Behavior of Geogrid Reinforced Soil Wall Using Box-type Wall

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ABSTRACT: Not only the reinforced embankment with geogrid but also the retaining wall by concrete box-type wall have become popular geotechnical structures. This is because the effectiveness and reliability for those structures have been well evaluated. On the other hand, the ground conditions and the circumstance where these structures are constructed have become more complicated, so that the combined techniques for those two structures have also been conducted nowadays. It is expected for this combined technique that the advantages for both structures have to be well performed individually. So far, not many measurement data for this combined technique at the real construction site have been obtained and the accumulation of these data is expected in order to evaluate this combined technique quantitatively. The objective of this paper is to evaluate the reinforcing effect for this combined technique based on the measurement data at in-situ construction site of cut slope for road construction in Kyushu, Japan. At the construction site, earth pressure, deformations of the backfill and geogrids, and pore water pressure were measured during step-by-step construction. Finally, the effectiveness of the use of geogrids for concrete box-type retaining wall was discussed based on those measured data.

1 INTRODUCTION

Not only the reinforced embankment with geogrid but also the retaining wall with concrete box-type wall has become popular geotechnical structures. This is because the effectiveness and reliability for those structures have been well evaluated. On the other hand, the ground conditions and the circumstance where these structures are constructed have become more complicated, so that the combined technique for those two structures has also been used nowadays. It is expected for this combined technique that the advantages for both structures have to be well performed individually. But so far, not many measurement data for this combined technique at the real construction site have been obtained and the accumulation of these data is expected in order to evaluate this combined technique quantitatively. The objective of this paper is to evaluate the reinforcing effect for this combined technique based on the measurement data at the real construction site of cut slope for road construction in Kyushu, Japan. Photo-1 shows the picture of the construction site after completion of the construction. At the site, earth pressures, deformations of the backfill and geogrids, and pore water pressure are measured during step-by-step construction. Finally, the effectiveness of the use of geogrids for concrete box-type retaining wall structure is discussed based on those measured data.

Photo-1 Whole view of the field measurement site

2 OUTLINE OF DESIGN CALCULATIONS

The design calculations have been done under the guideline of the contents of Chapter 7 in the Manual of Rational Design and Construction, Reinforced Soils with Geotextiles (Public Works Research Center, Japan (1993)). This chapter includes the contents of new earth reinforcement technique and for the construction site discussed on this paper, geogrid reinforcement was used for the purpose of earth pressure reduction.

2.1 *Earth pressures*

At the first step of design calculations, earth pressure against retaining wall with the effect of the reinforcement by geogrids is computed. The basic concept of force equilibrium on the soil wedge in the backfill is shown in Figure-1. The active earth pressure without the effect of reinforcing material, P_0 is calculated using limit equilibrium method based on Figure-1. Then, the horizontal component of total earth pressure, P_H is calculated under the consideration of the tensile force in geogrids. This is formulated as follows:

$$P_H = P_{HO} - \sum T_i \geqq P_{HO} \times 2/3 \quad (2.1)$$

where P_{HO}: horizontal component of the active earth pressure, P_O.
It is noted here that the minimum value of horizontal component of earth pressure, P_H is considered to be 2/3 of the earth pressure, P_{HO}. The reasons for this assumption are listed as follows:

1) There are not much case histories considering the effect of earth pressure reduction by the reinforcement; and
2) The design calculation for this type of combined structures should be stick with the current design method for the general retaining wall structures.

Those calculations are applied to the design condition of the construction site as shown in Figure-2. The height of the retaining wall constructed by 8 layers of box -type walls (1 block: 1.0m height with 2.0m width) was 8.0 m with its angle of 59 degree. This retaining wall was constructed by step-by-step construction and there was 0.7m embedded depth for the bottom layer of the box-type wall. As shown in Figure-2, there is another slope beyond this retaining wall, in which the angle of the slope was 1:1.5 and the total height for this part was 5.0m. The value of the maximum horizontal earth pressure P_{HO} was computed by the limit equilibrium method based on the equation (2.1), and the calculated value of P_{HO} was 90.5 kN and the critical angle for active shear failure, ω was 43.7 degree.

