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The Construction Technology and the Environmental Effect of Geotextile Tube

지오텍스타일 튜브의 시공방법 및 환경적 영향에 관한 연구

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요 지

지오텍스타일 튜브공법은 준설토, 준설모래, 오염토사 등을 수리학적 채움을 통하여 해양구조물이나 수리학적 구조물을 축조하는 공법이다. 본 연구에서는 지오튜브공법의 국내적용을 위하여, 미국공병단의 최소 요구사항을 바탕으로 지오텍스타일을 선정하여 다양한 실내시험과 현장 적용성 시험을 실시하였다. 실내시험은 지오텍스타일과 토사간의 접촉마찰특성 분석을 위하여 대형직접전단시험을 실시하였으며, 해양구조물 설치 시 파도와 조수의 영향으로 인한 토사유출량 분석을 위한 유실율시험을 실시하였다. 또한, 오염토사를 채움토사로 적용할 경우에 장 · 단기 환경적 영향에 대한 환경시험을 실시하였다. 현장시험은 실내모형시험을 바탕으로 토사와 물의 슬러리 혼합비율에 따른 지오텍스타일 튜브 채움방법 및 유효높이 및 단위중량 등의 계측을 실시하였다. 각종 실내 및 현장시험결과, 채움토사입자의 유실율은 약 5.0~6.0%를 유지하였으며, 지오텍스타일의 투수계수는 $\alpha \times 10^{-4}$cm/sec 이상이 되어야 하며, 물과 토사의 혼합비율은 6:4이상이 되어야 한다. 환경적 영향 분석결과, 오염토사의 적용시 국내환경기준을 만족하는 것으로 나타났다. 또한, 수리학적 펌핑 압력에 대한 지오텍스타일 튜브의 최대 유효높이는 튜브 전체높이의 약 80%의 채움이 완료되었을 시점인 것으로 판단된다.

Abstract

Geotextile tube is hydraulically filled with soil include dredged sand and mud, which has been successfully applied in hydraulic and coastal engineering projects. The tensile strength of geotextiles used for geotextile tube was 20 t/m, which were selected by the minimum specification requirement of the U.S Army Corps of Engineers. Laboratory direct shear tests were performed to determine the interface friction angle between backfill material and geotextile by using a large scale direct shear box. Laboratory cyclic fluctuation tests with 70rpm were also performed with utilizing a small geobag made of the same geotextiles used for geotextile tube to investigate the detention capability of dredged soil. The dredged soil was filled 80% in the small size geotextile tube by the volume. Based on the results of this research work, the percentage of soil particle loss was about 5.0~6.0% and the permeability of geotextile must keep up to the $\alpha \times 10^{-4}$cm/sec. The environmental test results indicated that the water quality is satisfied the minimum requirements suggested by the Korean EPA. The pilot scale field test results indicated that the water/soil mixing ratio should be more than 6:4. The maximum effective height of dredged fill in geotextile tube is about 80% and the rupture failure could occur if it is higher than this.

Keywords : Dredged soil, Environmental test, Geotextile tube, Specification, Tensile strength

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1. Introduction

Geotextile tube are made of permeable, soil-tight geotextile. They are hydraulically filled with dredged soil. Attempts are now being made to use geotextile tubes in coastal engineering projects such as shore protection and breakwaters, groyne, jetties, and so on. Geotextile tubes also help store and isolate contaminated materials obtained from dredging. The diameter and length of the geotextile tubes vary, depending on the field conditions. Typical length and width of geotextile tube are 150～180m and 4～5m, respectively, with the effective height of 1.5～2.0m. The inlet and outlet for filling the dredged soil by hydraulically is located on the top of geotextile tube. The interval of inlet is shorter for sandy soil(usually 10m) while longer for the case of clayey soil.

