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論 文

Instrumentations for the Behaviour Observation of the Geotextile on Marine Clayey Grounds

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해성점토지반에 설치된 지오텍스타일의 거동 관측을 위한 계측

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Key Words : Instrumentation(계측), Geotextile(지오텍스타일), Embankment(성토), Reinforcement(보강), Strain Gauge(변형률계), Soft Ground(연약지반)

Abstract

Reinforcement with geotextiles have been used in the foundation soil to enhance the resistance of embankments to avoid failure through excessive deformation or shear in the foundation. It is important to know the amount of the strain and the displacement of buried geotextiles for the verification of the reinforcement behaviour. Full scale trial constructions were performed to check the deformational characteristics of the polyester(PET) mat which was used for the embankment reinforcement. Many instrumentation equipments including surface settlement plates, profile gauges and inclinometer casings were installed to observe the behaviour of the soft ground due to the soil embankment. 60 electrical resistance strain gauges and 9 vibrating wire LVDT's were installed to measure the deformation of the polyester mat.

Results of various tests and investigations to suggest the proper installation method for the gauge bonding onto the geotextile, waterproofing and protection from the hazard environments were introduced. The proposed instrumentation method was effective for the monitoring of the geotextile behaviour. The direct attachment of electrical resistance strain gauges on the geotextile mat was able to measure small changes of the strain of geotextiles. At the end of the 5 month monitoring, 54 of 60 (93%) strain gauges and 7 of 9(78%) displacement transducers survived all perils of the compaction impacts and the humidity. And the tensile strain of geotextiles increased as the ground displacement became larger. Though the observed strain of mats under the 3m high embankment load was less than 1%, the magnitudes of the strain according to the mat spreading method were different from each other.

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1. Introduction

Geotextiles, a kind of geosynthetics have been widely used for purposes of drainage, separation, filtration, contaminant barrier and reinforcement in the ground. The recent annual amount of geosynthetics applied to civil works in Korea exceeded by 30million ㎡. Kinds and functions of geosynthetics are described briefly in Table 1. Figure 1 and 2 shows the amount of geosynthetics used in the national expressway construction.

In the case of expressway constructions on soft marine clay deposits, woven mats made of polyester(PET), or polypropylene(PP) have been used mainly for the embankment reinforcement, filtration and material separation(Figure 3). PET mats can be nicely complementary materials to what are good in compression but weak in tension, since they have sufficient tensile strength.

However, in-situ behavior of the PET mat on the ground is not made clear although this type of geotextiles generally has been used in most soft grounds under the embankment. This has been mostly due to the additional cost for the full scale monitoring and the difficulties of the instrument installation itself. Knowledge of the geotextile's strain-strength characteristics are essential not only for the selection of good products but also for the resonable design of the reinforcement and the constructions(Figure 4 and 5). Efforts to investigate the behavior of geotextile-spread grounds have been made with full-scale trial constructions and from these, appropriate