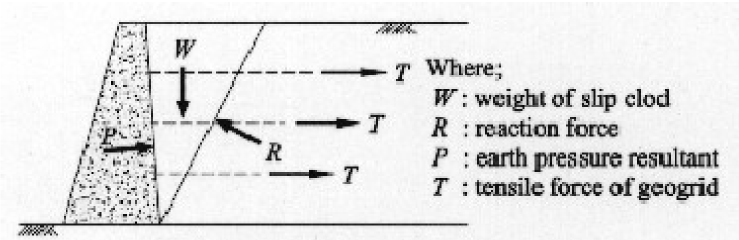

Figure-1 Design model (Balance of the force)

2.2 *Determination of the reinforcement condition*

Next, the reinforcement conditions which are the tensile forces and the arrangement of geogrids are determined. Here, the construction interval between two geogrids is assumed to be Δh =1.0 m which is a maximum value used in Japan. Thus, the total number of geogrid layers was 7 Tensile forces in each geogrid and the type of geogrid including its length are also determined under those conditions. First of all, the relation between the designed value of tensile force in each geogrid and the horizontal component of active earth pressure without the effect of geogrids, P_{HO} are obtained using the second and third terms of equation (2.1) which is shown as follows:

$$\Sigma T_i \leqq \frac{1}{3} \cdot P_{HO} \qquad (2.2)$$

The total tensile force for the designed value, T_i is also calculated by the number of geogrid layers and the design value of the tensile force and this relation is shown in equation (2.3).

$$\Sigma T_i = T_i \cdot n \qquad (2.3)$$

where n: number of geogrid layers, T_i: design tensile force (kN/m). And using equation (2.2) and equation (2.3), following relationship is obtained:

$$T_i \leqq \frac{1}{3} \cdot \frac{P_{HO}}{n} \qquad (2.4)$$

When the values of P_{HO}= 90.5 kN and n =7 is substituted in equation (2.4), then the design condition of tensile force is obtained as T_i = 4.31kN/m, so that the maximum value is 4.31 kN/m.

In the design calculation, the type of geogrid is determined by the following conditions:

$$T_A \geqq T_i \qquad (2.5)$$

which is the relation between the tensile strength, T_A and the calculated tensile force in each geogrid, T_i. Here, the tensile strength for design is T_A=17.7kN/m for maximum tensile force.

The length of geogrid in the ground is determined by the condition of sufficient bond length in order to satisfy the overall stability. The reinforcement length, L_i should be different in each layer and this is determined by following conditions.

$$L_i = L_{io} + L_{ip} \qquad (2.6)$$

where L_{io} : the width of soil wedge and L_{ip} :the bond length is calculated by

$$L_{ip} = \frac{F_S \cdot T_i}{2 \cdot \alpha_2 \cdot \gamma \cdot h_i \cdot \tan\phi} \quad (2.7)$$

where

T_i: design tensile force (kN/m)

α_2: revision coefficient about earth and the friction of geogrid

γ: unit weight of back-fill soil (kN/m^3)

: internal friction angle of back-fill soil (degree)

F_s: safety factor (=2.0)

h_i: construction depth of geogrid (m)

It is noted here that the minimum value L_{ip} is set to be L_{ip} =1.0 m.

The results after calculations are shown in Table-1 and the final arrangement of the geogrids is depicted in Figure-2.