Initial studies regarding geotextile containments are found in the work of Koerner and Welsh(1980). Botzan et al.(1982) and Harris(1987, 1989, 1994) reported the use of geotextile containments in erosion control. Bogossian et al.(1982) and deBruin and Loos(1995) evaluated the effectiveness of geotextile tube for erosion control. Environmental dredging and backfill technology using geotextile tubes were reported by Fowler et al.(1994) and Pilarczyk(1996).

In most cases, a single layer of woven geotextile is used to construct the geotextile tube. According th the U.S. Army Corps of Engineers, the minimum physical properties of woven geotextile to be used for constructing geotextile tube should be as follows :

Tensile strength : 175kN/m
Elongation : 10%
Trapezoidal tearing strength : 140～160kN/m
Seaming strength : 105kN
Punched strength : 61kN
Effective opening size : sieve No. 100

This paper summarizes the performance of a pilot scale field test using a geotextile tube in Song-Do, Incheon, Korea.

The pilot scale(length : 25m, circumference : 8m, effective height : 1.5m) test of geotextile tube in the field located on the Song-Do land reclamation project area was performed for evaluation of design and constructibility with considering pumping pressure, slurry mixing ratio, and filling height.

2. Properties of Soil and Geotextile

The soils used for this study were Jumoon Jin sand, dredged sand, dredged organic soil. Jumoon Jin sand is a standard poorly graded silica sand used in Korea.

The dredged sand was obtained from the Song-Do land reclamation area in Incheon, Korea. The dredged organic soil was collected from the detention basin located on the west coast of Incheon, Korea. The detention basin is used for temporarily holding the water before discharging it to the sea. The physical properties of these soils are tabulated in Tables 1 and 2.

Jumoon Jin sand and dredged sand from Song-Do are classified as SP by the Unified Soil Classification System. The content of organic is approximately 15.33% for dredged organic soil sampled from detention basin. The specific gravity is pretty low as much as 2.29.

The percentage of passing U.S. sieve no. 200 is about 60.94% for dredged organic soil. The grain size

Table 1. Physical properties of the sand

Item	Quantity	
	Jumoon Jin sand	Dredged sand
Effective size, D_{10} (mm)	0.37	0.99
Uniformity coefficient, C_c	1.53	4.67
Coefficient of gradation, C_u	1.10	1.06
Maximum dry unit weight, $\gamma_{d(max)}$, (g/cm^3)	1.64	1.56
Optimum moisture content, ω_{opt}, (%)	15.2	16.2
Specific gravity, G_s	2.65	2.65
USCS	SP	SP

Table 2. Physical properties of the organic soil

Item	Quantity
Specific gravity, G_s	2.29
Liquid limit, LL (%)	39.00
Plastic limit, PL (%)	30.25
Plastic index, PI	8.75
Passing 0.075mm sieve (%)	21.94
Organic content (%)	15.33
USCS	OL

