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A field instrumentation and FEM analysis for an isolated-reinforced earth wall

Y.Y. Kim, K.J. Han & K.M. Kim
E&S Engineering Co., Ltd., Seoul, Korea

ABSTRACT: During the construction of reinforced earth wall, an amount of accumulative horizontal deformation induced by backfilling compaction is inevitable. To reduce the horizontal displacement, an isolated-reinforced earth wall method was developed by isolating the facing blocks from the reinforced embankment. Field tests were performed by sequential construction of a 7.2 m high trial embankment in order to verify the effect of the method. Firstly, a reinforced embankment composed of geogrids, geotextiles and backfills was constructed. As a second construction stage, the facing blocks were installed in front of the embankment. During the construction, displacement pins and strain gauges were used to measure the horizontal deformations of the wall and the tensile strains of geogrids, respectively. Based on the field instrumentations of trial embankment, it is found that the reduction in horizontal displacement of facing blocks is significant; the horizontal deflection in the first construction stage was 70 mm and the corresponding value of second construction was approximately 0(zero). It is also found that the prediction by FEM analysis simulates well the general trend observed from field instrumentation.

1 INTRODUCTION

Construction of reinforced earth retaining walls has been continuously increased due to economical considerations, the effectiveness and practicality of the construction technique, and excellent appearance (Cho and Shin, 1999). However some amount of horizontal deformation is induced during the construction stages of reinforced earth walls. As the reinforced earth wall is constructed with compacting the backfill step by step, the accumulative horizontal deformation is inevitable.

To reduce the horizontal displacement, an isolated-reinforced earth wall method (named KOES-Wall System) was developed by isolating the facing blocks from the reinforced embankment(E & S Engineering, 1998).

The main purpose of this study is to verify the usefulness of this method and the reduction effect of horizontal displacement.

A 7.2 m high trial embankment was tentatively constructed in order to verify the effect of KOES-Wall. During the construction, displacement pins and strain gauges were used to measure the horizontal deformations of wall and tensile forces of geogrids, respectively. The result from the field instrumentation was compared with a FEM analysis.

2 DESIGN METHOD OF KOESWALL

The design of KOESWall system is based on tie-back analysis and slope stability analysis. The tie-back analysis is a sort of limit equilibrium analysis(Jewell, R.A., 1985). It has been assumed that the thrust of reinforced backfill is equilibrium with the resistant force induced from the soil-reinforcement interaction. In the slope stability analysis, we can calculate the equilibrium of forces and of moments on the potential failure line enhanced with reinforcement.

The potential failure line of geosynthetic reinforced earth wall is supposed to be a log-spiral, in which safety factor for moment about pole is minimum.

In the geosynthetic reinforced earth wall without facing blocks, the factor of safety for moment equilibrium(FS_m) about point O in Figure 1 (a) is defined by

