Jour. of the KGS, Vol. 22, No. 9. September 2006, pp. 61～68

Uplift Pressure Removal System in Underground Structure by Utilizing Geocomposite System

지오컴포지트를 이용한 양압력 제거공법

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요 지

최근 대규모 토목·건설 프로젝트는 용지 매입비용 및 각종 민원으로 인하여, 공유수면을 매립하거나 해안 및 하천지역의 용지를 활용하고 있다. 공유수면을 매립한 지반이나 해안 및 하천 지역의 지반은 충분한 지지력을 발휘하지 못하는 연약지반이 대부분이다. 이러한 연약지반은 주로 점토나 실트와 같은 미세한 입자의 흙이나 간극이 큰 유기질토 또는 이탄, 느슨한 모래 등으로 이루어진 토층으로 구성되어 있으며, 지하수위가 높기 때문에, 제체 및 구조물의 안정과 침하 문제를 발생시킬 수 있다. 본 연구에서는 지오컴포지트의 수리특성을 평가하기 위해 상재하중에 따른 통수성과 전수성 실내시험을 수행하였으며, 지하수위가 높은 지반에 지하구조물을 축조할 경우 발생될 수 있는 지하수 누수 및 양압력을 제거하기 위하여 토목섬유를 적용한 배수시스템을 연구하였다. 지반의 조건상 양압력으로 인한 문제점이 많이 발생되는 매립지의 준설토를 이용하여 실내배수실험을 수행하였다. 실내 배수실험에서는 실험기 하부에 토목섬유 배수층을 설치한 후에 상부에 준설토를 다져 넣고 상부에서 단계별 수압을 가하여 배수량과 간극수압을 측정하여 각각의 수압에 따른 계측값들과 이론적인 값들과 비교하였다. 실내배수실험의 타당성을 분석하기 위하여 흙이나 암석과 같은 다공질 재료의 간극수압 분포나 이동을 해석하기 위한 2차원 유한요소 해석프로그램을 이용하여 수치해석을 수행하여 실내실험의 결과와 비교하였다.

Abstract

Recently the large scale civil engineering projects are being implemented by reclaiming the sea or utilizing seashore and river embankment areas. The reclaimed land and utilized seashore are mostly soft ground that doesn't have sufficient bearing capacity. This soft ground consists of fine-grained soil such as clayey and silty soils or large void soil like peat or loose sand. It has high ground water table and it may cause the failure and crack of building foundation by uplift pressure and ground water leakage. In this study, the permittivity and the transmissivity were evaluated with the applied normal pressure in the laboratory. The laboratory model tests were conducted by utilizing geocomposite drainage system for draining the water out to release the uplift pressure. The soil used in the laboratory drainage test was dredged soil from the reclaimed land where uplift pressure problems can arise in soil condition. Geocomposite drainage system was installed at the bottom of apparatus and dredged soil was layered with compaction. Subsequently the water pressure was supplied from the top of specimen and the quantities of drainage and the pore water pressure were measured at each step water pressure. The results of laboratory measurements were compared with theoretical values. For the evaluation of propriety of laboratory drainage test, 2-D finite elements analysis that can analyze the distribution and the transferring of pore water pressure was conducted and compared with laboratory test results.

Keywords : Drainage test, Geocomposite system, Ground water, Permittivity, Transmissivity, Uplift pressure

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1. Introduction

Civil Engineering construction projects are being proceeded to use reclaimed land from the sea, or to utilize seashore and riverside because of the shortage of the available land in Korea. Most of these areas are soft ground that doesn't have enough bearing capacity for supporting the structures. These soft grounds consist of fine-grained soil such as clayey and silty soils or large void soil like peat or loose sand. The safety problems such as heaving for excavation, leakage, uplift pressure, failure and crack of foundation of structure, and excessive settlement can be caused by the high ground water level in these areas. Many of underground structures such as subway, underpass, parking lot, and LNG storage facilities are being constructed in the area of high ground water level. Removing the ground water and uplift pressure can be done after construction of these structures. The drainage system using geosynthetics is widely used in embankment, sub-base of road, and reinforced retaining wall. In this paper, uplift pressure removal system that utilized geocomposite system which consisted of non-woven geotextiles and geonet was studied by the laboratory model test and numerical analysis.