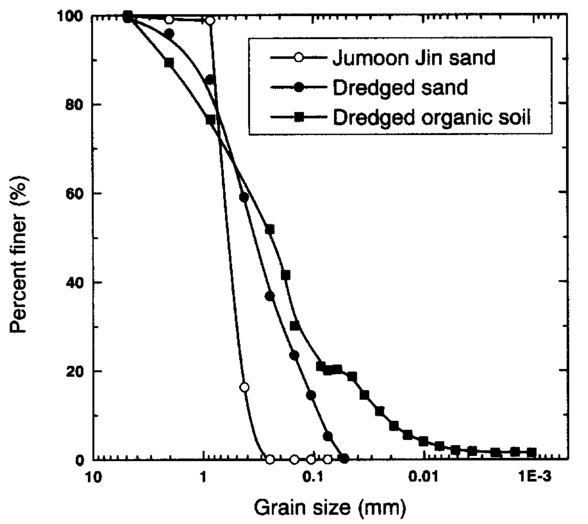

Fig. 1. Grain-size distribution of soil used for the present study

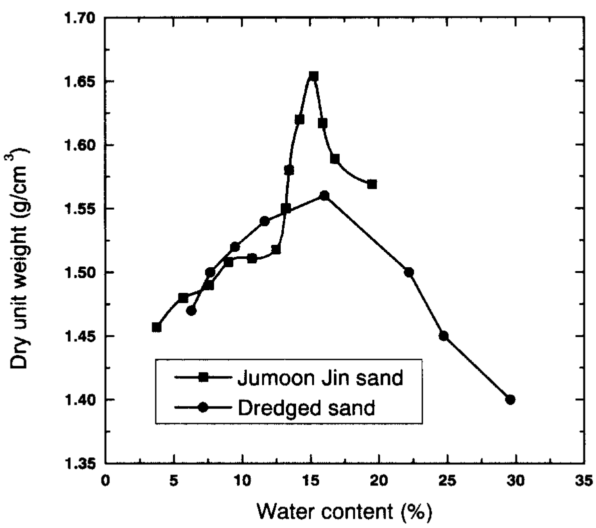

Fig. 2. Standard compaction curve of backfill soil

distributions of these soils are shown in Fig. 1. Standard Proctor compaction tests(KS F 2312) were conducted for Jumoon Jin sand and dredged sand from Song-Do, Incheon. The variation of the dry unit weight(γ_d) against moisture content(w) is shown in Fig. 2. The maximum dry unit weight($\gamma_{d(max)}$) and optimum moisture content (w_{opt}) are described in Table 1. Dredged soil from Song-Do gives lower value of maximum dry unit weight and higher value of moisture content. The geotextile generally used to construct geoextile tubes are either woven geotextile or composite geotextile(i.e., an external layer of woven geotextile and an internal layer of non-woven geotextile).

For the present study two woven geotextile, designated in this paper as K-1 and K-2, were used. The physical properties of these two geotextile are given in Table 3.

Geotextile specimen used for this study is shown in Fig. 3.

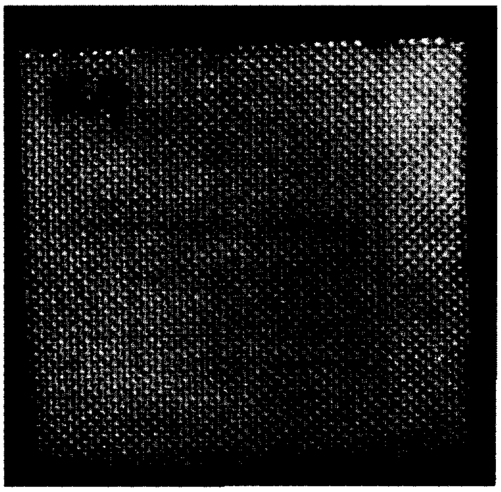

Fig. 3. Geotextile specimen(K-1)

3. Laboratory Tests

Before carrying out the pilot test in the field, several laboratory tests were conducted to determine the compatibility of the soil and geotextile. These tests are briefly described in the following sections.

Table 3. Properties of geotextile used for the present study

Property	Test Method (ASTM)	Unit	Geotextile	
			K-1	K-2
Mass per unit area	D-5261	g/m²	600	700
Tensile strength	D-4632, D-4595	kN/m	196	245
Elongation	D-4632, D-4595	%	10~50	10~50
Coefficient of permeability	D-4991	cm/sec	10^{-2} ~ 10^{-4}	10^{-2} ~ 10^{-4}
Material	-	-	Polyester(PET)	Polyester(PET)

