LONG-TERM DURABILITY OF GEOGRIDS LAID IN REINFORCED SOIL WALL

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ABSTRACT: Two types of 5m high geogrid reinforced soil walls (gradient V:H=1:0.1) with two kinds of wall facing (wrapping type and L-shaped concrete block type) trial soil walls were constructed in 1990, and an 8m high vertical reinforced soil wall with concrete block wall facing and a 4.5m high reinforced soil wall (gradient V:H=1:0.5) with a steel mesh frame as its wall facing trial soil walls were constructed in 1995. From the beginning of the construction stage, wall displacement or strain of the geogrid, the earth pressure, etc. were measured for a long period of time. In 2002, when the first walls were about 12 years old and the second walls were about 7 years old, parts of the four kinds of geogrids that were used as the reinforcement of the embankment and as the wall facing were sampled and underwent tensile tests to study their long-term durability. They were also immersed in various chemicals for a long period time then underwent tensile test to study their chemical degradation. The results confirmed that the geogrids buried in the soil for 12 years or for 7 years retained their original tensile strength.

1 INTRODUCTION

Two types of 5m high reinforced soil walls with two kinds of wall facing (wrapping type and L-shaped concrete block type) trial soil walls were constructed using geogrids in 1990, and an 8m high reinforced soil wall with concrete block wall facing and a 4.5m high reinforced soil wall with a steel mesh frame as its wall facing trial soil walls were constructed in 1995 in the site of the Public Works Research Institute (PWRI). From the construction stage, the wall displacement or strain of the geogrid, the earth pressure at the bottom of the reinforced soil wall and other characteristics of the reinforced soil walls were measured for a long period, revealing that no substantial change of the environments around any of these soil walls has occurred till the present time. The use of geotextiles to build reinforced soil walls has been increasing year by year since the method was first introduced to Japan in 1983, but because the method was at the research and development stage when it was introduced, many of the reinforced soil walls at that time were temporary or trial construction, with the result that there are few full-scale reinfoced soil wall built using geotextiles that have been measured continually for more than 10 years.

In addition to the measurements that were performed on these four kinds of reinforced soil walls, tensile test and chemical degradation test of samples of the geogrids that were used in these reinforced soil walls for 12 years or 7 years were performed. This report describes the results of a study of the behavior of the reinforced soil walls and the tensile properties and durability of the geogrids that were sampled.

2 LONG-TERM BEHAVIOR OF THE REINFORCED SOIL WALLS

Four kinds of reinforced soil walls, Type 1 to Type 4 were constructed. Table 1 presents outlines of the reinforced soil walls that were constructed. Type 1 and Type 2 walls were constructed in 1990 (Onodera et al.,1992) and Type 3 and Type 4 walls were constructed in 1995 (Ochiai et al., 1996, Nakajima et al.,1996, Tsukada et al.,1998). Different kinds of geogrids were laid in each type, and their specifications are presented in Table 2. Outlines of each type of reinforced soil wall and outlines of the results of the measurements are described as follows.

Table 1 Outline of Geogrid Reinforced Soil Walls

Type	Height (m)	Gradient	Geogrid	Construction Process		
				Start	Completion of Banking	Surcharge Banking
1	5.0	1:0.1	N	6/Dec/89	25/Jan/90 (50days)	2/Jun/90 (178days)
2	5.0	1:0.1	T (SR2)	6/Dec/89	25/Jan/90 (50days)	2/Jun/90 (178days)
3	8.0	1:0.0	T (SR55)	12/Mar/95	28/Apr/95 (48days)	9/May/95 (58days)
4	4.5	1:0.5	A	12/Mar/95	28/Apr/95 (48days)	

Table 2 Properties of Geogrids

Type of Geogrid	N	T (SR2)	T (SR55)	A
Main Material (covering)	Glass fiber (vinyl ester)	HDPE (NA)	HDPE (NA)	Alamido fiber (PE)
Structure	Bonded	Extruded	Extruded	Covering
Pitch of Ribs	100×30	166×22.5	166×22.5	26×28
Maximum Tensile Strength	100kN/m	80kN/m	50kN/m	50kN/m
Design Tensile Strength	40kN/m	32kN/m	30kN/m	24kN/m

Records of rainfall and earthquakes were also studied. The results of rainfall monitoring at a nearby monitoring station showed that the maximum daily rainfall was 192mm/day (Sep. 22, 1996) and the maximum hourly rainfall was 50mm/hour (Sep. 8 1991, 11:00 a.m. to noon). Results of nearby seismic observations show that the strongest acceleration was 139gal (June 14, 2002, horizontal direction).

