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Application of strain gauges to measure nonwoven geotextile deformation in reinforced soil wall

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ABSTRACT: This study proposes a new, more convenient method to measure the deformation behaviour of nonwoven geotextile by using a strain gauge; and examines the availability of the method by conducting laboratory tests and by applying it on two geosynthetics reinforced soil (GRS) walls in the field. A wide-width tensile test conducted under confining pressure of 7 kPa showed that the local deformation of nonwoven geotextile measured with strain gauges has a similar pattern to the total deformation measured with LVDT. In the field GRS walls, nonwoven geotextile showed a larger deformation range than the woven geotextile and geogrid; however, the deformation patterns of these three reinforcement materials were similar. The function of strain gauges attached to nonwoven geotextile in the walls works normally for 16 months. Therefore, the method proposed in this study for measuring nonwoven geotextile deformation by using a strain gauge proved useful.

1 INTRODUCTION

Because of the increasing need to use clayey soil as the backfill in reinforced soil wall, nonwoven geotextiles with the drain capability has been receiving much attention. Nonwoven geotextiles have merits of high drain capability and low cost, but also have demerits of low tensile stiffness and higher deformability than geogrids and woven geotextiles. To analyze the deformation behaviors of reinforcements, load-elongation properties and local deformation measurement data are needed; however, measuring local deformations of GRS walls in the field is not easy. Sluimer and Risseeuw (1982), Leshchinsky and Fowler (1990) have suggested using silicon to attach strain gauges to the woven geotextile. Strain gauges can be attached directly on to woven geotextile and geogrids (Boyle, 1995; Koerner, 1996). But, it is not easy to measure deformations of nonwoven geotextle by direct attachment of the strain gauges. However, Huang (1998) suggested a method of attaching strain gauges to the surface of nonwoven geotextile, which is composed of a core layer of knitted textile needle-puched two layers of nonwoven geotextile, by using gauge cement.

This study examines a method of using an adhesive to more easily attach strain gauges onto nonwoven geotextiles, and also proves the applicability of the examined method by laboratory and field tests. Also, to analyze the deformation behavior of reinforcements within GRS walls, two GRS walls in the field, each standing 5 m, were constructed on a shallow-layered weak foundation, installed with a compound arrangement of nonwoven and woven, and nonwoven and geogrids. The deformation behavior of geosynthetics inside the GRS walls was analyzed by using the data collected from 124 strain gauges attached to non-woven and woven geotextile and geogrid reinforcement for about 1.5 years.

2 STRAIN GAUGE ATTACHMENT METHOD

Tables 1 and 2 show the characteristics of nonwoven, woven, geogrid, and strain gauges used in this study. For woven and geogrid, strain gauges were attached directly onto them; for nonwoven geotextile, strain gauges were attached as shown in Fig. 1. Details of the attachment method are as follows.

(1) Draw on the nonwoven geotextile a rectangle big enough to fit the strain gauge and the terminal strip. Make the longer side of the rectangle face the direction of the tension.
(2) Spread sufficient amount of adhesive evenly on the drawn rectangle.
(3) Use a smooth, flat rubber board to press down for 10 minutes the part where adhesive is applied 3 to 5 minutes after applying the adhesive, so that the adhesive adheres flatly onto the nonwoven geotextile.

Table 1. Geosynthetics properties.

Products	Materials	Description	Thickness (mm)	Tensile strength (kN/m)	
				Manufacturer (KS K 0520)	Researchers (ASTM D 4595)
KOLON P5100	Polyester	Nonwoven needle-punched	5	100	89.7
KOLON KM5001	Polyester	Woven multi-filament	0.25	50	51.1
AKILEN GRID5/3	Polyester	Geogrid coated with PVC resin	0.5	50	44.3

Table 2. Strain gauge properties.