$$FS_m = \frac{M_{TR}}{M_{TD}} \qquad (1)$$

$$M_{TD} = M_{dw} + M_{dq} + M_{du} \qquad (2)$$

$$M_{TR} = M_{rc} + M_{rt} \qquad (3)$$

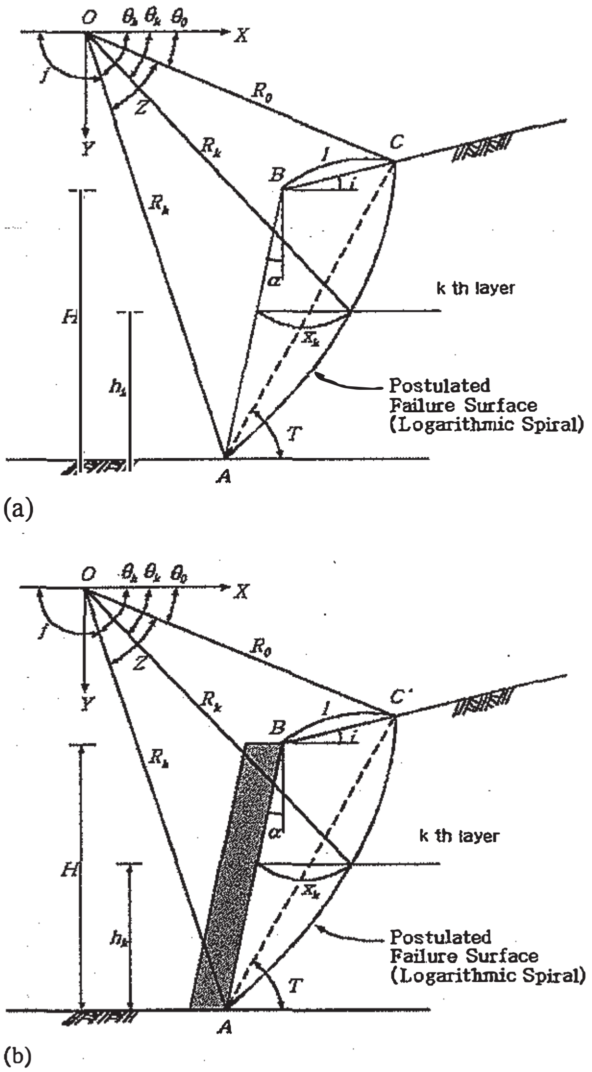

Figure 1. Potential failure surface of KOESWall

In which, M_{dw}, M_{dq} and M_{du} is driving moment by self weight of wedge, surcharge load (q) and seepage force, respectively. And M_{rc} and M_{rt} is resisting moment by cohesion and the maximum tension force of reinforcement(T_{max}), respectively.

As the facing blocks are placed in the front of reinforced earth (see Figure 1 (b)), an additional moment induced from facing blocks is developed. In this case, the additional moments may be considered as follows.

$$M_{TD} = M_{dw} + M_{dq} + M_{du} + M_{db} \tag{4}$$

$$M_{TR} = M_{rc} + M_{rt} + M_{rb} \tag{5}$$

In which, M_{db} and M_{rb} are driving and resisting moment by facing blocks, respectively.

The method which was proposed for the prediction and internal stability analysis of horizontal deformation of geosynthetic reinforced earth retaining wall by Kim et al.(1996) was adopted in the design program for the KOESWall system.

3 FIELD INSTRUMENTATION

The KOESWall was constructed on October, 1998 in Whasung, Kyunggi-Do, about 30 km south of Seoul. This wall was constructed to extend the site for the precast concrete manufacturing facilities.

The cross-section of the wall is schematically drawn in Figure 2. The major elements of the wall are categorized into three parts; backfill soil, geogrid as a reinforcement, and modular facing block. The decomposed granite soil as a backfill was obtained around the construction site. Its specific gravity is about 2.72 and contents of sand is about 82.6%. The silt and clay contents are 17.4%. Kim and Lee(1996) presented the effectiveness of decomposed granite soils as a backfilling material in reinforced earth structures.

Total height and length of the constructed reinforced wall are 7.2 m and 53.2 m, respectively. The surcharge height of 1.0 m was constructed by soil

Table 1. Details of compacted soil and geogrids (after Kim & Lee, 1996).

Compacted Soil		ES-grid	
γ_{dmax}	21.34 kN/m^3	Material	PET/PVC
w_{opt}	8.3 %	Tensile strength (Wide width)	113.01 kN/m
PI	N.P	Aperture size	25mm x 50mm
USUC	SM	Rib thickness	1.37 mm

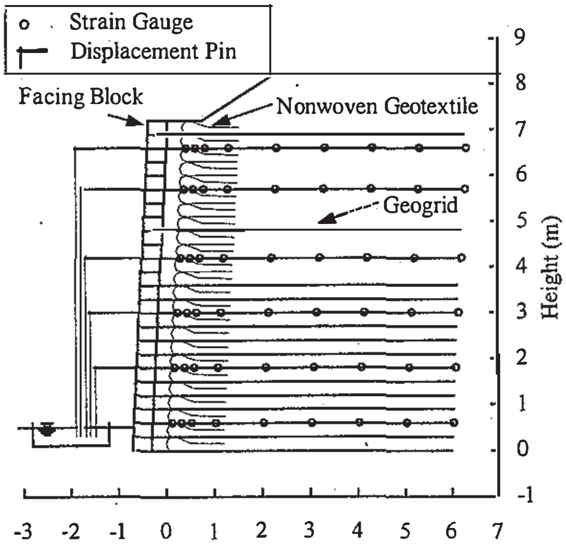

Figure 2. Cross section used for field instrumentation.