2. Ground Condition and Various Removal Systems for Uplift Pressure

If the structure is constructed below the ground water level, water pressure acts on the structure face from a right angle. Specilly, it is called uplift pressure that acts upward water pressure at the bottom of underground structure. The uplift pressure is also created problems such as boiling, piping, and heaving. Therefore, the ground would loss of its strength and excessive settlement, thus the underground structure could be failed (Chang et. al., 1996).

The Ministry of Construction and Transportation of Korea recommends that the uplift pressure must be considered when the buoyancy or uplift pressure acts. When underground floor is constructed under the ground water level, the safety factor must be evaluated during the period of construction with considering external condition. The safety factor of uplift pressure can be determined by Eq. (1).

$$F_s = \frac{W_b + Q_s}{U_p} \geq 1.2 \tag{1}$$

Where, W_b is the weight of structure, Q_s is the shear resistance of soil or the frictional resistance between the soil and the wall surface, and U_p is the uplift pressure on the base of structure. The shearing resistance of soil, Q_s has to be applied or not after considering construction conditions.

Various methods such as dead weight, preloading method, holding down anchor method, external drainage system, and permanent under drainage system are usually used for countermeasure method (Rumann, 1982, Holts et. al., 1995, Korner et. al., 1990).

3. Permittivity and Transmissivity of Geosynthetics Drainage Layer

When the geosynthetics are used for filter, ground water flows over perpendicular to normal plane of geosynthetics, and flow area is considered normal permeability in a direction normal to the plane of geosynthetics. Geosynthetics filters are compressed by the overburden pressure and earth pressure in a soil mass. Hence, the thickness of geosynthetics can be prone to decrease (Palmeira and Gardoni, 2000). The ratio of decrease is more remarkable in needle punched geosynthetics (Dhani, 2005). Needle punched geosynthetics are compressible material, so the coefficient of normal permeability and the coefficient of in-plane permeability are analogous. However, geonet, woven geotextile, and heat bonded geotextile are less influenced by compression stress. Therefore, the permeability of geosynthetics vs. thickness change is defined as permittivity and it can be expressed as Eq. (2).

$$\Psi = \frac{k_n}{H_g} \tag{2}$$

In which Ψ is the permittivity ($\sec^{-1}$) of geosynthetics, k_n is the normal permeability (cm/sec), and H_g is the thickness of geosynthetics (cm). Eq. (2) can be derived from Darcy's law (Darcy, 1856) as follows,

$$q = k_n i A = k_n \frac{\Delta h}{H_g} A \tag{3}$$

$$\Psi = \frac{k_n}{H_g} = \frac{q}{\Delta h(A)} \tag{4}$$

Where, q is the quantity of flow, i is defined as hydraulic gradient $(\Delta h / H_g)$. Δh is the change in hydraulic head or head loss across the geosynthetics (cm) and A is the area of geosynthetics (cm^2). Also, the normal permeability of geosynthetics is expressed as

$$k_n = H_g \Psi \tag{5}$$

In case geosynthetics are used for drainage, ground water flows over in-plane of geosynthetics. Referring to in-plane permeability for the drainage function, we must recognize that the geosynthetic's thickness will decrease with increasing normal stress on it. This transmissivity can be discharge capacity of drainage, and expressed as Eq. (6).

$$\theta = k_{pg} H_g \tag{6}$$

Also, in-plane permeability can be derived from Darcy's law as follows,

$$\frac{Q_p}{L} = k_{pg} H_g \frac{\Delta h}{L'} \tag{7}$$

$$k_{pg} = \frac{Q_p L'}{H_g L \Delta h} \tag{8}$$

Where, Q_p is the quantity of flow (cm^3/sec), L is the length of geosynthetics cross-section for perpendicular direction flow (cm), k_{pg} is the coefficient of in-plane permeability of geosynthetics (cm/sec), H_g is the thickness of geosynthetics, L' is the length of geosynthetics parallel flow.