Manufacturer	CAS Corporation
Type	AE-11-S80N-120-EL
Gage factor	2.1 ± 1.0%
Transverse sensitivity	1.20%
Resistance	120Ω ± 0.2%

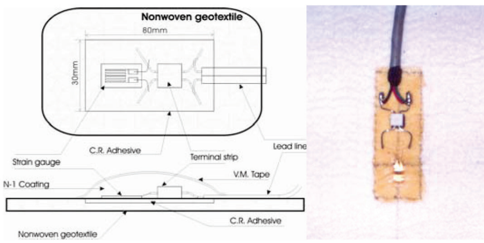

Figure 1. Attaching a strain gauge onto nonwoven geotextile.

(4) Place strain gauge and terminal on the adhesive area 24 hours after the application of adhesive.
(5) Connect the lead line. Protect the strain gauge from damage by covering it up by using N-1 coating and water proof tape.

Using adhesives to attach strain gauge onto the nonwoven geotextile creates less resistance against tension stress because the adhesive is ductile and elastic, and prevents the water rise from below. Therefore, the deformation behaviour of the nonwoven geotextile can be effectively measured in atmospheric and actual work conditions.

In Fig. 2 (a) and (b), shows the result of a wide-width tensile test (ASTM D4595), which was conducted under 7 kPa of confining pressure to confirm if the deformation behaviour of the nonwoven suggested in this study can be effectively measured on field GRS walls. In the figure, the local deformation measured with strain gauges look similar to the total deformation measured with LVDT. Especially, repeated loading-unloading cycles appear in the same pattern at the total deformation strain of 38~48%. This means that the method suggested herein was effective in measuring the nonwoven's deformation behaviour. Strain gauge 2 shows larger local deformation than strain gauge 1 does, presumably because the gauge 2, compared with gauge 1, was placed nearer to a tensile loading plate. According to Boyle (1995), measurement of geosynthetic's deformation by a strain gauge is affected by the degree of flatness of the geosynthetics, conditions of the fibers and filament bundles in the strain direction, Poisson's ratio, and confining pressure during the test. Kim and Won (2001) reported that the size of the specimen, strain rate, and confining pressure affect the strain gauge measurement of geosynthetics deformation. Figs. 2 (c)~(e) show all of the relationships between the local deformation and the total deformation with respect to the specimen size, strain rate, and confining pressure from the study of Kim and Won (2001). The result in Figs. 2 (c)~(e) show good geogrid, woven, nonwoven in order. In this study, using the average curve of each reinforcement material in the figure, the local deformation, measured with strain gauges, was converted into total deformation. The relationship between local deformation and total deformation according to the variation of the specimen size, strain rate, confining pressure was reported in detail by Kim and Won (2001) and Won (2001).

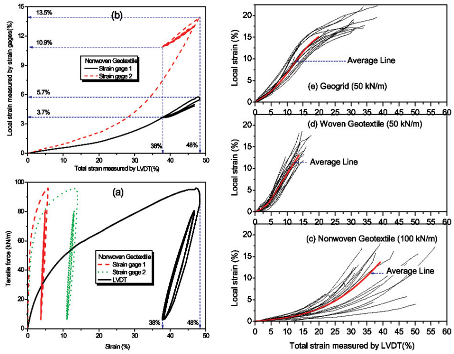

Figure 2. Relationship between the local deformation and the total deformation.

3 FIELD GRS WALLS CONSTRUCTION AND THE ANALYSIS OF THE DEFORMATION BEHAVIOR OF GEOSYNTHETICS

3.1 *Field GRS walls construction*

As illustrated in Table 3, the GRS wall was constructed upon a shallow layer of a weak foundation with the average N value of 4 in 5 m depth as shown in Fig. 3(a). Low plasticity clayey soil (CL) from a nearby

