area of woven geotextile amounted to some 600~700 thousand m^2. The characteristics of some kinds of woven geotextile are shown in Table 3.

There are four kinds of soil distrbuted along the Liaohe river: clay, Loam, sandy loam and sand. The d_{90} of which is 0.07~0.09, 0.08~0.10, 0.10~0.30, 0.20~0.40mm respectively. The ratio A of the equivalent opening size to d_{90} is listed in Table 4.

Table 3 Characteristics of some kinds of woven geotextile used for bank protection of Liaohe river

No.	Weight (g/m^2)	Thickness (mm)	Equivalent opening size O_{90}(mm)	Coefficient of permeability k_g(cm/s)
GT_w-1	100	0.20	0.10	4.0×10^{-3}
GT_w-2	103	0.21	0.15	
GT_w-3			0.29	
GT_w-4			0.33	
GT_w-5	100	0.20	0.70	6.84×10^{-4}
GT_w-6	110	0.45	0.72	3.57×10^{-3}

Table 4 Computation of $A=O_{90}/d_{90}$

Woven geotextile	Classification of soil			
	Clay	Loam	Sandy loam	Sand
GT_w-1	1.11~1.43	1.0~1.25	1.0~3.0	0.25~0.50
GT_w-2	1.67~2.14	1.5~1.88	0.50~1.5	0.38~0.75
GT_w-3	3.22~4.14	2.9~3.63	0.97~2.9	0.73~1.45
GT_w-4	3.67~4.71	3.3~4.13	1.1~3.3	0.83~1.65
GT_w-5	7.78~10.0	7.0~8.75	2.33~7.0	1.75~3.5
GT_w-6	8.0~10.3	7.2~9.0	2.4~7.2	1.8~3.6
Recommended A	10	10	2~5	2

3.2 Slope protection of tide barrier

The woven geotextile of $GT_W-5(O_{90}=0.70mm)$ was used as the filter of slope protection of tide barrier with 1000 m or more long at Dawa Delta in 1989~1990. The structure is shown in Fig. 1.

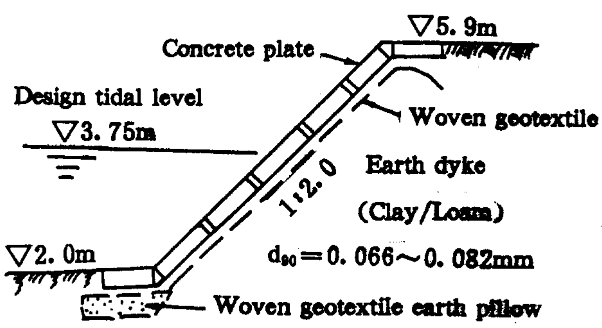

Fig. 1 Structure of slope protection of tide barrier of Dawa Delta

All the filters of slope protection of tide barrier are designed in accordance with criterion $O_{90}\leqslant10d_{90}$, they have kept in good condition since operation.

3.3 Scouring control for gate

A new method of scouring control using mattress made of woven geotextile GT_w-5 and weighted with riprap was adopted at the reverse side of the sea of Hunjianggou tidal sluice gate of Dawa Delta in 1990. The mattress was 30 m wide and 70m long placed in front of the gate, which has achieved a good result. The d_{90} of the protected soil is 0.068 ~0.080mm, and $O_{90}=(8.75-10.3)d_{90}$.

4 THEORETICAL DISCUSSION ON FILTER CRITERIA OF GEITEXTILE USED FOR PROTECTIVE WORKS

The fundamental of theoretical analysis is that the deposition and condensation of the silt in water flow of open channel are simialr to that in water moving through granular filter.

The incipient velocity of soil particles can be expressed by following equation:

$$V_c=\varphi_s\sqrt{\frac{\rho_s-\rho}{\rho}gd_{50}} \tag{3}$$

Where V_c is the critical incipient velocity of soil particles, φ_s is the comprehensive coefficient determined by experiment only, ρ_s and ρ is the specific gravity of soil and water respectively, d_{50} is the mid-value of particle diameter of soil. Let $\rho_s=2.65,\rho=1.0$, if $V_c/V_p=K$, The critical pore velocity of granular filter will be:

$$V_f=nV_p=1.29\frac{n\varphi_s}{K}\sqrt{gd_{50}} \tag{4}$$

Where n is the porocity of filter layer, V_p is the critical pore velocity, K is the ratio of incipient velocity of soil to pore velocity of filter, $K=f(R_e)=f(\frac{V_f d_{f50}}{\nu})$, which should be determined by laboratory test, where d_{f50} is the mid—value of particle diameter of soil, ν is the kinetic viscosity of water.