4. Geosynthetics and Hydraulic Test

4.1 Geocomposite

Geocomposite used in this test consists of 4 layers of geosynthetics. The bottom layer is a black non-woven geotextile with the thickness of 3 mm, the second layer from the bottom is a geonet of 5 mm thickness, the third layer is a white non-woven geotextile with the thickness of 4 mm, and the top layer is a woven geotextile (Fig. 1). Fig. 2 shows a cross sectional view of geocomposite. The thickness change of geosynthetics was observed with the applied compressive stress in the laboratory.

4.2 Permittivity and Transmissivity Tests

The normal-plane permeability (permittivity) test apparatus is composed of hydraulic loading system, cylinder, elevated water tank, and piezometer. The loading system can control the degree of loading and loading speed from 0.1 mm/min to 10 mm/min. The bottom of cylinder is made of steel and the others are made of acryl for

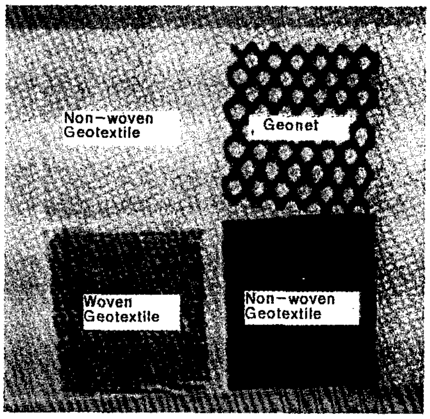

Fig. 1. Components of geocomposite

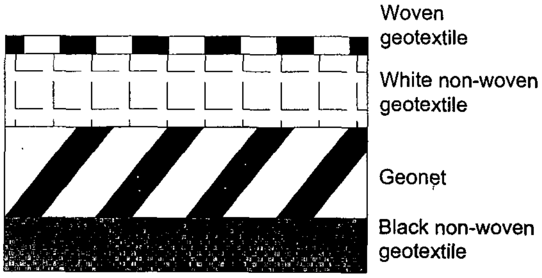

Fig. 2. Cross-section of geocomposite

investigating inner condition during the permeability test. The diameter of cylinder is 145 mm and it has inlet and outlet valves. The piezometer is a part of gauge to measure the volume of the supplied water (ASTM, 2002). Fig. 3 illustrates the permeability testing equipment.

The geocomposite specimen has the same diameter to that of cylinder and saturated in the water tank for more than 24 hours. The saturated geocomposite was layered to be 2 cm at least in thickness and loaded to the designed stress. For loading off and on, the thickness of geocomposite was measured to calculate the ratio of compression.

The test was conducted 3 times for each step of loading, and took an accurate measurement of the amount of discharged flow, different hydraulic head, and the thickness of geocomposite. The mean value was then used as the results of permeability and permittivity. The in-plane permeability (transmissivity) test apparatus has the same loading system, however, the specimen bed has a rectangular shape. The in-plane test apparatus was made of acryl and the inlet and outlet heights are 400 mm and 20 mm, respectively. The size of loading plate is 300 mm by 100 mm and the specimen is the same in size. Fig. 4 is a schematic diagram of testing device.

