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Field monitoring of two geogrid-reinforced steep soil walls in a 2-tiered configuration

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ABSTRACT: This paper describes a field experience on high-raised geogrid-reinforced soil walls having a length of approximately 1,450 m and a height of maximum 29.5 m. Since experiences of design and construction on very high-raised geogrid reinforced soil wall were limited, thorough design and constructionmanagement was performed for safe construction of the wall. Moreover, a series of instrumentations wereperformed. Based on the monitoring results, the reinforced soil wall technology could be applied successfully for high-raised tiered wall more than 20 m heights.

1 INTRODUCTION

In 1980, a reinforced soil wall system using galvanized steel strip reinforcements was introduced in Korea. However, this technology was not well used because the steel reinforcement had problems related to zinc plating technology, backfill material selection, and construction management. In 1986, a strip type geosynthetics was introduced as reinforcement in Korea. Since then, reinforced soil wall system became popular because it could solve the corrosion problem of the steel reinforcement. A block type reinforced soil wall using high-strength geogrids as reinforcement was introduced in 1994. At present, a block-type reinforced soil wall using geogrids has been widely used (Cho, 2001).

Recently, reinforced soil walls have been extensively used in Korea because these technologies have advantages such as economical efficiency, graceful appearance, and easy construction.

Especially, a number of reinforced soil walls having more than 15 m heights have been constructed to make more effective land development since Korea is a small and overpopulated country where 70% of the country is occupied mountainous area. However, many cases of troubles, which include a severe deformation of facing, cracks of facing block, overall sliding failure and so on, have been reported in Korea since a reasonable design on such high-raised wall is not easy(Han et al., 2005). Inappropriate design and construction management mainly induce these problems.

This paper describes a field experience on geogrid-reinforced soil walls rising up to 29.5 m in height. A field experience includes the results of design, construction and monitoring on the large reinforced soil wall.

2 MONITORED WALL

2.1 *Description of walls*

During the land development for a industrial complex, geosynthetic reinforced soil walls having a length of about 1,450 m was applied as summarized in Table 1. Many high-raised wall sections up to 29.5 m heights were contained for the more effective land development. The wall in a tiered configuration was designed on the sections having more than 13.5 m heights.

Table 1. Application of geogrid reinforced soil walls

Section		Wall type	Length (m)		Height (m)	
			Upper wall	Lower wall	Upper wall	Lower wall
A		Tiered	182.50	182.50	13.5	2.7~12.3
B	B-1	Tiered	223.79	223.79	0.9~13.5	12.5~16.5
	B-2	Non-tiered	–	1,043.71	–	2.9~13.5

Since experiences of design and construction on very high-raised geogrid reinforced soil wall were limited, thorough design and construction management was required for safe construction of the wall.

Regarding the design of the wall, both internal and external stabilities were examined based on the design guidelines specified by FHWA(Elias & Christopher, 1996) and overall slope stability analyses were performed by using TALEN program. In that

Table 2. Results of stability calculations for the geogrid reinforced soil wall.

Section	Analyzed section No.	Height	Factor of safety					
			External stability				Internal stability	
			Overall stability (≥ 1.5)	Overturning ≥ 2.0	Overturning e/L ≤ 0.167	Bearing capacity (≥ 2.0)	FS_p (≥ 1.5)	FS_t (≥ 1.0)
A and B-1	1-1	16.9 m	1.866	2.99	0.098	7.44	1.544	1.012
	1-2	19.3 m	1.880	2.76	0.1287	5.71	1.680	1.024
	1-3	21.9 m	1.867	2.53	0.1572	4.45	1.525	1.021
	1-4	24.3 m	1.912	2.51	0.1664	4.02	1.639	1.006
	1-5	25.3 m	1.949	2.55	0.1651	4.02	1.561	1.006
	1-6	27.7 m	2.005	2.60	0.1665	3.90	1.563	1.002
	1-7	28.1 m	2.026	2.63	0.1645	3.96	1.566	1.027
	1-8	28.5 m	2.031	2.63	0.1651	3.93	1.515	1.076
	1-9	29.1 m	2.039	2.63	0.1661	3.88	1.647	1.052
	1-10	29.5 m	2.057	2.67	0.1642	3.93	1.502	1.036
B-2	2-1	3.5 m	1.785	3.47	0.0483	6.39	5.717	1.762
	2-2	4.3 m	1.708	2.82	0.1015	4.57	5.447	1.126
	2-3	4.9 m	1.822	2.88	0.1053	4.40	5.676	1.065
	2-4	5.3 m	1.792	2.67	0.1253	3.85	5.992	1.095
	2-5	5.7 m	1.821	2.63	0.1328	3.65	5.259	1.065
	2-6	6.3 m	1.811	2.46	0.1527	3.17	5.485	1.081
	2-7	6.7 m	1.839	2.44	0.1575	3.06	5.426	1.033
	2-8	7.1 m	1.914	2.53	0.1523	3.19	5.718	1.081
	2-9	7.5 m	1.891	2.41	0.1654	2.90	6.528	1.093
	2-10	8.1 m	1.972	2.49	0.1614	2.99	4.932	1.048
	2-11	8.5 m	2.037	2.58	0.1566	3.11	5.192	1.017
	2-12	9.1 m	2.109	2.65	0.1536	3.20	5.230	1.081
	2-13	9.5 m	2.168	2.73	0.1497	3.31	6.411	1.049
	2-14	9.9m	2.226	2.81	0.1460	3.41	5.940	1.063
	2-15	10.5 m	2.290	2.88	0.1437	3.49	6.177	1.020
	2-16	11.1 m	2.353	3.62	0.0183	6.44	6.410	1.007
	2-17	11.5 m	2.407	3.03	0.1381	3.67	6.664	1.070
	2-18	12.1 m	2.469	3.10	0.1357	3.75	6.904	1.065
	2-19	12.5 m	2.523	3.18	0.1327	3.85	10.034	1.033
	2-20	13.1 m	2.585	3.26	0.1302	3.93	7.398	1.044
	2-21	13.5 m	2.640	3.34	0.1273	4.03	7.650	1.001