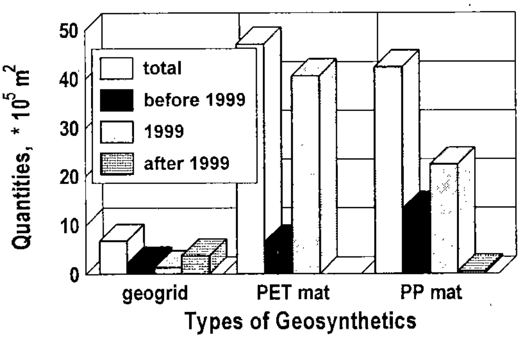

Fig. 1 Geosynthetics used in expressway

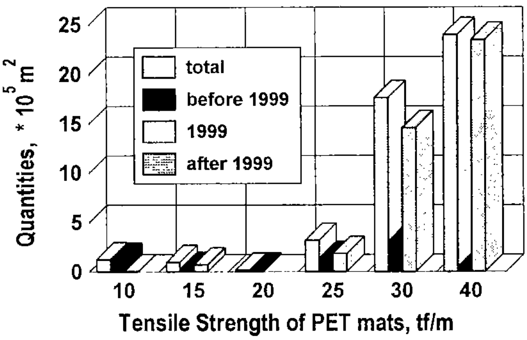

Fig. 2 Amount of the PET mats

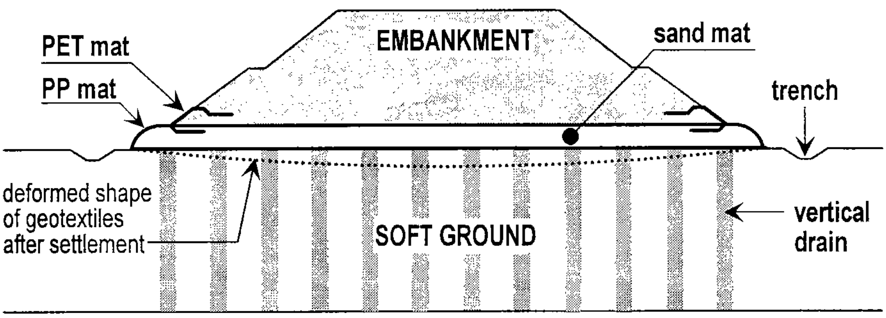

Fig. 3 Typical features of embankment constructions on the soft grounds

Table 1 Types of Geosynthetics

Type	Material	Main Function
geotextiles	PP, PET, PE, PA	reinforcement, separation, drainage, filtering, cutoff
geogrids	HDPE, PP, PET	reinforcement
geonets	PE	drainage
geomembranes	HDPE, VFPE, fPP	barrier to fluids, water proof, cutoff
geosynthetic clay liner	PP, PET, PE, bentonite	barrier to fluids, water proof, cutoff
geopipe	PVC, HDPE, PB, ABS, CAB	drainage
geocomposites	all above	reinforcement, separation, drainage, cutoff

[Abbreviation] PP:polypropylene, PET:polyester, PE:polyethylene, PA:polyamide, PB:polybutylene, ABS:acrylonitrile butadiene styrene CAB:cellulose acetate buytrate, HDPE:high-density-PE, VFPE:very-flexible-PE, fPP:flexible-PP, PVC:polyvinyl chloride

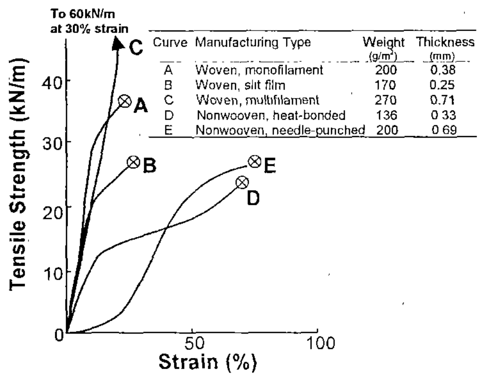

Fig. 4 Strength-strain relations in geotextiles (Koerner, 1998)

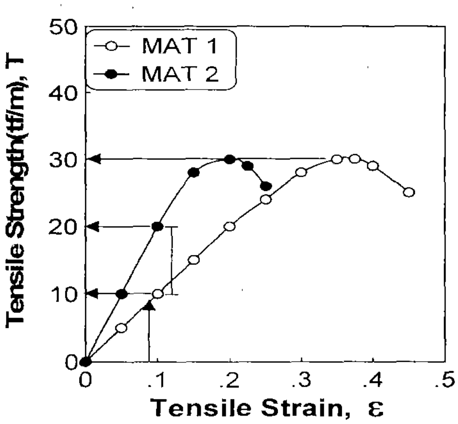

Fig. 5 Difference of strength-strain curve at same ultimate strength

attaching methods of measuring instruments on the geotextiles were suggested.

2. Trial Constructions

The purposes of the trial construction were to verify the instrument installation method on the high strength mat and to investigate the difference according to spreading types of the mat. The research site is located on the west-coast expressway construction field(Figure 6). Figure 7 shows the schematic features of the trial construction.