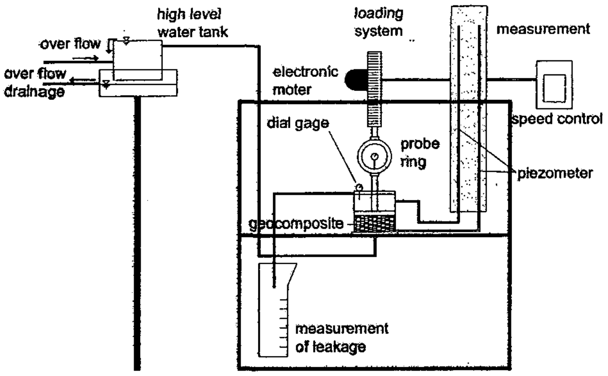

Fig. 3. Schematic diagram of normal plane permeability testing equipment

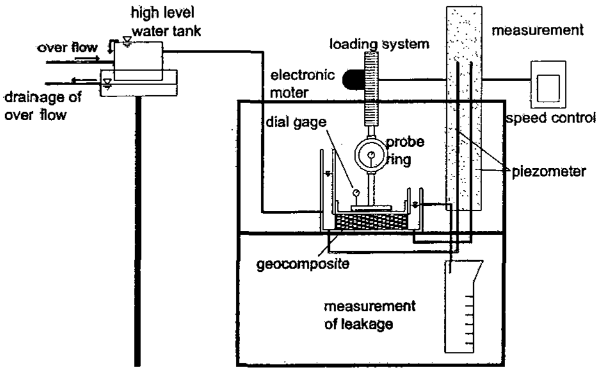

Fig. 4. Schematic diagram of in-plane permeability test equipment

In the normal plane and in-plane permeability tests, the compression stress was 0.0~3.0 kgf/cm^2 throughout 7 loading steps and then the coefficient of the permeability was determined at each step. The compression ratio of geocomposite was calculated as follows,

$$C_r = \frac{H_{g0} - H_{g1}}{H_{g0}} \times 100(\%) \tag{9}$$

Where, C_r is the compression ratio of geocomposite, H_{g0} is an initial thickness of geocomposite, and H_{g1} is the thickness of geocomposite under compression stress.

As the result of the compression test, the compression ratio of geocomposite was 5.5% at 0.5 kgf/cm^2 compression stress, and 12% at 3.0 kgf/cm^2, respectively. Fig. 5 is the result of compression test at each loading step. The compression ratio didn't exceed 13% in common normal stress, and compression ratio decreased with the increase of the compression stress. The range of permeability was 0.040~0.018 cm/sec under the compression stress levels ranging from 0.0 kgf/cm^2 to 3.0 kgf/cm^2. Fig. 6 shows the results of plane permeability and permittivity tests with respect to the compression stress.

The in-plane permeability test results are represented in Fig. 7. The test results show the same aspects to those

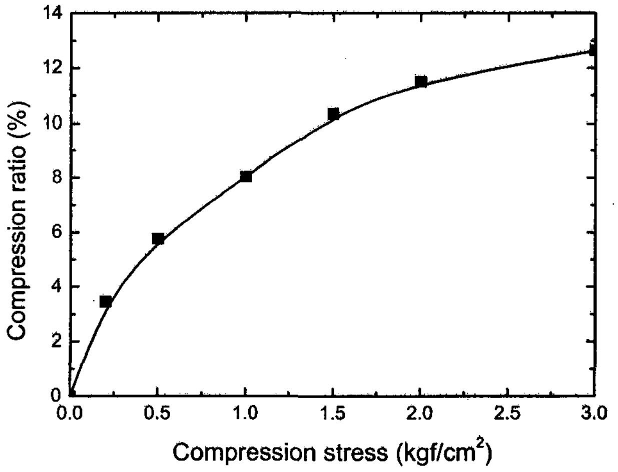

Fig. 5. Compression ratio of geocomposite with compression stress

of normal-plane test. The range of test results is from 10.09 to 0.64 cm/sec. The curves are getting converged and close with each other by the stress level of 2.0 kgf/cm^2. It seems to decrease with the compression stress of geocomposite. The normal-plane and in-plane permeabilities of geocomposite decrease by about 55% and 94% with increasing the compressive stress and the rate of decreasing tends to become smaller. The ratio of normal-plane and in-plane permeabilities ranges from 35% to 250%, and it decreases with the increase of the compression stress.