over the top of the wall as shown in Figure 2. The nonwoven geotextile was used for rapping part of soil to restrain the backfill soil. The compaction of backfill soil was proceeded by 0.7 ton (KD85, 7HP) hand-guide roller. Geogrid from the main body of reinforced wall was connected to the modular facing block by placing it on the top of the block without using any special gear. The front top part of block is a little bit higher than the rest part of block in order to hold the geogrid with self-weight of stacked blocks. The shear test was performed to evaluate the required shear resistance in this type of connection.

Major measurement devices such as horizontal displacement pins and strain gauges were installed at various levels of the wall. Five displacement pins were fixed on the various levels of facing blocks to measure the wall displacement due to the compaction-induced earth pressure. The strain gauges were attached on the geogrid at 9~12 places along the geogrid layer to measure the mobilized tensile strength and strain due to the horizontal earth pressure. The strain gauges are set at the same levels of displacement pins.

Figures 3 and 4 shows the measured horizontal deformation at the two instrumentation points, respectly. The maximum horizontal deformation developed at a height of about 2/3H in both cases.

The reduction effect of horizontal displacement and the mobilized tensile strain of the reinforcement of the wall will be compared with the results of FEM analysis.

4 FEM ANALYSIS

PENTAGON-2D developed in Korea was used for the FEM analysis of test wall.

PENTAGON-2D is the comprehensive finite element analysis program to calculate the variables in the continuum model subject to the external load and/or seepage boundary conditions.

The displacement method is implemented to solve the equilibrium equation. Here, the primary variable is the displacement vector and the secondary variable is the stress. To limit the stresses the structure may retain, the plasticity theory is used as a constitutive model. If the elastic stress violates the limit, the stress-strain relationship is assumed to follow the flow rule.

Figure 5 shows the finite element mesh used for the analysis. It is composed of 2873 nodes, 912 Quad8 elements (eight nodes Quad elements), 534 Truss2 elements (two nodes truss elements) for geosynthetic reinforcements.

The soil is modeled by Quad8 elements. The fill was assumed to be an elastic-perfectly plastic material with a Mohr-Coulomb failure criterion. The foundation of the wall was to exhibit an elastic behaviour.

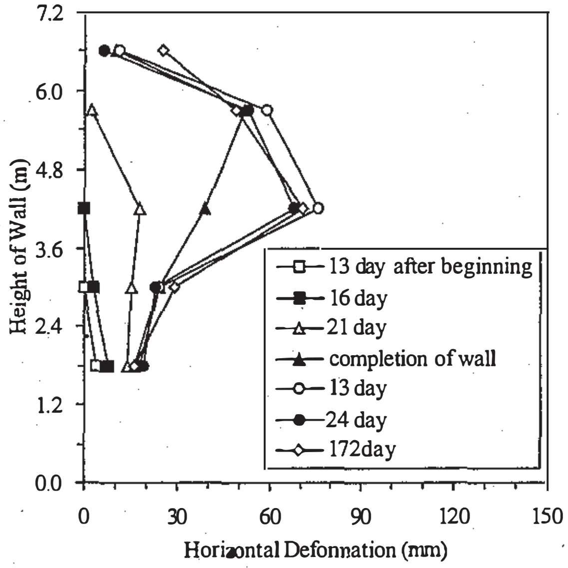

Figure 3. Measured horizontal deformation I.