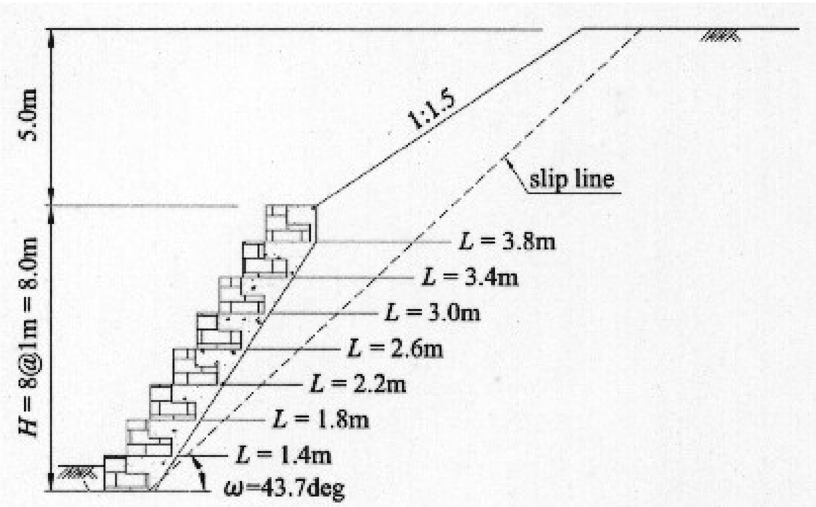

Figure-2 Design section

Table–1 Design calculation result

Layer	h_i (m)	L_{io} (m)	L_{ip} (m)	L_i (m)	
7	1.0	2.775	1.0	3.775	3.80
6	2.0	2.379	1.0	3.379	3.40
5	3.0	1.982	1.0	2.982	3.00
4	4.0	1.586	1.0	3.568	2.60
3	5.0	1.189	1.0	2.189	2.20
2	6.0	0.793	1.0	1.793	1.80
1	7.0	0.396	1.0	1.396	1.40

3 FIELD MEASUREMENTS

3.1 *Outline of measurements*

The site was a cut slope for local road construction and is located at the central crater hill in southwest foot of Mt.Aso in Kumamoto Prefecture, Japan, which is the biggest volcano of caldera type. The geological feature of the foundation soil is lava bed of the central crater of Mt.Aso and most of the ground are the deposits of volcanic ash silt which is called Kuro-boku and Aka-boku in Japanese. A box-type wall which is made by concrete block is applied for the wall structure at this site and the size of this block is 1.0m height and 2.0m width with its weight of 1.3tf in each. All the blocks are placed individually without any connections between two blocks. First of all, the mountain muck for a backfill soil is filled and the geogrid is placed as the first layer from the bottom in which the one step of the construction height is 1.0m with sufficient compaction and this step was repeated until the completion of the construction as shown in Figure-3. The soil properties at this site, which are obtained by laboratory testing are shown in Table -2.

The field measurements were conducted from the beginning to the end of construction. The all the devices for the measurements were installed in the period from June 24th to August 20th in 1997 and the measurements were continued until the end of December in 1997 which is total of about 180days. In the measurements, following values were picked up:

(1) Earth pressures: earth pressure gauges (the three horizontal directions, the one vertical direction);

(2) Deformation of the ground: inclinometers (three pieces of pipe gage);

(3) Strain in the geogrids: strain gauges (the geogrid 7 layers: 34 in amount); and

(4) Pore water pressure: pore pressure cells (two locations).

Those are indicated in Figure-3 and the photographs for those instrumentations are shown in Photo-2 to Photo-7.

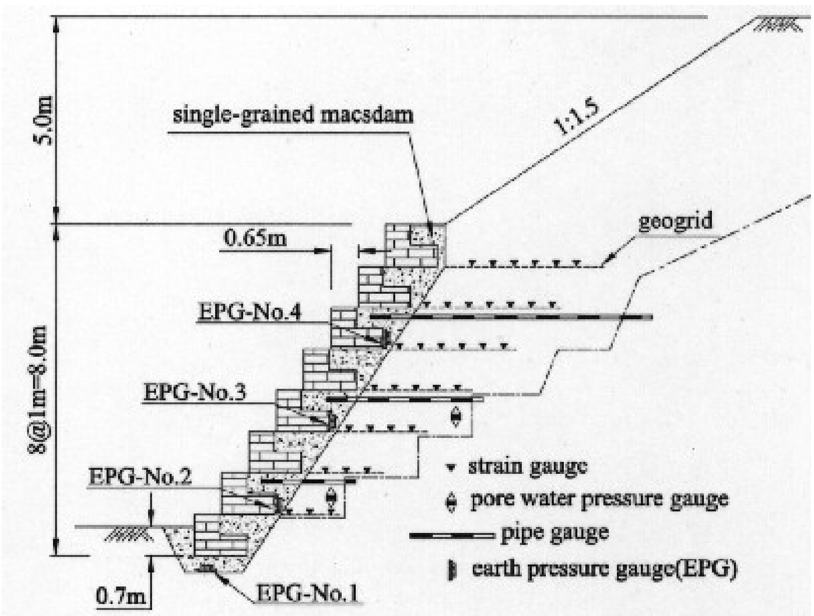

Figure-3 Arrangement figure of the measurement receptacle

3.2 *Results and discussion*

The items of the measurements are (1) horizontal earth pressure against box-type wall, (2) vertical pressure at the bottom of box-type wall, (3)displacement in the backfill, (4)tensile strain in the geogrids, (5)displacement of the wall, and pore water pressure in the backfill.

