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A 12-year long-term study on the external deformation behavior of Geosynthetic Reinforced Soil (GRS) walls

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Abstract. Geosynthetics reinforced soil (GRS) walls constructed on weak grounds may change in both the horizontal earth pressure and deformation on wall facing. However, only few studies were done in the literature to measure and analyze the horizontal external deformation behavior of GRS walls constructed on soft grounds for a long period of time. The present study describes the external deformation behavior of GRS walls observed for 12-year long-term performance. The horizontal deformation of the geosynthetics-wrapped-facing GRS walls shows a passive behavior along one third of the wall height, from top going downwards, and active behavior for the rest of the wall height. Even if the geogrid and nonwoven geotextiles are exposed directly to sunlight and rainfalls in a span of 12 years, they have functioned well as wall facing. Therefore, the geosynthetic reinforcement material is strong enough to resist ultraviolet rays.

Keywords: GRS walls; long-term deformation behavior; geogrid; nonwoven geotextile; wall facing

1. Introduction

Geosynthetics reinforced soil (GRS) walls introduce various types of geosynthetics reinforcement and facing system. GRS walls have gained widespread popularity in the geotechnical engineering. GRS walls gradually replace the existing reinforced concrete retaining walls. Among the main reasons for their popularity are reduced cost, ease of construction and better performance compared to conventional unreinforced soil wall alternatives (Santos *et al.* 2013). In recent decades, extensive experimental and numerical studies have been undertaken to examine the behavior of GRS walls (Allen *et al.* 2002, Allen and Bathurst 2003, Berg *et al.* 2009, Chrisopher 1993, Ehrlich and Mirmoradi 2013, Elias *et al.* 2001, Koseki 2012, Ling and Leshchinsky 2003, Liu and Ling 2007, Liu and Won 2009, Rowe and Skinner 2001, Tatsuoka *et al.*

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2014, Won and Kim 2007, Zarnani *et al*. 2011).

Tatsuoka (1993) reported the lateral displacement of GRS wall facing decreases as the facing stiffness increases. Allen *et al*. (2002) studied 20 well-documented GRS wall case histories constructed 25 years ago. These case histories cover a wide variety of wall heights, surcharge conditions, foundation conditions, facing types and batter, reinforcement types and stiffness, and reinforcement spacing. These case histories showed that the AASHTO (2002) design code is significantly conservative. Note that considering some factors such as compaction-induced stresses, toe conditions, and reinforcement stiffness this method may under predict the measured forces and deformations in GRS walls (Ehrlich *et al*. 2012, Mirmoradi and Ehrlich 2015a, b).

Long-term behaviors of GRS walls have become one of the most critical issues in design. However, the study on long-term horizontal earth pressures and deformation behaviors for GRS walls are limited, especially the observation for the external state of GRS walls (Won and Kim 2014).

2. GRS walls construction

As shown Table 1 and Fig. 1, GRS walls of 5m in height were constructed on a shallow weak ground with an average N value of 4 from ground surface to approximately 5 m deep at Chonbuk National University in Korea on September 1998. Tables 2 and 3 illustrate the respective backfill material and reinforcements used.

In Fig. 1, SECTION I used nonwoven and woven geotextiles as reinforcements, and Section II used geogrid and nonwoven geotextiles as reinforcements. The vertical space for the reinforcement was 0.3 m, and the reinforcement length (excluding the 1st, 7th, 12th, and 17th layers from the bottom of the walls) was 1.5 m, which is 30% of the wall height. One of the objectives to construct these walls is to examine whether the wall could be constructed on shallow weak ground with short reinforcement length or not. Therefore, the reinforcement length in this study is shorter than the value usually found in the conventional reinforced soil structure wall (RSW) designs (Christopher *et al*. 1990).

Table 1 Field boring log results

Item	Fill	Silty clay	Gravel	Soft rock
Depth (m)	0~1.4	1.4~4.8	4.8~5.5	5.5~8.0 (end boring)
N value	-	3~4	50	-

Table 2 Backfill material properties

Unit weight	Cohesion	Frictional angle	Moisture content	USCS
18.5 kN/m^3	54.8 kPa	29.1 °	17.0 %	CL

Table 3 Geosynthetic reinforcement properties

Material	Description	Thickness	Tensile stiffness	Tensile strength
Polyester	Nonwoven (needle-punched)	5.00 mm	156.4 kN/m	89.7 kN/m
Polyester	Woven (multi-filament)	0.25 mm	235.2 kN/m	51.1 kN/m
Polyester	Geogrid coated with PVC resin	0.50 mm	215.2 kN/m	44.3 kN/m