2.1 *Types 1 and Type 2 reinforced soil walls*

2.1.1 *Configuration of the reinforced soil walls*

Type 1 and Type 2 reinforced soil walls are 5m high with slope gradients of 1:0.1. The wall facing used to build Type 1 was piling 50cm high L-shaped concrete blocks connecting with geogrid. Type 2 was constructed with wall facing by wrapping the soil bags using a geogrid. Figure 1 shows the configurations of the Type 1 and Type 2 reinforced soil walls.

The banking material was sandy soil, and because it contained fine-grain soil as banking material of reinforced soil wall, drainage sand layer were taken by placing horizontally and vertically behind the wall facing as shown in Figure 1. The banking material was compacted to be 85% or more of maximum dry density.

The arrangement of geogrids was designed in order to satisfy the target safety factor (Fs = 1.2) through stability calculations for circular slip in order to ensure the safety of a truck driving test above the reinforced wall after completion of the banking work.

Four months after completion of the banking work, an overburden embankment equivalent to the surcharge trafic load considered for the design (10kN/m^2) was constructed on top of each soil wall and monitored for a long period.

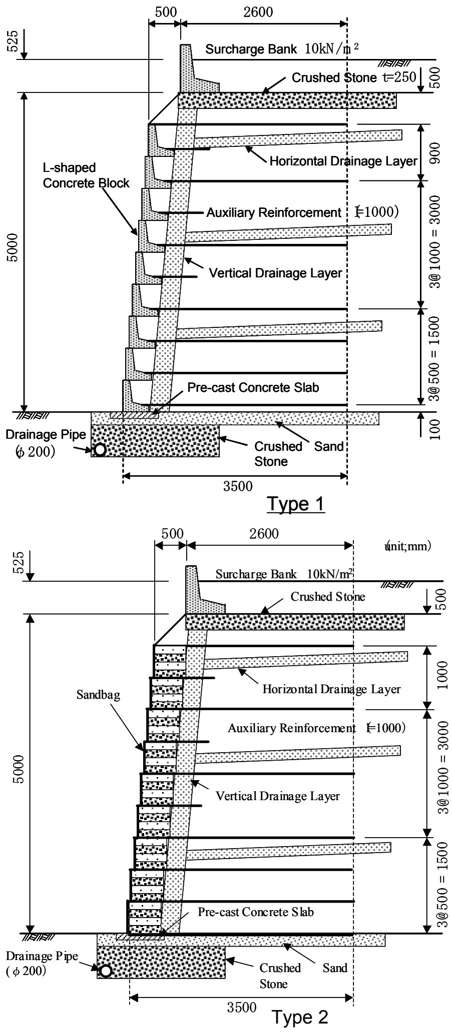


Figure 1 Cross-section of Type 1 & Type 2 Walls Constructed in 1990

2.1.2 *Outline of the measurement results*

The instrumentations were vertical and horizontal displacement of the walls, strain of the geogrids, and the vertical earth pressures at the bottom of the reinforced soil walls.

Figure 2 shows the distributions of the horizontal displacement of the walls after the completion of each type wall. If relatively flexible material is used as wall facing as in the Type 2 case, displacement of the top layer of the wall tends to lean forward. If relatively stiff matrial as in the Type 1 case is used, arc-shaped distribution with the maximum level midway in the wall height tends to occur.