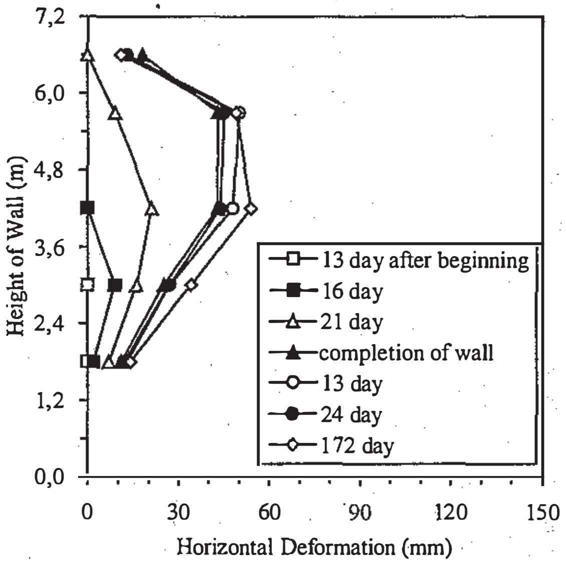

Figure 4. Measured horizontal deformation II.

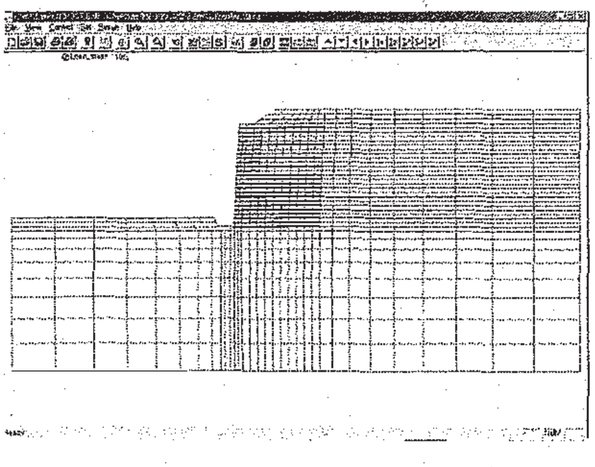

Figure 5. Finite element mesh.

Table 2. Material properties.

	Fill	Foundation	Crushed rock	Facing
Bulk modulus, K (MN/m^2)	24.53	735.75	57.22	98.10
Shear modulus, G (MN/m^2)	11.32	339.57	26.41	81.75
Cohesion, c (kN/m^2)	9.81	9.81	9.81	98.10
Internal friction angle, ϕ (°)	30	35	35	40
Unit weight, γ (kN/m^3)	20.6	19.6	20.6	23.5

	Grid Reinforcement	Nonwoven geotextile
Young's modulus, E (MN/m^2)	4563	98.10
Sectional area, A (m^2)	0.00032	0.03
Tensile strength, (MN/m^2)	14.60	9.81
Compressional strength, (kN/m^2)	0	0

The facing block is modeled using Quad8 elements and was assumed to be elastic.

The geotextile sheets were modeled using elastic-perfectly plastic truss elements with negligible compressive strength and no bending stiffness. And the reinforcements is modeled with perfect interface adherence to the adjacent soil at the point of maximum tension. This means that there is no slip between the soil and the reinforcements; the soil and reinforcement strains are the same at this interface.

In the FEM analysis, by only the applying body force, the deformation behavior of geosynthetic reinforced earth wall under the compaction can not be fully simulated. Thus, we attempt to simulate the compacting effect by loading and unloading of a uniform surcharge(0, 49.05, 68.67, 98.10 kPa) at the top of every soil layer.

To reflect upon backfilling compaction efforts, Figure 6 shows the calculated horizontal displacement of reinforced embankment with incremental uniform surcharge loads. In case of only considering the selfweight of embankment, the horizontal displacement is relatively small and the location of maximum horizontal displacement is H/3 from bottom of embankment. But the horizontal displacement is increased with increasing the applied load and the location of maximum horizontal displacement changed to 2H/3 from bottom of embankment, which seems to be similar to the actual behavior of geosynthetic reinforced earth wall. So the case of the surcharge load q = 9.81 kPa is recommended as a modeling of compaction effects in the FEM analysis.