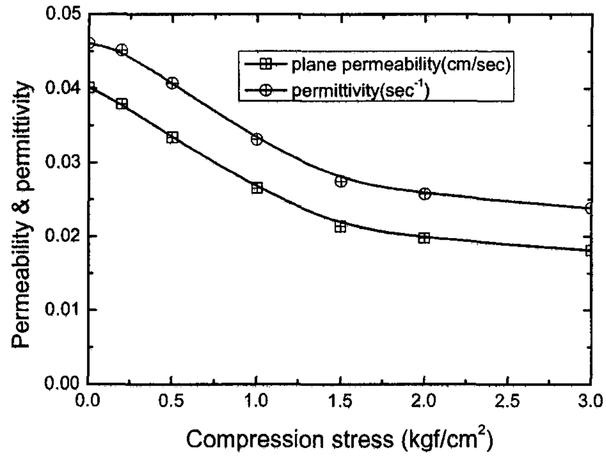

Fig. 6. Permeability and permittivity in normal plane condition

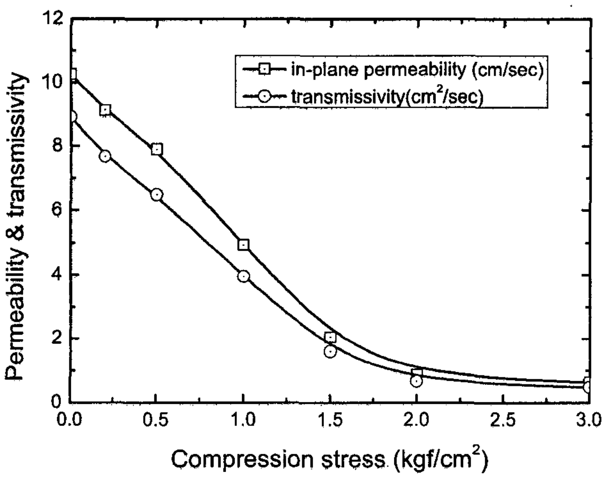

Fig. 7. Permeability and transmissivity of in-plane condition

5. Laboratory Drainage Test

5.1 Soil Property

In this test, silty soil which was sampled from the west sea of Korean Peninsula was used. The physical soil properties are tabulated in Table 1. The specific gravity of soil specimen is approximately 2.66, and the maximum dry unit weight of soil is 1.65 gf/cm^3. The optimum moisture content is about 16.23%, and the result of Atterberg limit test is N.P. The permeability of this soil is 7.83×10^{-7} cm/sec. The soil specimen is classified as silty sand, SM, by the Unified Soil Classification System.

5.2 Test Apparatus and Test Procedures

Test apparatus has a water pressure cylinder that is connected with the air compressor, pore water pressure measurement, and data logger. Fig. 8 shows the schematic diagram of the cross-section for the laboratory drainage system and Fig. 9 shows the test apparatus of the laboratory drainage system. The apparatus consists of two steel cylinders, bottom plate, and upper cover. The sizes of interior and exterior cylinders are 674 mm, and 800 mm in diameter, respectively. The water pressure cylinder is made of acryl to observe the quantity of water, and bottom and top covers are made of steel. This cylinder contains water and it can be compressed by air compression. Its

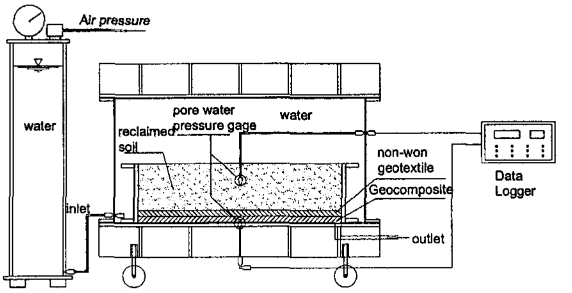

Fig. 8. Cross-sectional view of laboratory drainage system

Table 1. Physical properties of silty sand

Specific gravity	Maximum dry unit weight (gf/cm^3)	Passing % of #200 (%)	Optimum moisture content (%)	Permeability (cm/sec)	Atterberg limit	USCS
2.66	1.65	17.79	16.23	7.83×10^{-7}	N.P	SM

Fig. 9. Test apparatus of laboratory drainage system

function is to supply the pressured water to the apparatus and soil specimen. The pore water pressure is measured in the plastic tube which is installed at soil specimen, and above of bottom cover.

Geocomposite that has 650 mm in diameter is installed in the interior cylinder and the sand was put in the edge of cylinder. Then non-woven geotextile filter is installed over the geocomposite and bentonite was put in the edge of geotextile for preventing leakage against the side surface of testing equipment. Sufficiently pressured water is supplied for de-air within geosynthetics specimen. Reclaimed soil is then compacted by layer after installing drainage and filter layers. The relative compaction was achieved to 90%. After compacting of soil, the water is supplied to the exterior cylinder and the soil specimen is saturated for over 24 hours.