Note: FSp – factor of safety against pullout, FSt – factor of safety against tensile overstress

place, a series of monitoring programs were planned for careful construction management of the wall.

2.2 *Design and construction of walls*

Table 2 summarizes the results of the external and the internal stability calculations. These calculations were performed at 31 sections as shown in Table 2.

Weathered granite soils were used as the backfill material. Based on the results of laboratory tests, an internal friction angle of 33° and a unit weight of 17 kN/m^3 were used for the backfill soils for the design. Based on the Unified Soil Classification System, the soil was classified as SW. According to the standard proctor test, the maximum dry unit weight was 19 kN/m^3 when the optimum water content was 8.2%. The backfill material was compacted using a 10-ton vibrating drum roller to insure 95% of proctor density.

Extruded HDPE (High Density Polyethylene) geogrids were used as reinforcements as summarized in Table 3. In Table 3, allowable tensile strengthes of geogrids are calculated considering the tensile strength reduction factors which consider all time dependent strength losses over the design life period.

Table 3. Tensile strength of geogrid reinforcements.

Geogrid	Type 1	Type 2	Type 3	Type 4
Ultimate tensile strength (kN/m)	60.0	90.0	120.0	160.0
Allowable tensile strength (kN/m)	27.0	40.4	53.9	71.9

The wall was constructed using key-type facing blocks having a compressive strength of 23.5 MPa. The gravel was extended to a distance of 300 mm behind the facing blocks with non-woven geotextile filter to make a drainage layer.

2.3 *Monitoring program*

During the wall design, special wall sections were considered, in which large surcharges on the wall are expected or a high-raised tiered wall is constructed. Therefore, monitoring programs were prepared for the safe construction and the behavior assessment of the walls. The monitoring items included horizontal earth pressure acting on the wall, horizontal deformation at the wall face, and strain in the reinforcements. The instrumentations were performed on 12 sections of the wall as shown in Table 4.

Table 4. Instrumentation plan.

Instrumented section	Wall height (m)	Wall type	Instrumented Quantity: earth pressure cell	strain gage	optical survey target
A-1	19.1	Tiered	–	–	5
A-2	20.7		3	12	5
A-3	25.1		–	–	6
A-4	25.5		–	–	6
A-5	29.3		6	21	6
B-1	8.3	Non-tiered	–	–	4
B-2	9.1		–	–	4
B-3	9.7		–	–	4
B-4	12.5		–	–	4
B-5	13.1		–	–	4
B-6	13.3		–	–	4
B-7	13.5		3	9	3

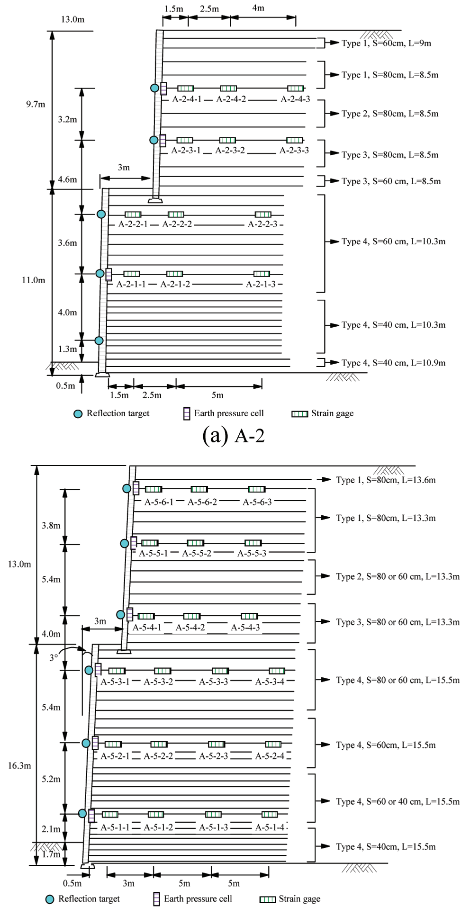
At present, the construction of the wall has been completed and the upper structures on some wall sections are under construction. In this paper, some monitoring results, which were measured at the high-raised wall sections (A-2 and A-5), are illustrated.