The test site was divided into 3 blocks according to the spreading type of PET mats. Each end of PET rolls was just laid one upon another in 'BL-1' block. The ends of rolls joined together with sewing in 'BL-2' block. In 'BL-3' block, mat rolls spread at regular intervals of 20cm. 'BL-2' type is common in practical aspect -s. This classification of the site was to find the difference of reinforcement effects according to spreading methods. Grounds would deflect mainly in lateral direction of the highway embankment.

The surface of weak grounds were covered with non-woven polypropylene(PP) mats of 3tf/m tensile strength for the trafficability of the construction equipment and for the separation of clayey grounds from sand mats. 50cm thick sand-mat was overlaid on PP mats to promote the horizontal permeability and trafficability. PET mats having tensile strength of 15tf/m were overlaid on sand mats for the embankment reinforcement.

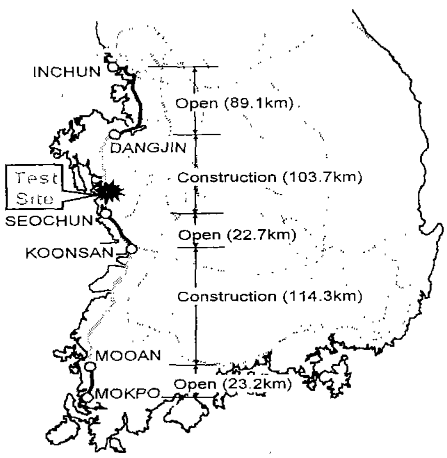

Fig. 6 Location of the test site

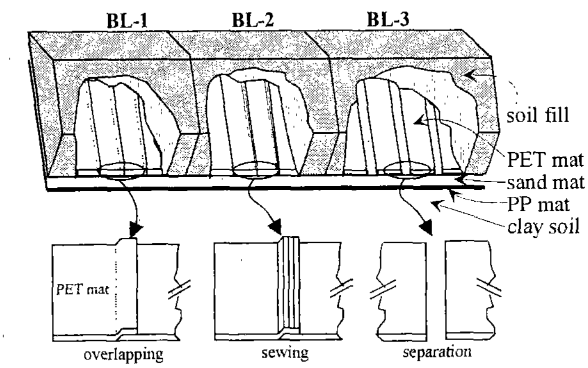

Fig. 7 Schematic features of the trial construction section

3. Subsurface Properties Of The Test Site

Laboratory tests and field investigations were carried out to define the subsurface geotechnical characteristics using the track mounted vehicle system for site explorations(GPMS) of Korea Highway Corporation. Some results of the ground investigation are shown in Figure 8. 'q_c' is the tip resistance and 'f_s' is the sleeve friction from static piezo-cone penetration tests. N values from the standard penetration test are also listed.

The subsoils consisted of the low plastic marine silty clay('ML'~'CL') and the sandy silt. The undrained shear strength, s_u of clayey layers from field vane shear tests and cone penetration tests ranged from 25 to 30kPa. The natural water content, w_n of clayey soils was about 40% and this was slightly less than liquid limit(w_L). The compression index, C_c of soft layers was about 0.25 and could be classified as a moderately compressible ground.

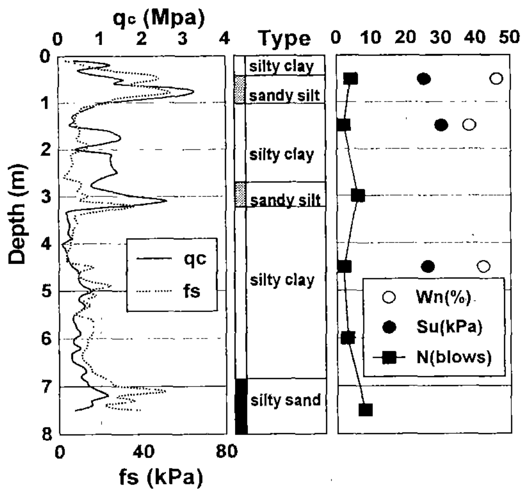

Fig. 8 Geotechnical characteristics of the site

4. Instrumentation

Various instruments to measure the strain, displacement and stress of the PET mat, and to observe the ground deformations were installed (Table 2). It was not easy to select the type of instruments and installation methods, since the field instrumentation of geotextiles is uncommon. Moreover, field environments differ from indoor conditions.