5.3 Test Results

The results of laboratory drainage test are shown in Figs. 10 and 11, respectively. The pore water pressure at the top of the filter slowly decreases with the elapsed time. However, the pore water pressure at the bottom of the layer quickly decreases. For evaluation of the theoretical drainage quantity (cm^3/min), the equation of permeability was modified as follows (Head, 1986).

$$q=\frac{60\times A\times 102\Delta p\times k}{L} \qquad (10)$$

Where, A is cross sectional area (356787.5 mm^2), k is the coefficient of permeability (7.83×10^{-9} m/sec), Δp is the inlet water pressure (kPa), and L is the specimen length (169 mm).

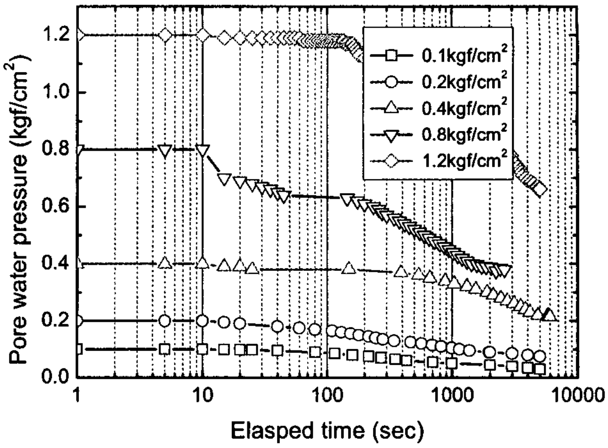

Fig. 10. Pore water pressure in soil specimen

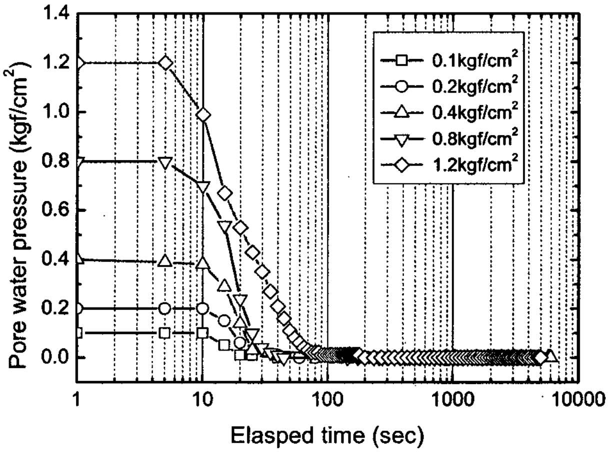

Fig. 11. Pore water pressure at the bottom layer

The pore water pressure at the top 10 cm of filter curves is obtained at each supplied water pressure as shown in Fig. 10. The pore water pressure is dissipated with the elapsed time and it seems to take more time for dissipating pore water pressure at higher water pressure. Fig. 11 shows the pore water pressure at bottom layer. All the pore water pressures irrespective of applied stress level are dissipated within 1 minute and converge to 0.0 kgf/cm^2. Fig. 12 is the comparison between experimental values and theoretical values. The quantity of drainage increases linearly with supplied water pressure. Experimental values are 3~20% higher than those of theoretical values, however they show very similar trend.

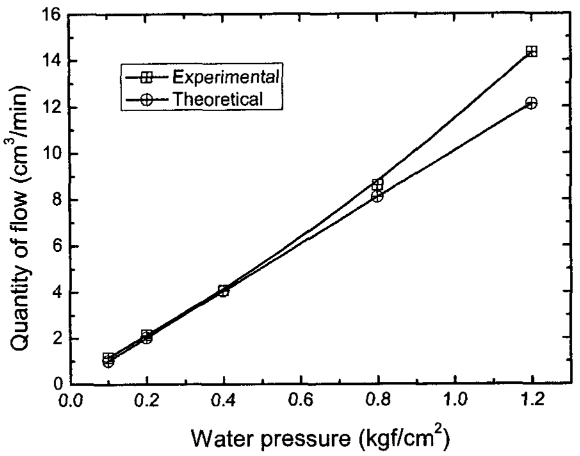

Fig. 12. Comparison of experimental drainage quantity with theoretical value

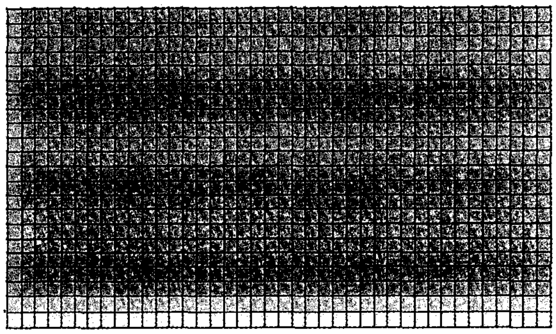

Fig. 13. Numerical analysis mesh for seepage flow in geocomposite drainage system