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field was used as the backfill, and nonwoven, woven, and geogrid were used as the reinforcement. In accordance with the assembly types of the reinforcement materials, the GRS walls were divided into SECTION I (nonwoven and woven geotextile) and SECTION II (nonwoven and geogrid), then subdivided into sections A, B, C, and D as shown Fig. 3(b). The wall surfaces of sections B and D were reinforced with concrete placement 18 months after the construction of the walls. GRS walls were constructed by a step-by-step method. In the beginning, the gravel-filled gabion was heaped in the front. And by using a mini vibrating compactor, each 30 cm layer was compacted twice at every 15 cm of spacing, and GRS walls with a total height of 5m was built by repeating the above method. During compaction, soil and reinforcement were incorporated by allowing horizontal deformation to prevent excessive horizontal deformations after completion of the walls. These GRS walls were completed in 57 days. As Fig. 3(b) shows, the measurement instruments were placed on the wall of SECTIONS I and II. The movements of these instruments on the GRS walls were automatically measured by using a data logger. The instruments used in the measurement are listed in Table 4.

Table 3. Results of the field boring log.

	Fill	Silty clay	Gravel	Soft rock
Thickness (m)	1.4	3.4	0.7	2.5
Depth (m)	0~1.4	1.4~4.8	4.8~5.5	5.5~8.0 (End boring)
SPT N Value	–	3~4	5	–

Table 4. Instruments installed in GRS walls.

Instruments	Quantities	Section			
		Section I		Section II	
		A	B	C	D
Strain gages	124	31	31	31	31
Horizontal earth pressure cells	4	–	4	–	–
Pore water pressure cells	4	–	4	–	–

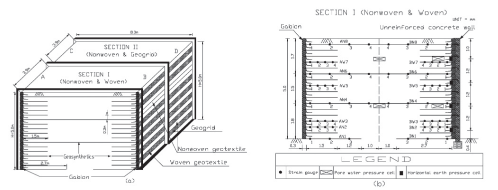

Figure 3. Schematic diagram of the GRS walls.

3.2 *Analysis of the geosynthetics deformation*

As illustrated in 3.1, local deformation of geosynthetics was measured with strain gauges attached on nonwoven, woven, and geogrid within the GRS walls. Figs. 4, 5, and 6 show local deformations converted into total deformation with the use of Figs. 2 (c)~(e). The nonwoven has a larger range of variance than the woven and the geogrid; however, this does not pose a serious problem in understanding the general deformation behaviour of nonwoven. These figures commonly show that, up to 25 days after the construction of the walls, deformation of the reinforcement materials increases. This increase seems to have been caused by the residual stress from compaction, and the rain storm that brought 180 mm/day of rainfall on the 13th day. Figures 7 and 8 show the deformation behavior of geosynthetics in SECTION I and II with elapsed time. The deformation of the nonwoven shows larger deformation than the woven and the geogrid; and the difference tends to increase in the upper part of the wall.

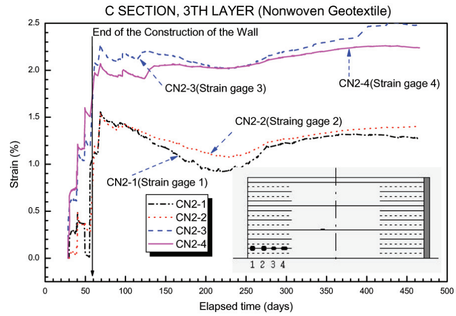

Figure 4. Nonwoven deformation on the GRS wall.

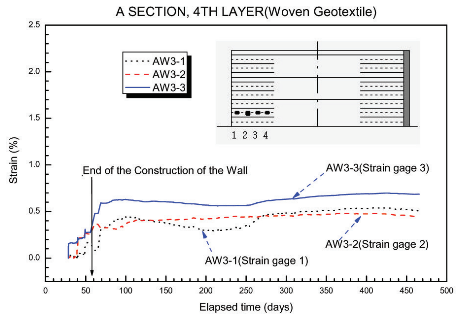

Figure 5. Woven deformation on the GRS wall.

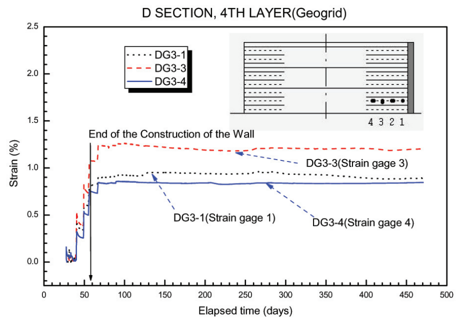

Figure 6. Geogrid deformation on the GRS wall.