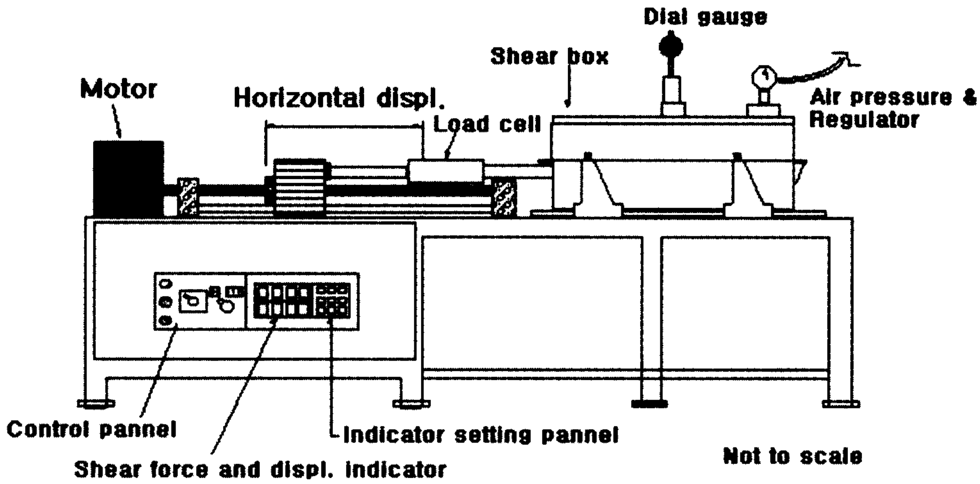

Fig. 4. Schematic diagram of large scale direct shear device

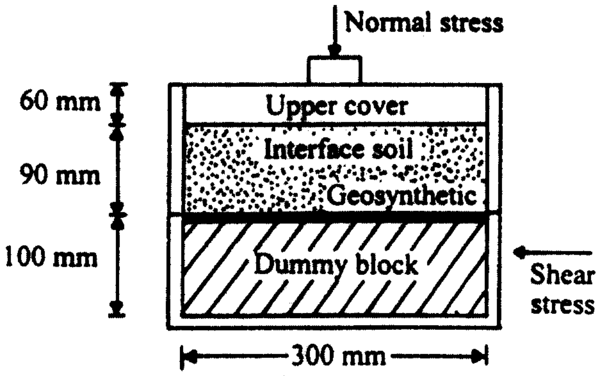

Fig. 5. Schematic diagram of direct shear box

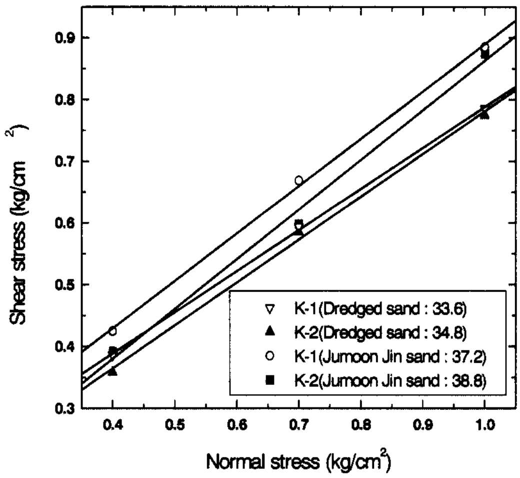

Fig. 6. Interface friction angle of sandy soil/ geotextile

3.1 Large Scale Direct Shear Tests

Large scale direct shear tests were conducted to determine the interface friction angle between the geotextile and the two types of sand described in Table 1.

The interface friction angle is an important parameter in determining the stability of geotextile tubes when they are placed on sloping ground for shore protection and projects such as the construction of breakwater. Figs. 4 and 5 are schematic diagram of the direct shear test device and shear box used for the tests. The size of the geotextile used for the tests was 0.3m×0.3m.

Test were conducted with normal stress varying up to 0.70kg/cm^2 (ASTM D-5321 test method). The sands were compacted to 90% of maximum dry unit weight($\gamma_{d(max)}$) as given Table 1. The interface friction angles thus determined are summarized in Table 4. It is also shown in Fig. 6. The results of these tests indicate that K-2 geotextile with higher tensile strength gives high degree of interface friction angle. The range of interface friction angles is 33.6°~38.8° which is pretty good value in terms of soil friction angle. This figure also shows that apparent cohesion intercept(c_a) of 0.33~0.38kg/cm^2.