Table 2 Kinds of the field installed instruments

Instruments	Specifications	Quntity
Electrical resistance strain gauge	post-yield type strain limit > 10% plastic carrier base (20×7mm) Cu-Ni wire sensing element	60
Vibrating wire displacement transducer	length : 30cm diameter : 0.8cm displacement limit > 15cm	9
Settlement plate	rod systems on steel plate need level survey	9
Hydraulic profile gauge	access tube(polyethylene) : l=70m, ϕ=5cm digital transducer	3
Inclinometer	casing (ABS resin) : l=15m, ϕ=6cm servo accelerometer probe	2

Because the survival of instruments attached on PET mats in fields was essential for this research, long-term stability in difficult environments was the primary point of instrument selections. So, many pre-tests were carried out to suggest the proper attaching method of gauges and to verify the waterproofing and protection from the hazard environments.

Electrical resistance strain gauges were decided to use for measuring the strain of PET mats under soil fills. These gauges utilize a plastic carrier base able to withstand extremely large elongations without creeping or cracking and are capable of measuring approximately 10 to 20 % strain. Strain gauges are not the only devices of the geotextile monitoring(Koerner, 1996). The use of inextensible flexible cables was reported by Bourdeau, et al.(1994) and has been used by Gugli emetti, et al.(1996).

Vibrating wire type linear displacement transducers were also selected to measure the displacement of the mats. These gauges of 30cm long were designed to measure movement across surface cracks originally and readable elongation was up to 15cm.

For measuring the ground deformation, hydraulic profile gauges, settlement plates and inclinometers were used. Profile gauges and surface settlement plates were selected to measure the settlement of geotextile-installed grounds. Inclinometers with servo-accelerometer probe were used to measure the subsurface lateral movement.

Critical point were the gauge bonding on the geotextile, their waterproofing, the protection of gauges, and the extending the wire leads to the monitoring station(Koerner, 1996). Risseeuw and Voskamp(1984) led to a technique of applying 100mm long electrical resistance strain gauges directly on high strength geotextiles. Specific problems arose in the measurement of the strain of geotextiles, especially when the expected strain was in the order of around 10 percent. they were the choice of a suitable strain gauge, the choice of a suitable gluing the strain gauges to geotextiles and the interpretation of the signal. As the response of the strain gauge mainly depends on the stiffness ratio of the geotextile to the strain gauge system, a correction factor had to be determined experimentally for each type of geotextiles(Sluimer and Risseeuw, 1982). The feasibility test conducted by Sluimer and Risseeuw shows that the measured strain by the strain gauge directly glued onto the geotextile using silicon gel deviates from the actual deformation of the glue and the interaction between geotextile and gauge. The most common problem associated with strain gauge measurement is the local stiffening effect of the geotextile due to the use of adhesive leading to the inability to maintain the flexibility of the geotextile(Ng, et.al, 1999). The soft elastic silicon adhesive was used because it has a low modulus which minimizes the adverse effects on the geotextile behaviour. However, its cementation may be insufficient to prevent relative movement between the elongating geotextile and the adhered strain gauge. Hence, a laboratory tests were conducted to determine a correction factor (Leshchinsky and Fowler, 1990). From these pre-studies, Ng. et. al(1990) recommended to use the external strain gauging method(Figure 9).

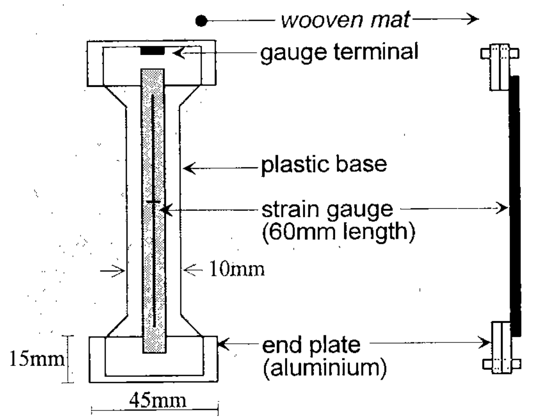

Fig. 9 Schematic view(plan and side) of external strain gauging (Ng, et. al.; 1999)