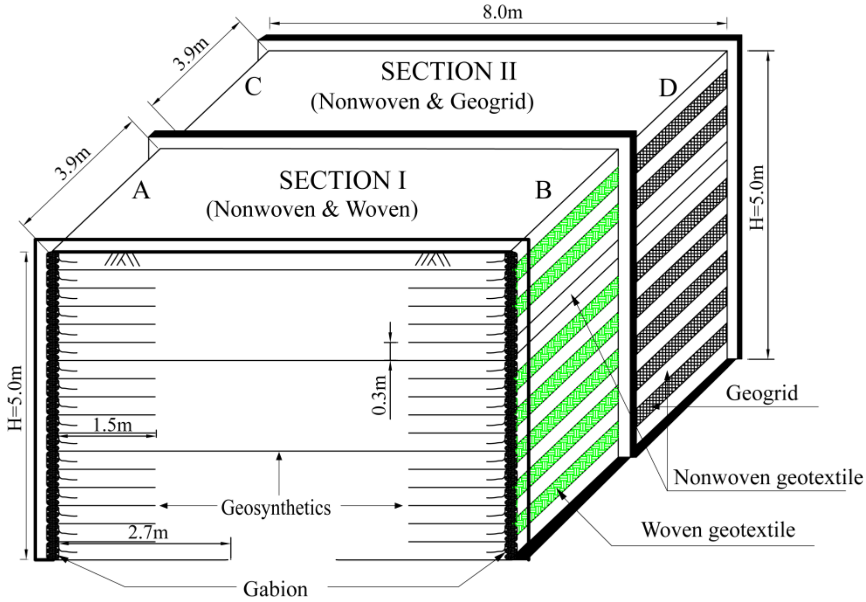


Fig. 1 Schematic diagram of GRS walls

In accordance with the assembly types of reinforcement material, the GRS walls were divided into sections as follows: Section I (composed of nonwoven and woven geotextiles) and Section II (composed of nonwoven geotextiles and geogrids). Sections I and II are then subdivided into subsections A, B, C, and D, as shown in Fig. 1. The wall facing of sections B and D were reinforced with cast-in concrete to examine full-height ridged facing effect (the study spanned 18 months after the wall construction). However, the wall facing with geosynthetics wrapped systems at sections A and C were exposed to direct sunlight and atmosphere.

Fig. 2 shows the construction procedures of GRS walls. As shown Fig. 2, the facing foundation was constructed with unreinforced concrete. Section I and Section II were divided by bricks. The backfill material used was clay soil and compacted by hand vibration compactor at 15 cm per layer

(a) Foundation of GRS Wall facing

(b) Filling with clay soil

Fig. 2 Construction procedures of GRS walls

(c) Gabion installation

(d) Right after construction, A & C section

Fig. 2 Continued

(compaction thickness). The facing was constructed by geosynthetics-wrapped gabion. The dimension of the gravel-filled gabion was approximately 300 mm × 300 mm × 100 mm (width × length × thickness).

Won and Kim (2007) introduced the internal deformation behavior of the GRS walls based on the data measured by instruments such as strain gages, horizontal earth pressures, pore water pressures, during one and half year after the construction of the walls.

This paper presents the long-term external deformation behavior, and the observed external state of GRS walls.

3. External deformation behavior of GRS walls for 12 years

The maximum horizontal displacements of the facing at SECTION I and II after the construction of walls were 60 mm (1.25% of H) and 80 mm (1.6% of H) respectively. Settlements at the center of the top surface on SECTION I and II within 15 days after the construction were 8 mm and 22 mm respectively. External deformation measurements were only conducted within 15 days after the construction.

In this paper, the external deformation behavior of the GRS walls occurred within 12 years after the construction of the walls were described based on observations (however, no regular measurements were conducted within this duration: i.e., 15 days to 12 years after construction).

Figs. 3, 4 and 5 shows the external deformation state of the walls and results. After the construction GRS walls, marked lines were placed at the end of the wall facing on the side brick walls. Therefore, only the deformation at the top of the walls were measured from the line to the wall facing with tape measure, and deformation at these facings showed a trend based on observations. The deformations illustrate arch types at the facing and at the top surface of walls. After 12 years, a horizontal displacement of approximately 250 mm at the top of the wall facing has moved towards the backfill portion. The maximum settlement at the center of the top surface is approximately 250 mm and 100 mm for the geosynthetics wrapped facing. However, no external deformation was observed on the GRS wall with concrete facing. One of the interesting part of this study is the result for the horizontal displacements of the GRS wall with geosynthetics wrapped facing. One third of the wall height from top shows passive a deformation behavior and the

(a) A & C section (geosynthetics wrapped)

(b) B & D section (concrete facing)

Fig. 3 External facing state of the GRS walls 12 years after construction (March 4, 2010)