The interface friction angles reported in Table 4 are fairly large and are workable in the stability analysis of geotextile tubes in the field.

Table 4. Direct shear test results

Geotextile	Interface friction angle(deg.)	
	Dredged sand	Jumoon Jin sand
K-1	33.6	37.2
K-2	34.8	38.8

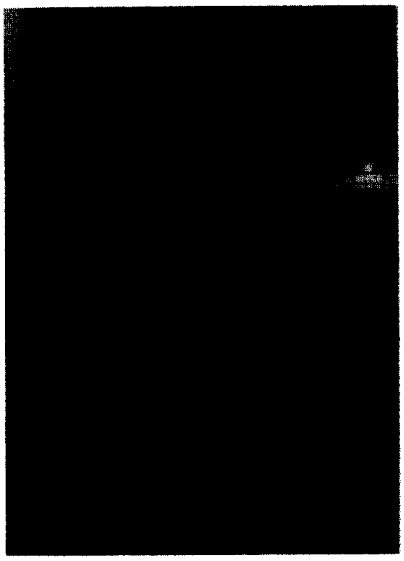

Fig. 7. Cyclic fluctuation testing device

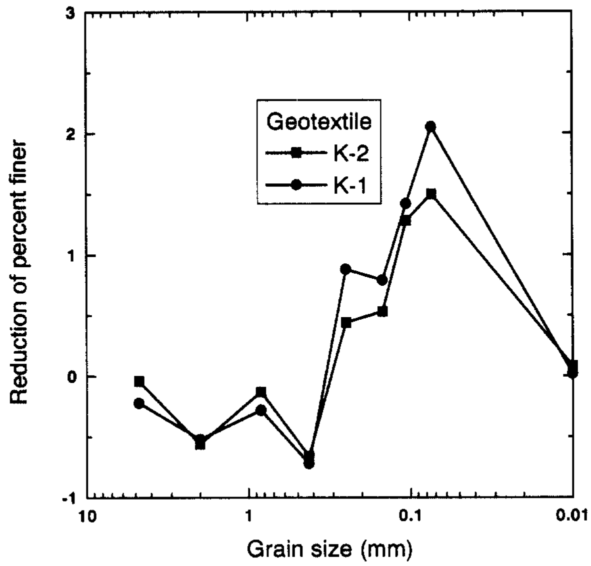

Fig. 8. Cyclic fluctuation test results

3.2 Cyclic Fluctuation Tests

One important function of a geotextile tube is its capability to hold the filled soil inside the tube with minimal loss. A quantitative evaluation of this factor can be done using a cyclic fluctuation device(Fig. 7).

The device used for the present test had a water basin measuring 1.3m(length) × 1.3m(width) × 1.7m(height). The box for holding the small size geotextile tube inside the water basin was made of steel wire and fixed to a vertical pole that moved up and down at a desired rate. To conduct the tests, the small size geotextile tube was filled with dredged sand(see Table 1) up to 80% of its total volume. The small size geotextile tube was subjected to 10,000 cycles of vertical fluctuation in water at the rate of 70 cycles/min. At the end of test, the loss of soil particles was determined by measuring the grain-size distribution.

The total loss of soil for the two geotextile under consideration is shown in Table 5. The soil particle loss rate for various grain sizes is shown in Fig. 8.

The geotextile specimen K-1 gives lower particle loss of 5.05% and 6.09% for K-2 geotextile specimen. Fig. 8 shows that silt size particle is the highest loss rate compare to the rest of grain-sizes.

Table 5. Cyclic fluctuation test results

Geotextile	Soil loss(%)	EOS(mm)
K-1	5.05	0.12~0.15
K-2	6.09	0.11~0.14

3.3 Environmental Tests

Two types of environmental tests were conducted short-term self-weight filtration tests and long-term diffusion tests. The short-term self-weight filtration test was performed in the field at the water detention basin in Incheon.