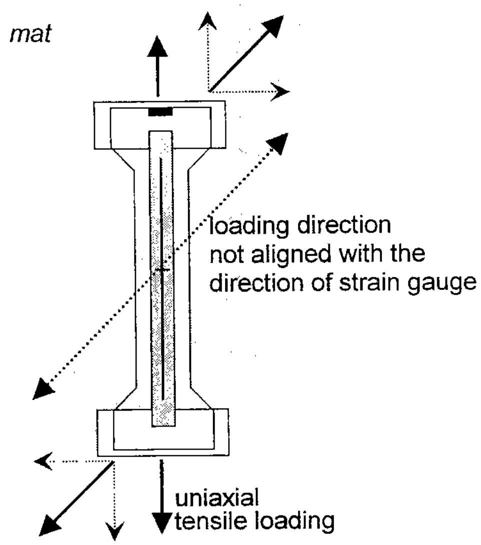

Fig. 10 Shear force component around the strain gauge (Ng, et. al.; 1999)

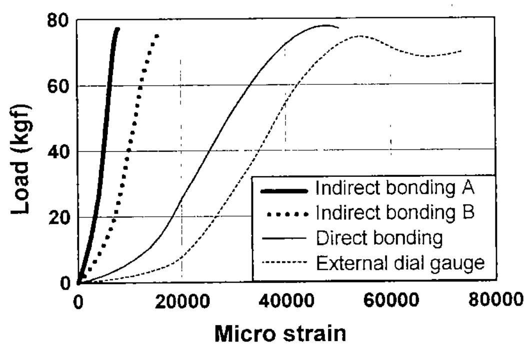

Fig. 11 Load-strain relations from bonded strain gauges on the PET mat

However, strain gauges can fail prematurely due to the present of large shear force component acting on the external strain gauge system and this is shown in Figure 10(Ng, et.al., 1999).

For the trial construction, 3 types of the gauge bonding method were considered and laboratory tests for indirect bonded gauges('A' type : 0.2mm thick rubber membrane was used as the medium between the geotextile and the strain gauge. 'B' type : a rubber membrane thinner than 0.1mm was used) and direct bonded gauges attached by manufacture recommended adhesive(CN-adhesive by TML) were performed. Test results showed the direct bonding onto the geotextile was better than the indirect bonding with mediums(Figure 11). So, strain gauges to measure the tensile strain of the PET mat were attached on the mat with manufacturer recommended adhesives. Some drops of this liquid adhesive were spilled around the gauge to prevent lateral infiltration of the external water along the mat section. Then silicon gel was plastered over the gauge and insulated tapes were stuck on the silicon. Steel guide frames and epoxies were used to fix the linear displacement transducers onto the mat. The sensing element was covered with the PVC shell to be protected from the soil clogging(Figure 12).

Dummy gauges and thermometers were used for temperature compensations. Figure 13 is the instrument arrangement diagram of the BL-3 area. Cables of every instrument were collected to the

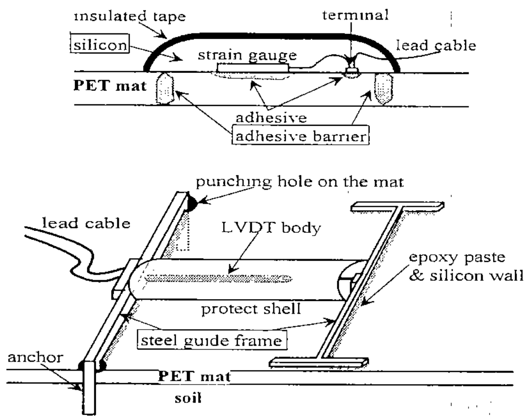

Fig. 12 Attachments of the strain gauge and the displacement transducer onto the PET mat