Figure-4 shows the change of earth pressures and vertical pressure due to the step-by-step construction of the backfill. The number of the elapse days shows the number of the days from the beginning of the bottom part of construction. The 8th layer construction which is the height of 8m from the bottom was finished within 70 days and then, the slope(1:1.5 inclination) beyond this retaining wall was constructed. The total days of construction was 90 days and the measurements were continued until 180 days from the beginning of the construction. The result of No.1 in Figure-4 shows the change of vertical pressures under the box -type wall at the bottom and this shows the increase of the load by the construction. The results from No.2 to No.4 show the horizontal earth pressure at three locations. Those results are gradually increased until 50days after completion of the construction but it becomes consistent after all until 150 days. Figure-5 shows the comparison of earth pressure distribution between the measurement data and the one computed by current design method (Public Work Research Center,Japan,1993). The designed values were computed for both reinforcement case and unreiforcement case as shown in Figure-5 and it is easily realized that the measured values are fairly closed to the one computed for the reinforcement case. It is also noted that the total earth pressure computed by measurement data is P_{Hm}= 53.7kN and its designed value are 60.3 kN.

Table-2 Soil quality condition of the field

	Unit Weight (kN/m^3)	Adhesive Force (kPa)	Internal Frictional Angle (degree)
Mountain muck (Back-fill soil)	17.7	4.9	35
Single-grained Macadam	19.6	0.0	40
Volcanic ash silt	12.6	27.5	0

Photo-2 Earth pressure gauge (vertical direction)


Photo-3 Earth pressure gauge (horizontal directions)


Photo-4 Strain gauge (7 layers: 34 in amount)

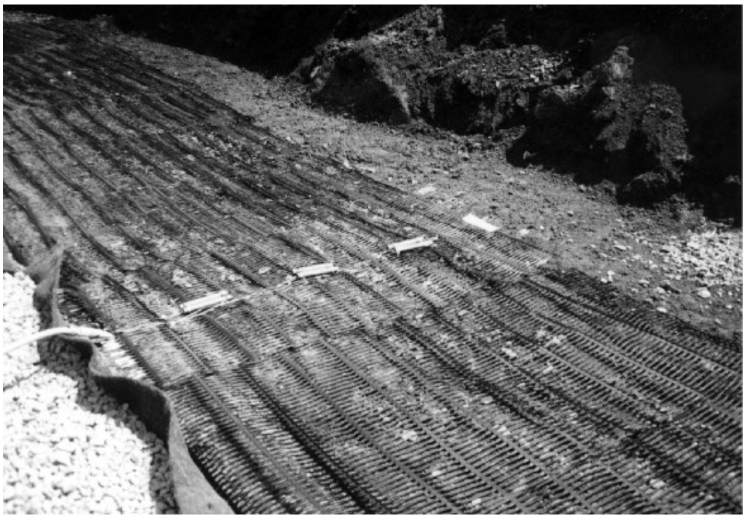
Photo-5 Strain gauge (installation of Geogrid)


Photo-6 Inclinometer (pipe gage)

Photo-7 Inclinometer (installation of pipe gage)