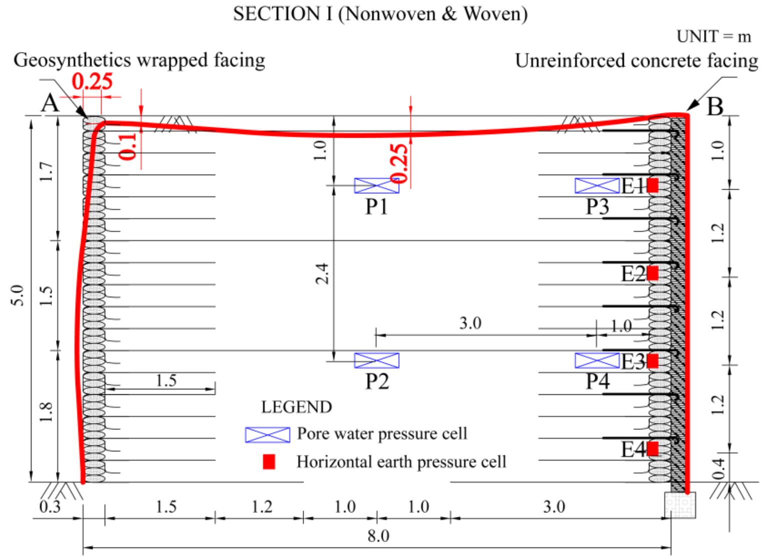
(a) Measurement of horizontal displacements at top

(b) Measurement of vertical displacements at top

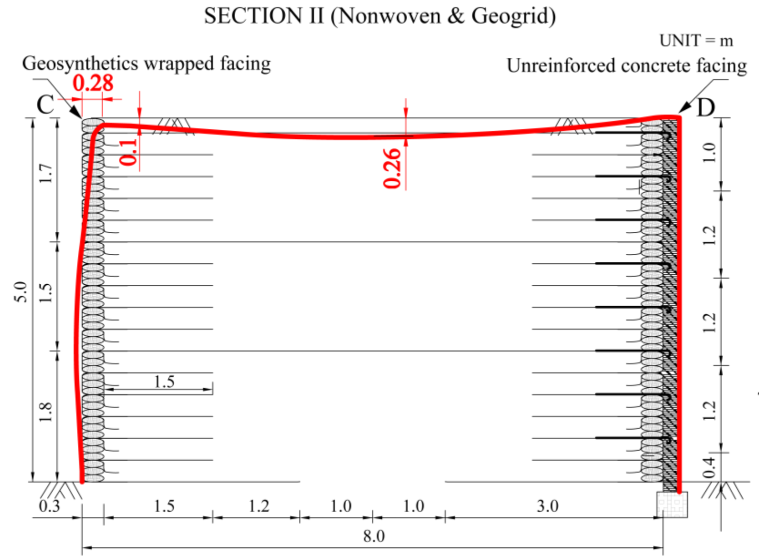
Fig. 4 Measurement of external deformation of the GRS walls 12 years after construction (March 4, 2010)

remaining two-thirds shows active deformation behavior. This phenomenon is probably caused by the settlement of backfill and foundation because the walls were constructed on weak ground and used clay soil as backfill. Also, the lengths of reinforcement probably gave some influence to the deformation because it should be noted that the lengths of the reinforcements are much less than the value usually found in the GRS design. This factor significantly influences the magnitude of the external deformation on the GRS walls. Therefore, the results presented in this paper may not significantly improve the database of GRS walls regarding long-term issue and it can only be considered a case study with the special design condition.

Fig. 6 is prepared by back analysis of the lateral stress ratio K_r from available field data where stresses in the reinforcements were measured and normalized as a function of the Rankine active pressure coefficient, K_a (Berg *et al*. 2009). The lateral earth pressure coefficient K_r is determined by applying a multiplier to the active earth pressure coefficient. Considering the external deformation behavior of the geosynthetics wrapped facing and Fig. 6, the lateral stress ratio K_r for clay soils used as backfill on weak ground and the reinforcement length is much less than the



(a) External deformation at SECTION I



(b) External deformation at SECTION II

Fig. 5 External deformation of the GRS walls after 12 years of the construction

value usually found in the GRS wall design might be suggested as shown in Fig. 7.

Won and Kim (2007) and Skinner and Rowe (2005) reported that the horizontal earth pressures at the flexible facing of GRS walls constructed on weak ground and using clay soil as backfill appeared larger than earth pressure at rest at the bottom and the upper part of the wall. Therefore, the lateral earth pressure coefficient K_r suggested in this study, as illustrated in Fig. 7, should be applied for the long-term safety of GRS walls construed on weak ground with clay soil as backfill.