Figures 7 and 8 show the horizontal displacement contour with respect to before and after block installation. In these figures, the trends and values of horizontal displacement are nearly same. The horizontal displacement of backfilling embankment does not affect on the front blocks.

Figure 9 shows the horizontal deformation of geosynthetic reinforced embankment with the construction stages in the FEM analysis. In this figure, with the construction stages, the horizontal deformation of upper part of the wall became greater than that of the lower part, which is similar to the field measurements.

Figure 10 shows the distribution of tensile force developed in the reinforcement. The location of maximum tensile forces of each reinforcement is near the wall face.

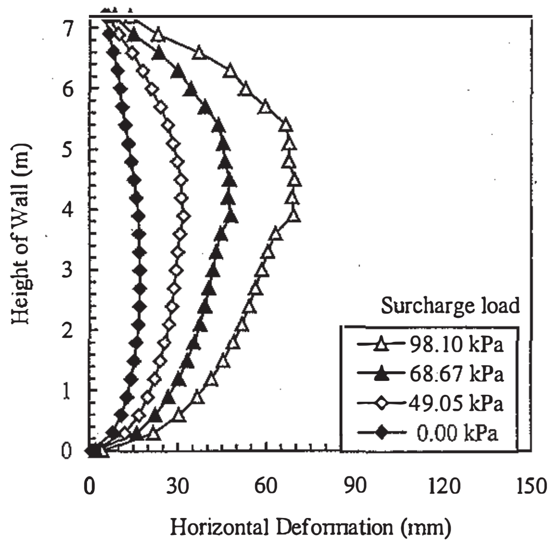

Figure 6. Variation of horizontal deformation with applied compaction load.

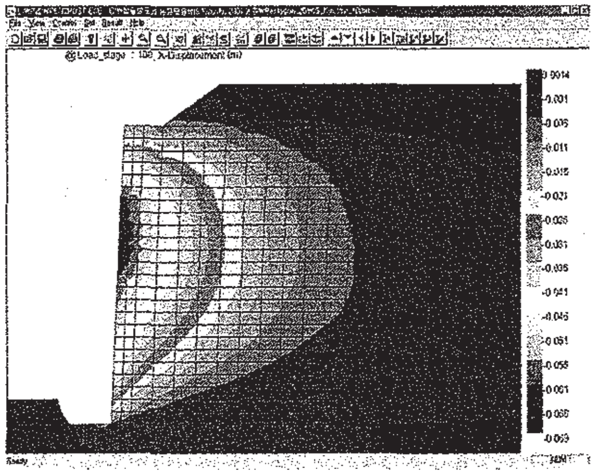

Figure 7. x-displacement contour after the construction of geosynthetic reinforced earth wall (q = 9.81 kPa).

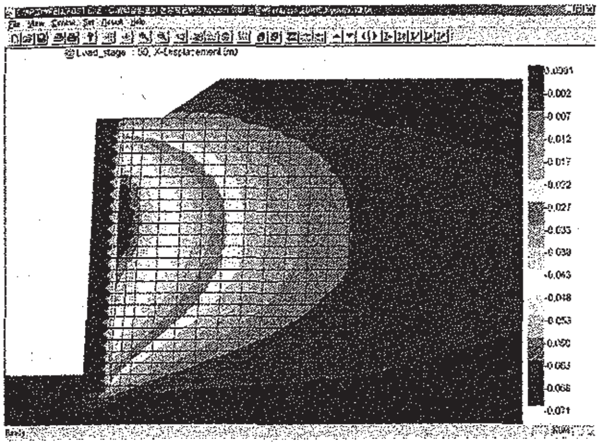

Figure 8. x-displacement contour after the installation of facing block (q = 9.81 kPa).