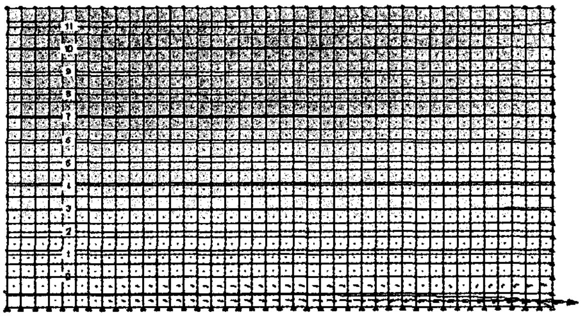

Fig. 14. Total head of numerical analysis at 1.2 kgf/cm^2 of supplied water pressure

6. Numerical Modeling

SEEP/W computer program is a general 2D finite element software to solve the problem of seepage and the pore water pressure within the porous media such as soil and rock. It can be used to analyze and design seepage problems for civil engineering and geotechnical engineering structures. In this study, SEEP/W was used for numerical seepage analysis. Analyses were performed at the same supplied water pressure as the laboratory test. The parameters are obtained from the laboratory test and analysis condition was axisymmetric. Fig. 13 is the numerical analysis mesh that consisted of 40 elements of geocomposite and geotextile and 800 elements of dredged soil. Fig. 14 illustrates representative total head of seepage analysis at 1.2 kgf/cm^2 of supplied water pressure. It tends to decrease with the distance from upside to downside linearly. Fig. 15 is the result of comparison of experimental and numerical analysis of total head in soil specimen at the top 10 cm of filter layer. They were very similar and the difference of values ranges from 4% to 13%.

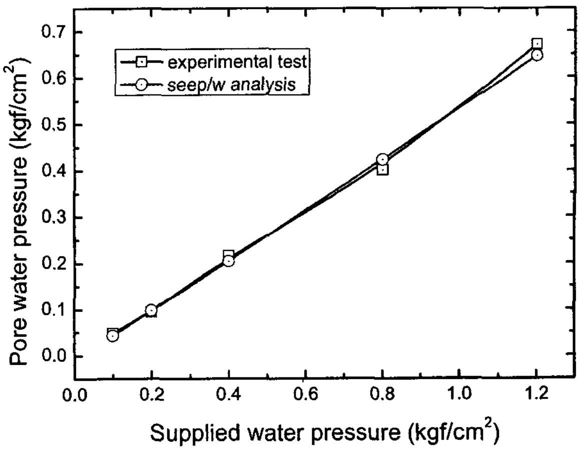

Fig. 15. Comparison of pore water pressure between experimental test and numerical analysis

7. Conclusion

When the geosynthetics are used in soil structure, they must be compressed by normal stress, so we have to consider the thickness of geosynthetics to calculate the quantity of flow and to evaluate hydraulic properties. Permittivity decreases to 51.7% and transmissivity decreases to 5.5% at 3.0 kgf/cm^2 of normal stress. The rate of decrease is higher in the case of transmissivity than that of permittivity case.

The quantities of drainage are very similar to the results of experimental test, theoretical values, and numerical analysis; it increases linearly with the supplied water pressure.

In this paper, the feasibility of utilizing geocomposite system was studied for the uplift pressure removal drainage system. When the structure is constructed at high water level area such as reclaimed land, geocomposite system is very much useful for reduction of uplift pressure. Consequently, the construction has economical benefit. However, the problems of creep and clogging of geosynthetics should be solved.

Acknowledgement

The authors wish to extend special thanks to Korea Research Foundation for supporting research funds. "This work was supported by Korea Research Foundation Grant (KRF-2001-041-E00513)".

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(received on Jun. 8, 2006, accepted on Sep. 25, 2006)