Since the K-1 and K-2 geotextile essentially gave similar results, it was decided to conduct further tests only with the K-1 geotextile. Thus for the environmental tests the geotextile tube was made from the K-1 geotextile.

The geotextile tube was 2m long and 1m wide. It was filled with 3.5m^3 of dredged organic soil(Fig. 9). Dissipated water samples of 1000ml each were collected from the geotextile tube at time intervals of 0, 0.33, 0.5, 1.0, 2.0 and 3hours. These water samples were used to determine the suspended solids(SS) and the chemical oxygen demand (COD). The variations of SS and COD with time are shown in Fig. 10.

From this figure it may be seen that the magnitudes of SS and COD rapidly decreased within 20minutes after filling the dredged organic soil in the geotextile tube. After the first 20minutes, the rate of decrease of SS and

Fig. 9. Self weight filtration test

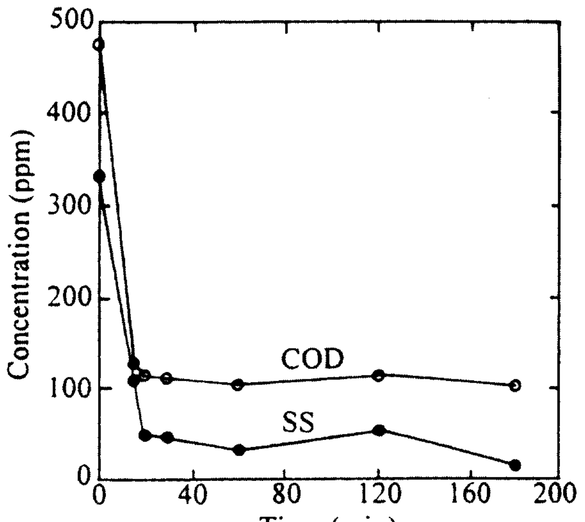

Fig. 10. Variation of SS and COD (Self-weight filtration test)

COD with time dropped rapidly. The results of SS = 110ppm and COD = 45ppm at time = 20minutes after the beginning of the test are below the Korean EPA standards of SS = 120ppm and COD = 130ppm.

A long-term diffusion test, which lasted for six months, was also performed on a geotextile tube filled with dredged organic soil obtained from the detention basin. The geotextile tube had a circumference of 250mm and a length of 500mm. The small size of geotextile tube filled with dredged organic soil placed inside the distilled water tank. Diffused water samples were collected by time interval. The variation of SS and COD with time

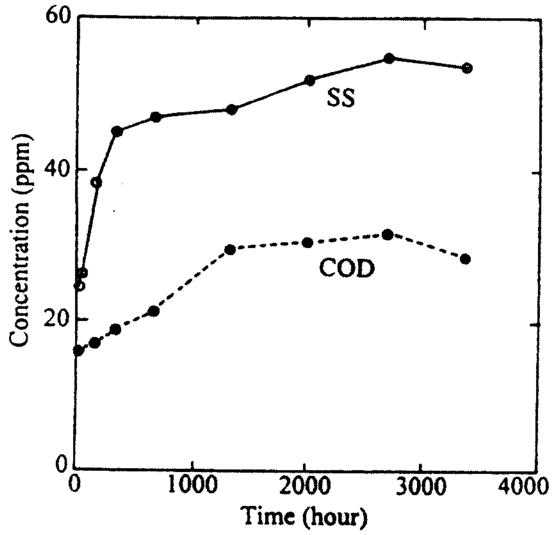

Fig. 11. Variation of SS and COD (diffusion test)

obtained from this test are shown in Figure 11.

The magnitudes of SS and COD increased with time and reached maximum values in about 100days. These maximum values of SS and COD are substantially lower than those specified by the Korean EPA. Based on the environmental test results, it can be concluded that geotextile tube is very efficient method to retain the soil solid particles and hence reduce the water pollution during the dredging work.