3 RESULTS OF FIELD MEASUREMENTS

A series of instrumentations was performed to assess the behavior of the wall. The monitoring items included horizontal deformation at the wall face, horizontal earth pressure acting on the wall, and strains in the reinforcement. Based on the measurement results, horizontal deformation in all instrumented wall sections was less than 10mm. This result means that the horizontal movement of the wall was very small and the wall was safely designed and constructed.
The results measured by earth pressure cells and strain gages are illustrated as following sections.

3.1 *Horizontal earth pressure acting on walls*

Data from earth pressure cells placed at the back of the wall facing is presented in Figure 2. These Figures, Figure 2(a) on section A-2 and Figure 2(b) on section A-5, show similar trends. As shown in Figure 2, horizontal earth pressures acting on the facing were increased with increasing the construction height of the wall and remain unchanged after the completion of the wall. The measured pressures indicated larger tendency at those locations toward the wall base. Magnitude of the all measured pressures was less than 50 kN/m^2 which was about 40% of the predicted maximum values. Such small stresses may be due to



(a) A-2

(b) A-5

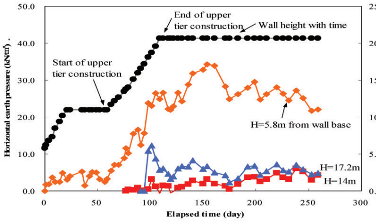
Figure 1. Cross sectional view of the instrumented A-5.

interaction effects between the backfill soils and geogrid reinforcements.

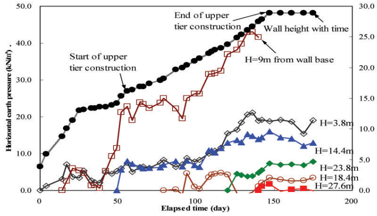
3.2 *Tensile forces in reinforcement*

Based on the measurement results of strain gages, tensile forces developed in reinforcements are shown in Figure 3 and Figure 4. The results of the tensile forces were similar to the results of horizontal earth pressures: the tensile forces were increased with increasing the construction height of the wall and remain unchanged after the completion of the wall.

The tensile forces tended to show larger tendency at those locations toward the wall face. The maximum tensile force was less than 0.6 kN/m in both wall sections. This result indicated that the tensile forces were very small and the walls were safely designed and constructed.

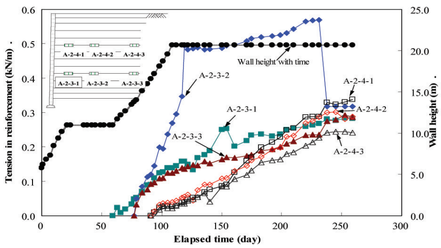


(a) A-2

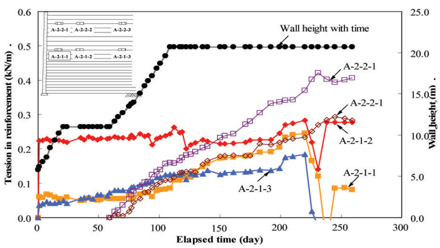


(b) A-5

Figure 2. Horizontal earth pressures measured at the back of the wall facing.



(a) upper wall



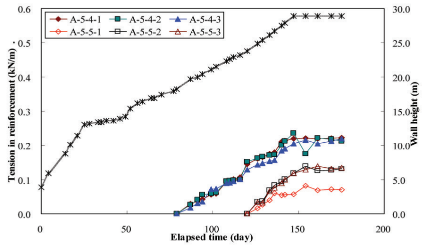
(b) lower wall

Figure 3. Tension in reinforcements on the section A-2.

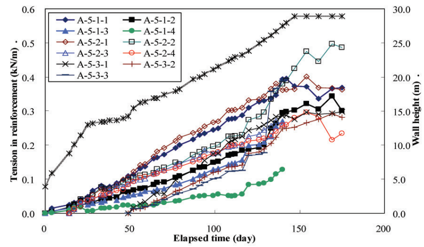
4 CONCLUSIONS AND DISCUSIONS

The geogrid reinforced soil wall having a length of approximately 1,450 m and a height of maximum 29.5 m was constructed. Regarding design of the wall, both internal and external stabilities were examined based on the design guideline specified by FHWA and overall slope stability analyses were performed by using TALEN program. In that place, a series of instrumentations were performed. The results of instrumentation for two tiered reinforced soil wall showed that not only the deformations of both the wall face and the reinforcement but also the horizontal earth pressures acting on the wall facing were very small. These results indicate that FHWA design guideline is very conservative for a high-raised tiered wall higher than 20 m heights.

Hereafter, the assessment of long-term behavior of the walls will be performed through the continuous monitoring during and after the construction of upper structures on the walls.



(a) upper wall



(b) lower wall

Figure 4. Tension in reinforcements on the section A-5.

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