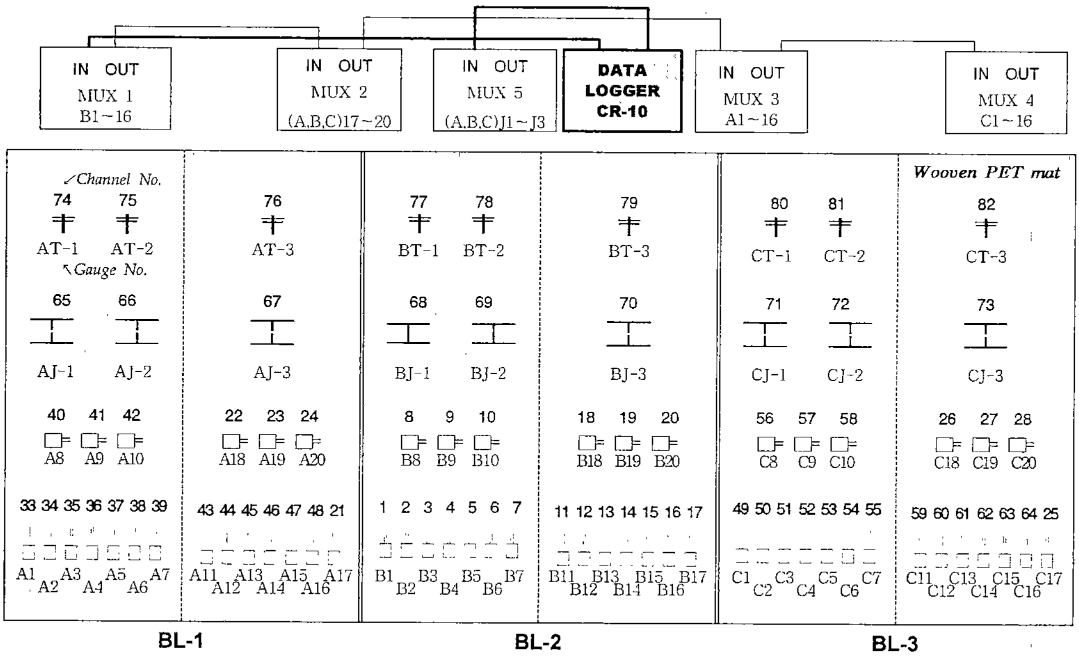

Fig. 13 Schematic diagram of gauge connections
(□=:strain gauge, I:jointmeter(LVDT), ╤:temperature gauge)

multiplexer and finally connected to the automatic data-logging system.

Profile gauge tubes and settlement plates were installed in sand mats below the PET mat. Inclinometer casings were installed in the toe of the embankment slope.

project, only 4 of 60 strain gauges and 2 of 9 displacement transducers were broken down due to compaction impacts and the humidity. 93% of installed strain gauges and 78% of displacement transducers survived during 5 months in difficult environments.

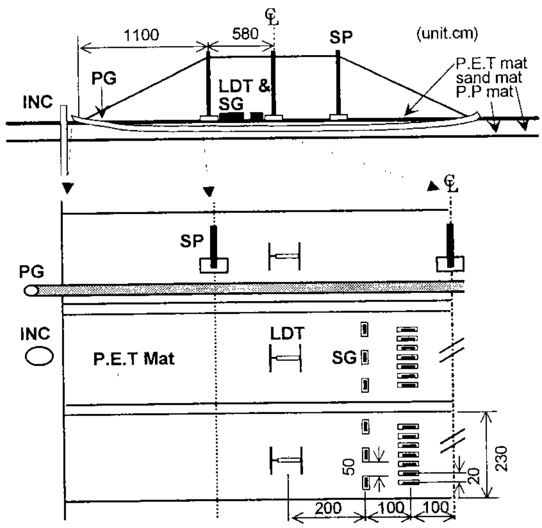

Fig. 14 Instrumented section (case of BL-3)