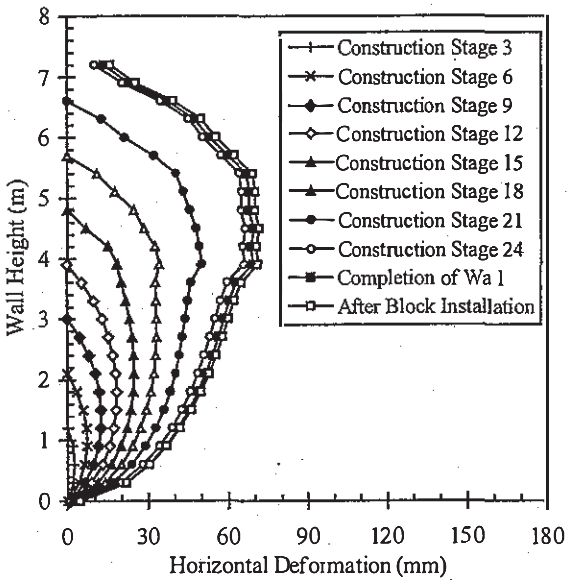

Figure 9. Horizontal deformations at several construction stages (q = 9.81 kPa).

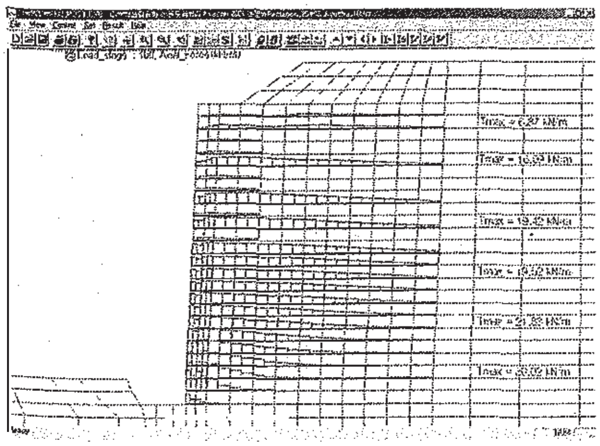

Figure 10. Distribution of tensile force in the reinforcements.

5 COMPARISON BETWEEN MEASURED AND COMPUTED RESULTS

5.1 *Comparison of horizontal deformation*

In Figure 11, the horizontal deformation measured in the trial embankment is compared with the result of FEM analysis and design program. In the most cases, the maximum horizontal deformations are developed at about 2H/3. However, in the FEM analysis, there were relatively large deformations in the lower part of the wall height.

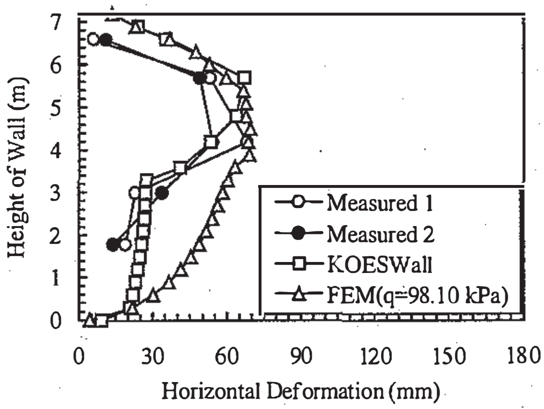

Figure 11. Horizontal deformation of geogrid reinforced embankments.

5.2 *Comparison of the horizontal displacement of facing block*

Figure 12 shows the horizontal displacement of front blocks after their installation. The measured values were greater than the calculated values. It may be caused by the instrumental error. But the values are much smaller than the mobilized horizontal deformation of the reinforced embankment. This shows the effectiveness of discrete construction method in KOESWall system.

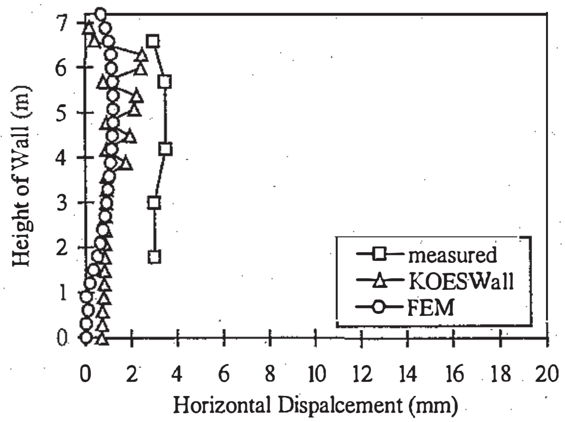

Figure 12. Horizontal deformation of facing blocks.