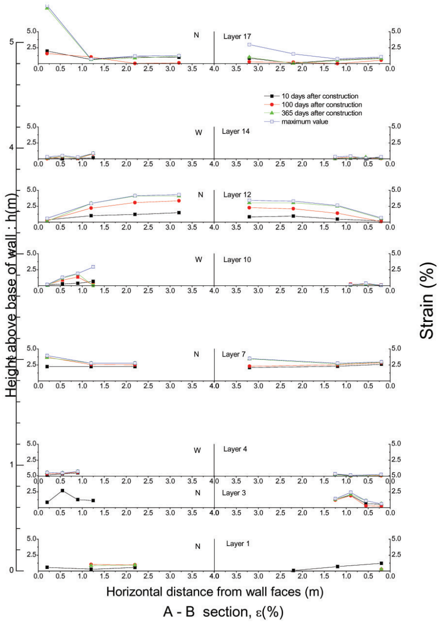

Figure 7. Geosynthetics deformation in SECTION I.

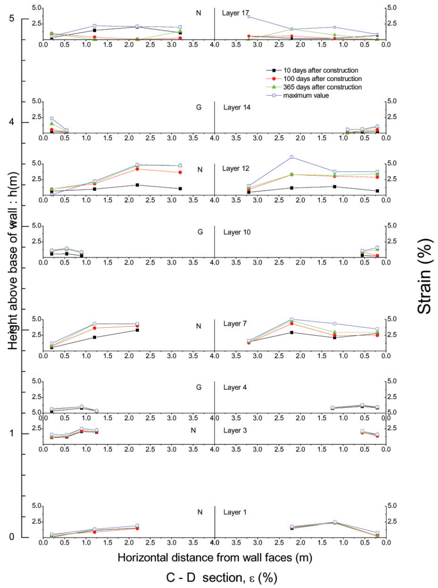

Figure 8. Geosynthetics deformation in SECTION II.

In the 7th, 12th, and 17th reinforcement layers, nonwoven geotextiles were laid to cut across the wall's length, resulting in relatively heavier vertical soil pressures on the reinforcement materials and greater influence of unequal settlement. The maximum deformation measured during construction to 10 days after the completion of the walls was as follows: nonwoven, 2.938%; woven, 0.650%; and geogrid, 1.067%. The maximum deformation measured for 16 months was as follows: nonwoven, 9.054%; woven, 2.915%; and geogrid, 2.326%.

However, the maximum deformation of nonwoven occurred at the 17th layer of SECTION I. Since this seems to be a value affected by outside elements, this value was considered an exception. Then, the maximum deformation of nonwoven was 6.052%. Generally, the allowable deformation strain of geosynthetic reinforcement is 5-10% according to the elongation and stiffness of the reinforcement material. The deformation measured in this study was within the allowable range.

4 CONCLUSIONS

The conclusions reached as the result of this study are as follows.

(1) A laboratory wide-width tensile test conducted under confining pressure of 7 kPa showed that the pattern of the local deformation on nonwoven geotextile measured with strain gauges resembles that of the total deformation measured with LVDT.
(2) In cases of nonwoven geotextile, woven geotextile, and geogrid used in this study, most deformation occurred within 25 days after the installation of GRS walls. Maximum deformation that occurred for 16 months ranged 2.3~6.1%. Thus, the geosynthetics installed within the GRS wall appear to be safe.
(3) In GRS walls, nonwoven geotextile shows larger deformation range than woven geotextile and geogrid; however, deformation patterns of these three reinforcement materials are similar, and the strain gauges attached to geosynthetics have been functioning normally for 16 months. Therefore, the method of measuring a nonwoven geotextile deformation by using a strain gauge, as suggested by this study, proves useful.

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