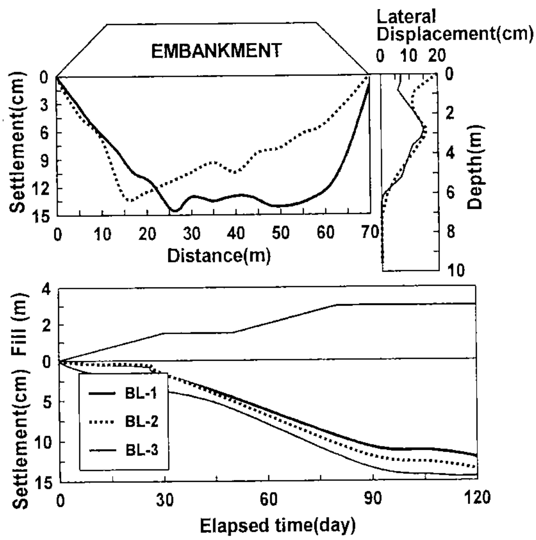

Fig. 15 Measured ground displacements

Figure 14 is the instrumentation section of 'BL-3'. 20 strain gauges(SG), 3 displacement transducers(LDT), 1 profile gauge(PG), 3 settlement plates(SP) and 1 inclinometer casing(INC) were installed in each block

5. Results And Discussion

Field monitoring was continued about 5 months after gauge installations. The 3m-high soil fill was started to construct a month later from gauge installations. Figure 15 shows the brief results on the ground displacements induced by the soil embankment during 4 months. At the end of this

Figures 16, 17, and 18 show the selected tensile strain of the PET mat against the elapsed day for each block after the soil fill started. All the values of measured strain reset by the initial value of the gauge right after installation was ended. Negative values of measured strain represents the condition of the compression and this state could be possible in the first stage of soil filling. However, negative values of the strain were not considered meaningfully in this case, because the absolute value of difference between measurements was a point to analysis. At the beginning of embankment constructions, an element of the geotextile mat can be in tensile, or compressive conditions repeatedly because of the wrinkle, or the folding in the surface.

The measured strain of PET mats shows similar typical trend. Though the measured strain of geotextiles is very small, it is obvious that the tensile strain increased as the ground displacement became larger. The observed strain of PET mats under the 3m high embankment load is less than 1%. This small value of strain was due to the hardness of the site ground. As shown in figure 8, soft deposits of the trial construction site was thin and the ground compressibility was not high. However, the magnitude of the strain in each blocks is different from each other. Each block was classified according to the seaming method of the geotextile(Figure 7). The maximum magnitude of tensile strain in "BL-3"(each mat spread separately with space) was about 3 times larger than that in other blocks, on the other hand the strain in "BL-1" was nearly same as that in "BL-2". This shows that, in the viewpoint of embankment reinforcement functions, the overlapping method of the end of each geotextile has not a problem in longitudinal embankment constructions.