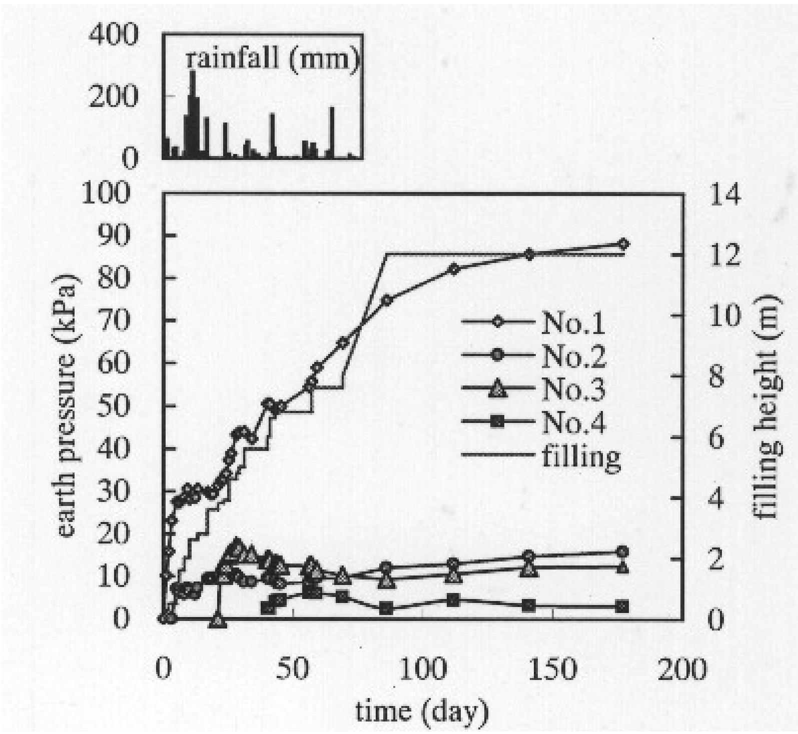

Figure-4 Filling height and earth pressure

Figure-6 shows the distribution of the tensile strain in each geogrid after the completion of construction (after180days). It is noted that the strain was increased as the proceed of the construction of fill and it became consistent after the completion of the total height of embankment. The strain at No.1 and No.2 layers are relatively large than those of other layers and the peak value appears clearly for those two layers. Also, the locations of the maximum strain in the geogrid for No.1 layer, No.2 layer, and No.5 layer agree with the location of failure surface which was computed in the design although those of the other 4 layers are not.

Table -3 shows the maximum value of the measured strain and the tensile force calculated using this measured value of the strain for all the reinforcement layers. The tensile force for the designed value was T_i = 4.31 kN/m and those values from measurements are acceptable values, in which the tensile strength of geogrid is T_A=17.7kN/m and those measured values are obviously less than this value. Table-4 shows all the comparisons between the measured values and the design values it is noted from this comparison that the total measured value for tensile forces is less than its design value and the earth pressure for the measured value is also less than the design value. This means that there is another reinforcement effect except the one by the tensile force in the geogrids. Figure-7 shows the change of horizontal displacement of the box-type wall with elapse time and Figure-8 also shows the distributions of the horizontal displacement for both the conditions of the completion of the construction and after the 1 month from the completion of the construction. Based on those measurements, it is concluded that the direction of the wall displacement is forward for the blocks from No.1 to No.2 but backward for the blocks from No.5 to the top(No.7) and there is not much change after completion of the construction. Figure-9 shows the change of the settlement of box-type wall with elapse time. The final settlement for the bottom of the wall was about 18 mm and the relative settlement in each block is 2-5 mm.