From the seepage theory of granular material:

$$V_f=k_f \cdot i_f \quad (5)$$

Where k_f is the coefficient of seepage of granular filter, i_f is the critical hydraulic gradient

The theory and practice show that the coefficient of seepage of material with uniform particles is in proportion to the square of its diameter, while for non—uniform particles, it is in proportion to d_{f5}^2. Therefore, taking $k_f=\beta d_{f15}^2$, we have:

$$\beta d_{f15}^2\, i_f=1.29\,\frac{n\varphi_s}{K}\sqrt{gd_{50}} \quad (6)$$

According to the requirement of geotextile filter established by modelling on sand gravel, $O_e=\bar{O}=0.2d_{f15}$, then $d_{f15}=5O_{90}$.

If there is a good linearity in granulometric curves (well graded), then $d_{50}=Cu^{-0.8}d_{90}$, where Cu is the uniformity coefficient, we have:

$$25\beta i_f\, O_{90}^2=1.29\,\frac{n\varphi_s}{K}\sqrt{gCu^{-0.8}d_{90}} \quad (7)$$

The design criterion of soil conservation property for geotextile filter can be expressed as:

$$O_{90}\leqslant(\frac{0.05n\varphi_s}{\beta i_f K})^{1/2}(gCu^{-0.8})^{1/4}d_{90}^{1/4} \quad (8)$$

Let $B=(\frac{0.05n\varphi_s}{\beta i_f K})^{1/2}(gCu^{-0.8})^{1/4}$, then $O_{90}\leqslant Bd_{90}^{1/4}$ (9)

It is shown that there are many factors influencing the coefficient B. Now we evaluate B roughly for well graded sand, taking $n=0.4$, $\beta=1.0$, $i_f=0.8$, $k=0.2$, $g=9800mm/sec^2$, $Cu=5$, and $\varphi_s=0.546$, we obtain $B=1.9$. It is identical with $A=1\sim2$ adopted domestically now. However, the d_{90} is measured in mm, and always less than 1.0, especially for fine soil, so that $d_{90}^{1/4}$ is much larger than d_{90}.

According to the analysis on the data of engineering practice for bank protection and tide barrier, it shows that the results of which are identical with those in field test.

With regard to the requirement of permeability of geotextile filter in protective works, even though it is not essential, the water infiltrating into the protected soil as a result of rainfall, flutuating seepage flow, and high water level, etc. will drain out through the geotextile filter, so that the drainage of it must be unobstructed and may not be clogged up during long—term operation. According to engineering practice in past few years and traditional sand—grovel filters, with the purpose of draining smoothly it is required that:

$$d_{f15}\geqslant5d_{15} \quad (10)$$

If $O_{90}=0.2d_{f90}$, then $d_{f15}=5O_{90}$ (11)

Therefore, the requirement for smoothly draining of geotextile filter is:

$$O_{90}\geqslant d_{15} \quad (12)$$

Which means $k_f\geqslant25k_s$, Give consideration to seepage coefficient, it is safe to adopt $k_g\geqslant5k_s$ for cohesive or non—cohesive soil, where k_s is the coefficient of seepage of protected soil, k_g is the coefficient of seepage of geotextile.

5. CONCLUSION

(a) According to the requirement of soil conservation property the woven geotextile covered by protective layer may be adopted $O_{90}\leqslant10d_{90}$ when the content of cohesive particles of protected soil is more than 10%, or $O_{90}\leqslant(2\sim5)d_{90}$ when it is less than 10%. The more the sediment concentration of river, the larger coefficient is used, because the water flow decreases on the surface of protective layer, a part of suspended sediment deposits in the pore of it. so that a less opportunity to scour directly the protected soil beneath the geotextile.

(b) In order to meet the needs of smooth drainage, $O_{90}\geqslant d_{15}$ or $k_g\geqslant5k_s$ may be used for clay or the soil containing more cohesive particles, and $k_g\geqslant5k_s$ for non—cohesive soil.

(c) To contact geotextile with protected soil as close as possible. It is a prerequisite to advance the new design criteria of woven geotextile filter in protective works, and an essential link in construction.

(d) Any standard or criterion has its own applicability. As a new engineering material, the geotextile filter is influnced by very complicated factors. The design criteria for woven geotextile filter advanced in this paper need still further study in accordance with various special conditions.

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