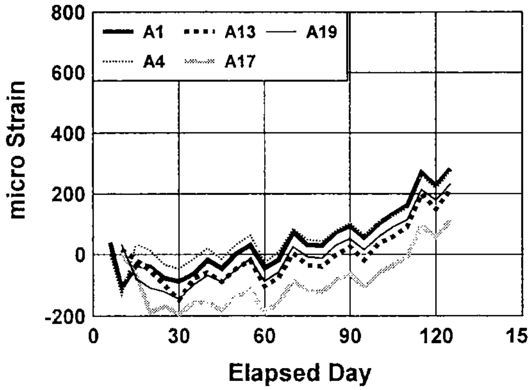

Fig. 16 Measured tensile strain : BL-1

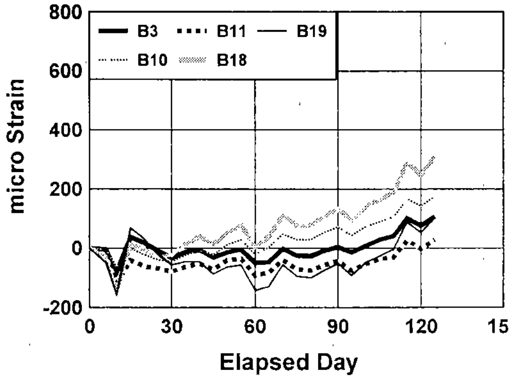

Fig. 17 Measured tensile strain : BL-2

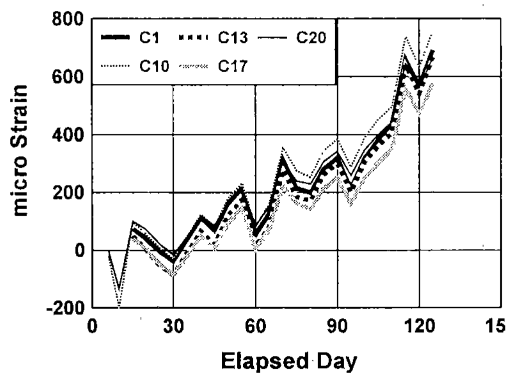

Fig. 18 Measured tensile strain : BL-3

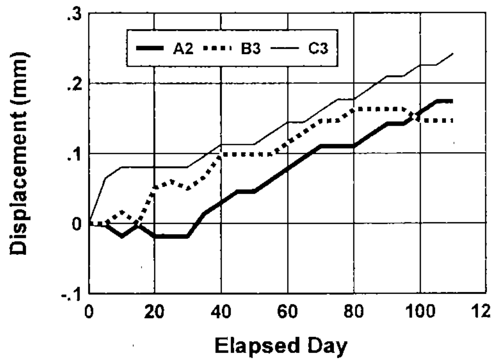

Fig. 19 Tensile displacement vs. time

Figure 19 shows the representative values of the displacement of PET mats in each block. Recorded total tensile displacements were less than 0.3mm per 30cm length(0.1% of strain).

Observed displacements of the mat in "BL-3" was also larger than those in "BL-1" and "BL-2", but the differences between these values were small as compared with results from the strain gauge. This result might be attributed to the fundamental limitation in the spreading of mats. It was not easy to spread the geotextile mat tightly and geotextile mats were certain to be in loose state, because there could be so many wrinkled, or folded parts. This kind of the error in displacement measurement will be increased as the stiffness of grounds become to larger.

6. Conclusion

Field monitorings to observe the behaviour of geotextiles on soft marine clayey grounds were performed and gauging methods were verified in the full-scale trial constructions. Based on the analyses of obtained data from the monitoring, followings were found.

1) The proposed instrumentation method was effective for the monitoring of the geotextile behaviour. The direct attachment of electrical resistance strain gauges on the geotextile mat was able to measure small changes of the strain of geotextiles. At the end of the 5 month monitoring, 54 of 60 (93%) strain gauges and 7 of 9(78%) displacement transducers survived all perils of the compaction impacts and the humidity.
2) The tensile strain of geotextiles increased as the ground displacement became larger. Though the observed strain of mats under the 3m high embankment load was less than 1%, the magnitudes of the strain in each blocks according to the mat spreading method were different from each other. The tensile strain in "BL-3"(each mat spread separately with space) was about 3 times larger than those in other blocks(each mat spread with end sewing, or overlapping).
3) In the viewpoint of embankment reinforcement functions, the overlapping method of the end of each geotextile was effective as well as the sewing method in the highway construction.

요 약

연약한 지반에 성토 구조물을 시공하는 경우에 연직배수공법, 선행재하공법 등과 같은 지반개량공법들의 적용과 함께 폴리프로필렌(PP)이나 폴리에스테르(PET), 고밀도 폴리프로필렌(HDPE) 등과 같은 합성섬유 재료를 이용한 지반 처리가 보편화되고 있다. 이 글에서는 현장에 적용된 토목섬유 매트(geotextile)의 실제 거동을 관찰하고 분석하기 위한 시험시공시 수행한 토목섬유에 대한 계측 방법과 그 결과를 정리하였다. 토목섬유에 설치한 계측기들은 전기저항식 변형률계, 진동현식 선형변위계 등으로 실내시험을 거쳐 최적의 모델과 부착 방법을 선정하였으며, 지반 변위를 관측하기 위해 침하판과 경사계도 설치하였다. 성토 후 5개월간 집중계측을 실시한 결과, 가혹한 현장 조건에도 불구하고 변형률계는 93% 이상, 변위계는 78% 이상 생존하였으며, 성토 하중에 증가함에 따라 매트에 작용하는 인장력이 증가하면서 변형률이 늘어나는 경향을 뚜렷하게 확인하였다. 또한 지오텍스타일의 현장 포설 방법에 대해서도 효용성을 검증하였다.

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