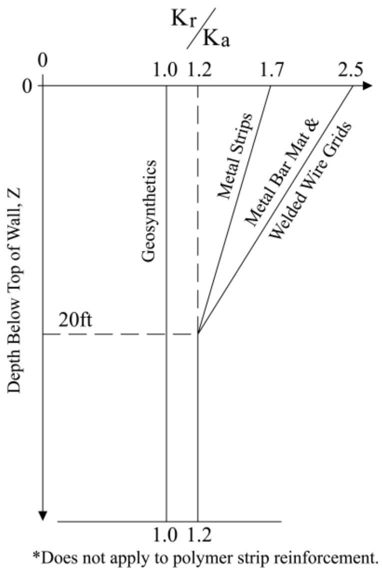


Fig. 6 Variation of the coefficient of lateral stress ratio (K_r/K_a) with depth in a mechanically stabilized wall (AASHTO 2002, Elias and Christopher 1997 as cited by Berg *et al*. 2009)

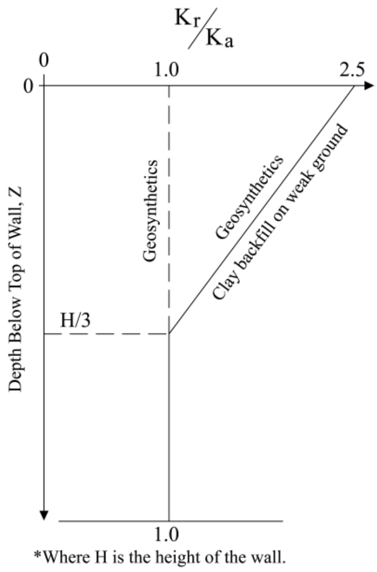


Fig. 7 Variation of the coefficient of lateral stress ratio (K_r / K_a) with depth in a GRS wall

(a) A, C sections, Sep., 1998

(b) A, C sections, Jun., 2007

(c) A, C sections, Mar., 2010

(d) B, D sections, Sep., 1998

Fig. 8 The external states of GRS walls according to the elapsed time

(e) B, D sections, Apr., 2000

(f) B, D sections, Mar., 2010

Fig. 8 Continued

(a) A section, June, 2008

(b) A section, January, 2009

(c) A section, March, 2010

(d) C section, June, 2008

(e) C section, January, 2009

(f) C section, March, 2010

Fig. 9 External states of GRS walls in detail with respect to time

4. External state of GRS walls for 12 years

Figs. 8 and 9 show the external state of GRS walls within the period of 12 years after its construction. According to the observation, the gabion made of a thin fabric on the wall facing could not function if it was directly exposed to the atmosphere for a year. However, crushed stones in the gabion did not fell down even if it was exposed to the atmosphere within 5 or 6 years unless external forces were applied, such as collision or crash. Small amount of crushed stones in the gabion fell after 7 years. The disintegration of the crushed stones was significantly increased after 9 years of exposure and during that time it was already supported by the reinforcing geogrids. There was no exposure of crushed stones on the wall facing wrapped by nonwoven and woven geotextiles observed within the 12-year period. Woven geotextiles became worn and partially torn down about 10 years after. However, nonwoven geotextiles and geogrids still appear to be strong enough to support the facing even after 12 years of exposure in the atmosphere as shown in Fig. 4. The B and D sections have a full-high rigid cast-in concrete facing construed after the deformation convergence of flexible facings by wrapping the gabion with geosynthetics did not display any deformation at the facing even after 12 years. However, A and C sections which have a flexible facing by wrapping gabion with geosynthetics developed an arch-type deformations and about 25 cm moved toward the backfill side at the top part of the walls. The facing of GRS walls might only be required for backfill compaction and prevention of backfill material loss, so initially its rigidity was not considered important, but in this long term study it was found that the rigidity of the wall facing has an important role in restricting GRS wall deformations. The wall facing at the top parts of the A and C sections moved about 25 cm towards the backfill side, however, the overall stability appeared to be safe enough.

5. Conclusions

The main conclusions drawn from the 12-year long-term GRS wall observation are as follows:

(1) The flexible facing with geosynthetic wrappings on the GRS walls were observed to have arch-type horizontal deformations, especially at the top where approximately 250mm has moved towards the backfill side, however no significant deformations were observed on the full-high ridged cast-in concrete facing. The full-high ridged wall facing performed an important role in restricting the deformation of GRS walls.

(2) The horizontal deformation of geosynthetics wrapped facings of GRS walls constructed on weak ground and used clay soil as backfill showed a passive behavior along one third of the wall height from top to middle and active behavior for the remaining wall height.

(3) The lateral earth pressure coefficient should be increased from active to passive, beginning from the topmost portion of the wall down to the middle approximately one third of its height, for the long-term safety of GRS walls construed on weak ground and used clay soil as backfill.

(4) Geogrids and nonwoven geotextiles exposed directly to sunlight and rainfall for 12 years have with stand against natural deterioration and are still in good condition. However, the woven geotextiles were worn and partially torn down approximately 10 years after the construction.

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