5.3 *Comparison of the strain in the reinforcements*

Tensile strain distribution on the reinforcement is shown in Figure 13. In case of FEM, there were large strains in the reinforcement located near the wall. But in case of the design program, the upper part reinforcements(#14, #16, #17) mobilize large strain. So the design program should be modified properly.

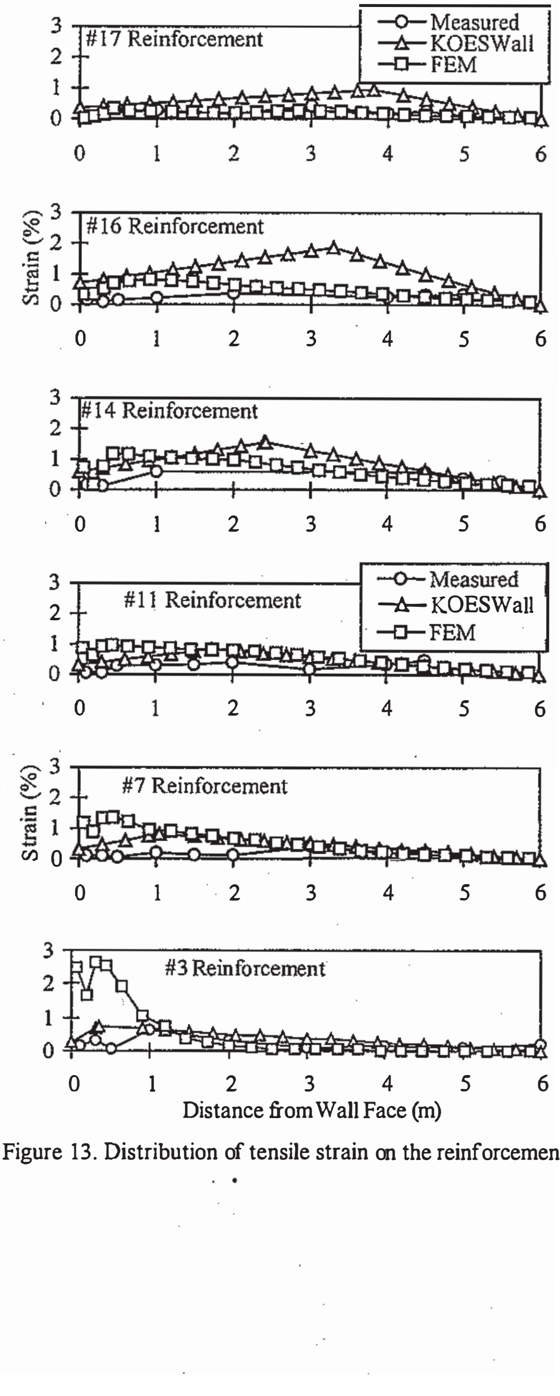

Figure 13. Distribution of tensile strain on the reinforcements.

6 CONCLUSIONS

Field Instrumentation and FEM analysis for the isolated-reinforced earth retaining wall constructed with geogrids and concrete modular facing block is performed. Based on the results of the field measurement and FEM analysis, the following conclusions are drawn.

1) In the FEM analysis, only with the applying body force, the compaction effect can not be fully considered. Thus, an attempt is made to simulate the compacting effect by loading and unloading of an uniform surcharge(0, 49.05, 68.67, 98.10 kPa) at the top of every soil layer. Using a surcharge load of q = 98.1 kPa is recommended in modeling the compaction effects in FEM analysis.
2) In the case of FEM analysis employing the uniform surcharge load q = 98.1 kPa, the maximum horizontal deformation of geosynthetic reinforced embankments developed at a height of about 2/3H, which is the same trend of field measurements.
3) In both cases, when the isolated-reinforced earth wall method were adopted, over 80 % of horizontal displacement can be reduced. The displacement of facing block is very small compared to the geosynthetic-reinforced earth body.

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