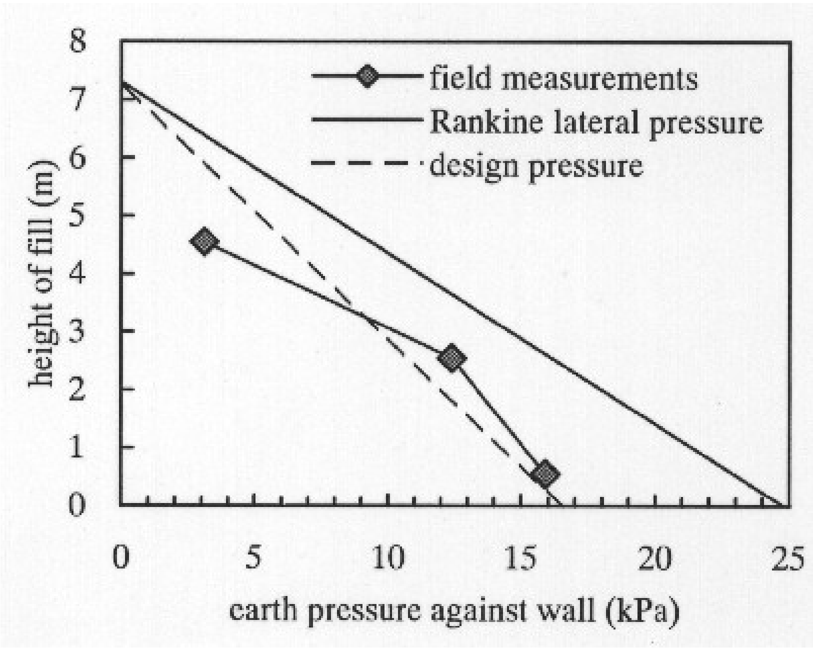

Figure-5 Distribution of earth pressure

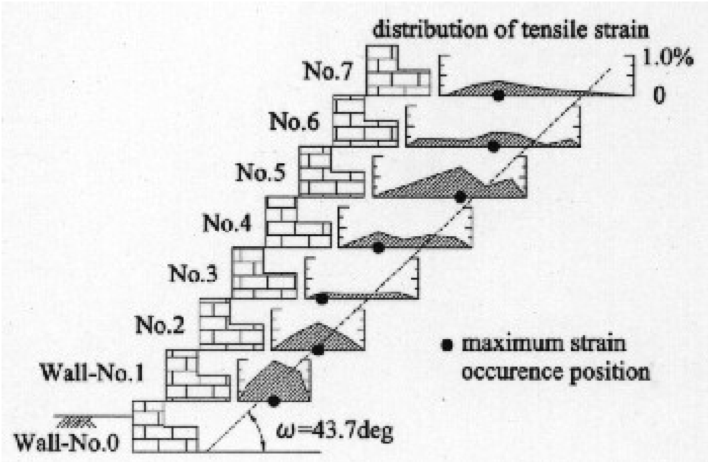

Figure-6 Distribution of tensile strain

Table-3 Estimated tensile force that acted on geogrid

Layer	Maximum strain	Estimation operation tensile force
1	ε_1=0.35%	T_1=2.10 kN/m
2	ε_2=0.35%	T_2=2.10 kN/m
3	ε_3=0.74%	T_3=4.44 kN/m
4	ε_4=0.39%	T_4=2.34 kN/m
5	ε_5=0.15%	T_5=0.90 kN/m
6	ε_6=0.66%	T_6=3.96 kN/m
7	ε_7=0.97%	T_7=5.82 kN/m
Σ		ΣT_i=21.7 kN/m

But, it computes as coefficient
J_{sec} (Young's modulus E × section area A) = 600kN/m.

Table-4 Comparison between the measurement result and the design

	Items	Horizontal Earth Pressure Resultant (kN)	Total with Operation Tensile Force ΣT_i (kN/m)
Design	The calculation value in the method of the wedge of the attempt at time (before geogrid arrangement)	P_{HO} =90.5	―――
	Present design (after geogrid arrangement) ※ $P_H = (2/3)P_{HO}$	P_H =60.3	30.2
	The value which was calculated based on the measurement value	P_{Hm} =53.7	21.7