4. Field Pilot Tests

A filed pilot test was conducted in the dike construction work of the Song-Do land reclamation project in the Bay of Incheon. A single layer of K-1 geotextile(Table 3) was used for fabricating the geotextile tube. The geotextile tube had a circumference of 8m and a length of 25m and it was filled by pumping in dredged sand from the site. The soil-water mixing ratio, pumping pressure, pumping speed were varied to determine the optimum values of those through the field pilot tests.

The unit weight of filled soil, elongation of geotextile, and vertical pressure were measured about 3months. The schematic diagram of geotube field pilot test is shown in Fig. 12 along the placement of pressure cell. The pressure cells were installed 4m intervals right below the non-woven geotextile. The non-woven geotextile can

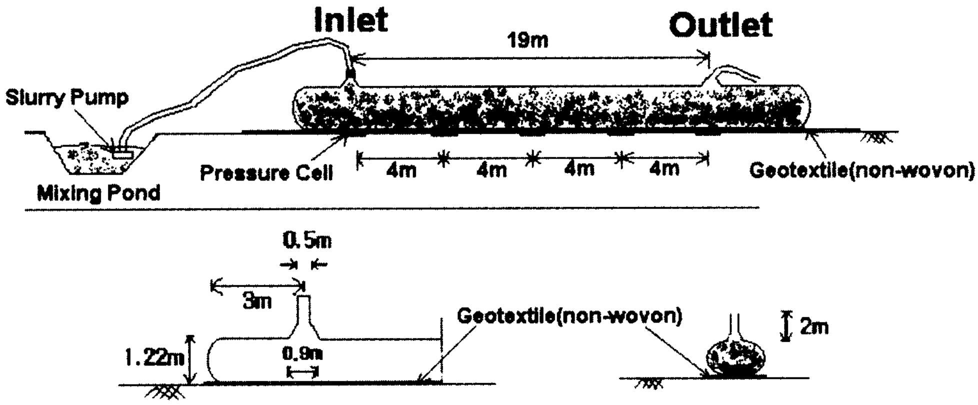

Fig. 12. Schematic diagram of the field pilot test

(a) Cover the area of subgrade by non-woven geotextile (b) Pumping the slurry into the geotube (c) Slurry mixing pond

Fig. 13. Construcition sequence of geotextile tube

prevent the erosion of soil around the geotextile tube by dissipating water from the geotextile tube. The distance of between inlet of dredged soil and outlet of overflow is about 19m. Temporary mixing pond was made for facilitating the mixing the dredged soil and water.

The construction sequence of the geotextile tube was as follows : (1) preparation of subgrade(foundation soil), (2) installation of pressure cell, (3) covering the area of subgrade with non-woven geotextile, (4) placing the geotube over the geotextile, (5) mixing and pumping the slurry into the geotextile tube; and (6) completing the slurry injection into the geotextile tube.

Geotextile construction sequences for the field test are shown in Fig. 13.

Starting with the beginning of slurry pumping, the effective height, the unit weight of soil, and vertical pressure were monitored by the pressure cells at various time intervals up to 3 months. The variation of the vertical pressure with time is shown in Fig. 14. This figure indicates that the vertical pressure increased up to 100minutes and then decreased. The pressure stabilized after 2days.

The observation of pressure with the pressure cells showed that the magnitude of vertical pressure is greater near the inlet compared to that near the outlet. This phenomenon is caused by the capability of the soil solid particle deposition through the water flow. It could be possible that large grain-size particles or more compacted soil are deposited near and bottom to the inlet than near to the outlet.

The effective height of geotextile tube and the unit weight of soil that was monitored with time are plotted in Fig. 15. The effective height of the geotextile tube reached 1.2m at a time of 100minute and stabilized at 0.7m.