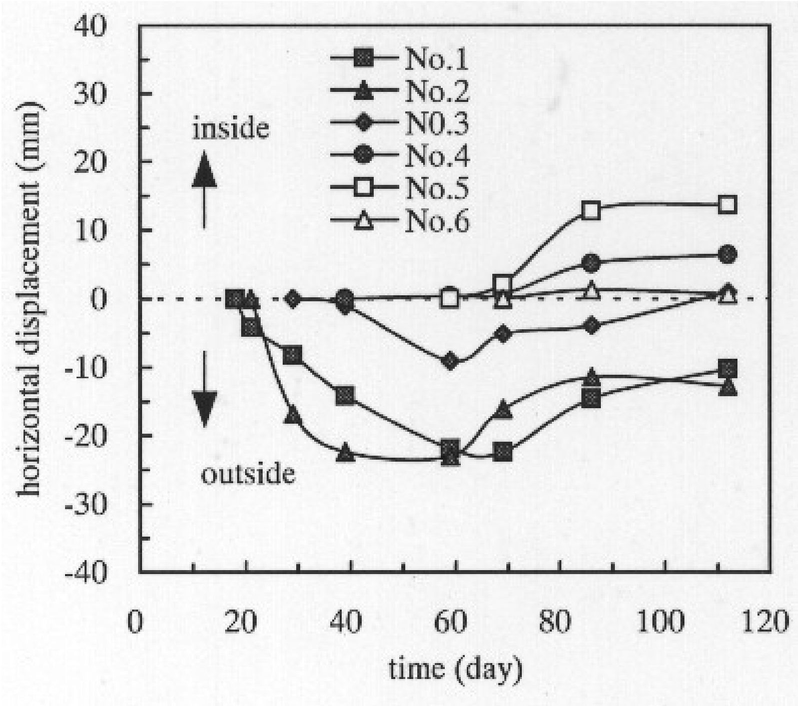

Figure-7 Horizontal displacement of wall

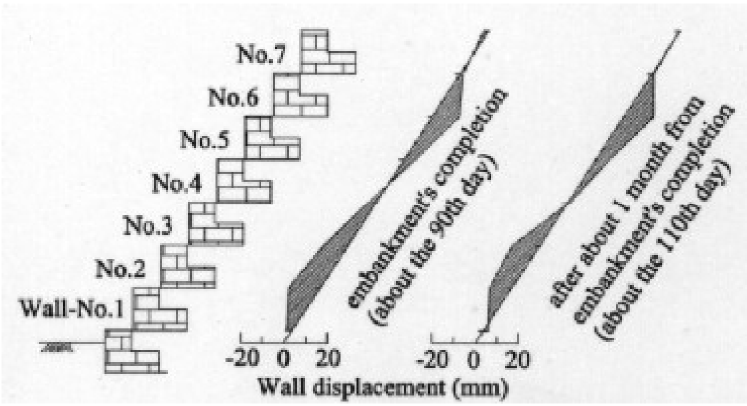

Figure-8 Horizontal displacement distribution of box-type-wall

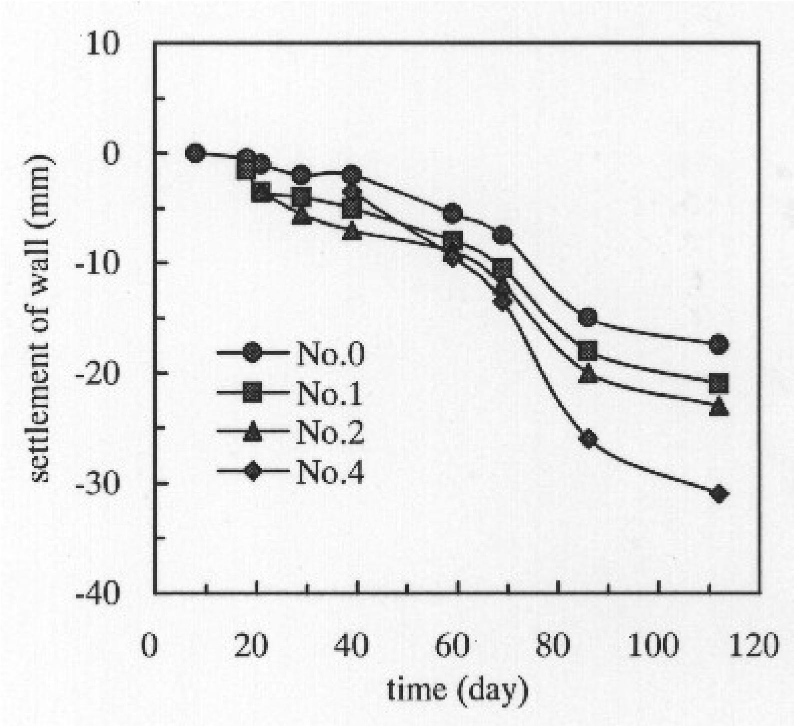

Figure-9 Settlement of box-type-wall

4 CONCLUSIONS

The field measurements for the construction of box-type retaining wall reinforced by geogrids were conducted and the results of those measurements were compared with the design values in order to check the performance of this structure. The conclusions drawn from this research are shown as follows:

(1) The total earth pressure estimated by the measurement of its distribution at the site was compared with the designed values for both the un-reinforcement case and reinforcement case and the effectiveness of the geogrid reinforcement for the purpose of earth pressure reduction was well evaluated.

(2) The maximum value of the stain in the geogrids was measured in 3 month after the completion of the construction and the tensile forces in the geogrids were calculated based on the measured strains. Although there are some variations among all the computed results of the forces, the computed results are well correlated with the design value. Besides, its value was within the tensile strength of the geogrid which was selected at this site.

(3) The consideration of the stability of this type of structure for earthquake is another key issue and this is the next target.

REFERENCE

Public Works Research Center. 1993. Manual of a Rational Design and Construction, Reinforced soils with Geotextiles