This trend is similar to that observed from the pressure cells; however, the unit weight of the pumped soil in the geotextile tube increased continuously with time due to

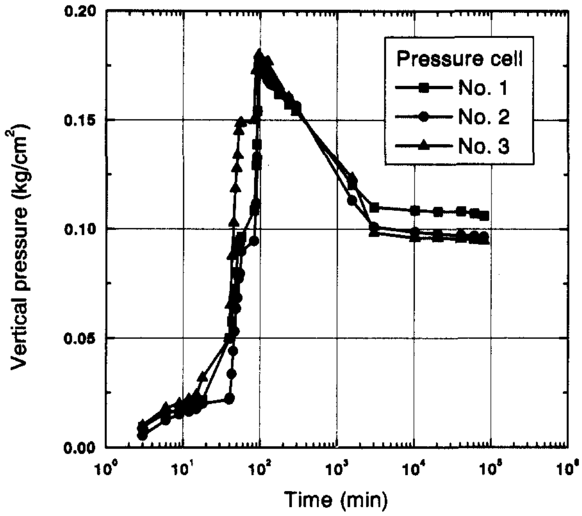

Fig. 14. Variation of vertical pressure with time

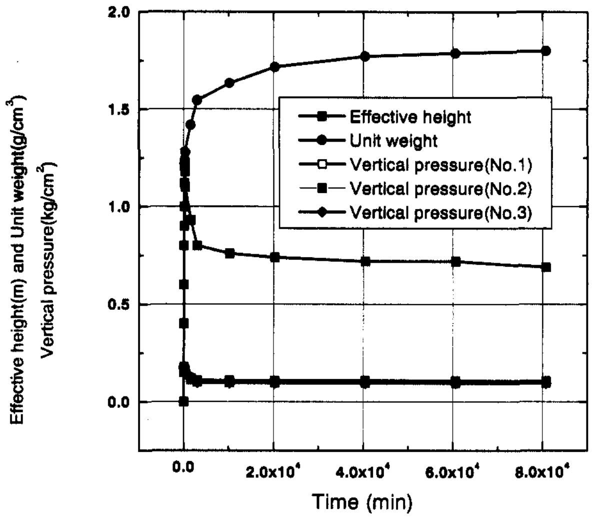

Fig. 15. Variation of effective height of geotextile tube and unit weight of soil with time

the dissipation of water from the tube. The effective height of 1.2m reached during pumping is about 80% of the maximum possible height of the geotextile tube. During the test it appeared that any further increase in effective height might cause rupture and failure of the geotextile tube.

5. Conclusions

Various laboratory tests were conducted to determine the properties of dredged backfill soil and geotextile used in fabricating geotextile tube. Direct shear test and cyclic fluctuation test were also performed to determine the interface friction angle and soil particle loss from the geotextile tube. As an environmental test, the short term self weight filtration test in the field and the long term diffusion test in the laboratory were performed to evaluate the environmental effect of dissipated water from the geotextile tube. Finally, field pilot test was performed to determine the optimum parameters of geotextile tube construction. Based on the various of laboratory tests, environmental tests and field pilot test reported, the following conclusions can be drawn :

(1) A geotextile for fabricating geotextile tubes should have a minimum permeability of $\alpha \times 10^{-4}$cm/sec and minimum EOS is less than U.S. sieve No. 100. This will keep the particle loss ratio to less than 10%, which is a desirable level.

(2) For the short-term self-weight filtration test, the magnitudes of SS and COD rapidly decreased within the first 20 minutes, after which the ratio of decrease of both SS and COD droped.

(3) The environmental test results indicate that the quality of dissipated water from the geotextile tube are far below the minimum of Korean EPA Standards.

(4) The large scale geotube for granular soil can be filled up by the slurry mixture within an hour and 40minites. The optimum ratio of the water-soil mixture is about 6:4. Also, the amount of filling the slurry mixture should not be more than 80% of the effective height of geotextile tube.

(5) Geotextile tube is fast, efficient and environmentally sound dredging fill technique.

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