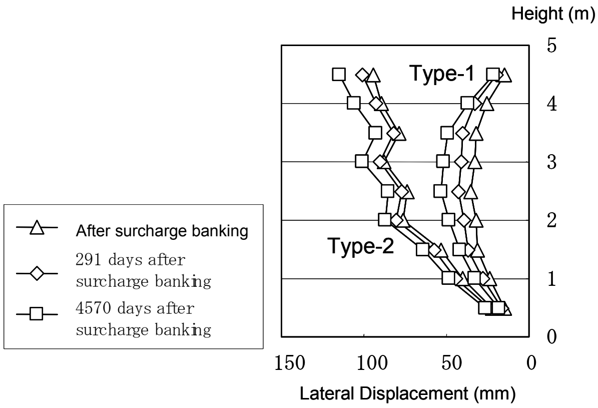


Figure 2 Lateral Displacement of Type 1 & 2 Walls

Figure 3 shows the strain distribution in the geogrids. And if relatively flexible wall facing material like that in the Type 2 case is used, the geogrid at each level has a distribution shape resembling a parabola with its peak near the active failure line. If stiff wall facing material like that in the Type 1 case is used, the strain of each geogrid has a distribution shape that is uniform or is triangular with its peak near the wall facing, revealing the effects of differences in the form of the wall facing.

Figure 4 shows the distribution shape of the vertical earth pressure at the bottom of the Type 2 reinforced soil wall from the embanking stage. In the Type 2 case with relatively flexible wall facing, from the banking stage, vertical earth pressure equivalent to the overburden pressure acts on the entire bottom surface of the reinforced zone, and the shape differs from the calculated earth pressure obtained assuming that the reinforced zone is a virtual gravity type retaining wall.

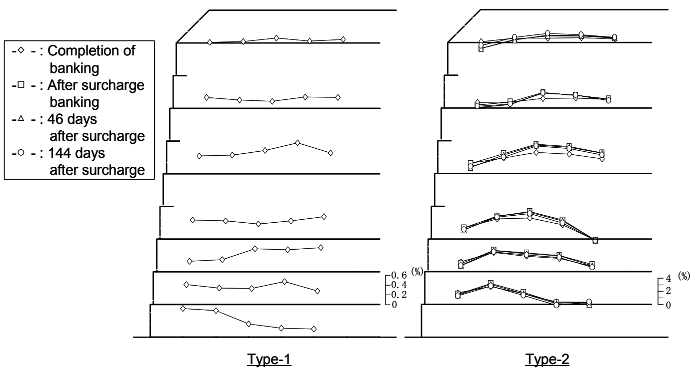


Figure 3 Strain Distributions of Geogrids (Type 1 & 2)

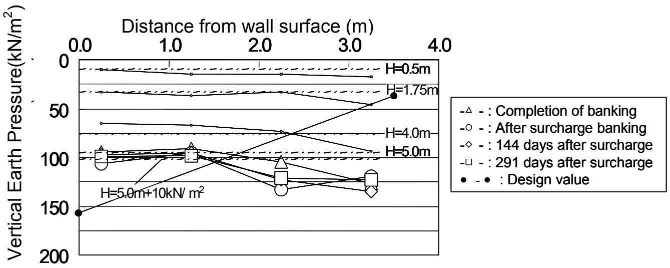


Figure 4 Vertical Earth Pressures at the Bottom of Type 2 Wall

2.2 *Type 3 and Type 4 reinforced soil walls*

2.2.1 *Configuration of the reinforced soil walls*

The Type 3 reinforced soil wall is a vertical 8m high reinforced soil wall with wall facing of piled 50cm high concrete blocks. In contrast, the Type 4 reinforced soil wall is a 4.5 high reinforced soil wall (gradient; 1:0.5) with wall work facing of steel mesh frame, and it was constructed to protect the side of Type 3. Figure 5 shows the configurations of Type 3 reinforced soil wall.

The banking material is the same sandy soil used for Type 1 and Type 2. A drainage layer was placed horizontally inside the embankment, and a vertical drainage layer of crushed stone was placed behind the wall facing. The banking material was compacted at least 90% of maximum dry density.

The Type 3 geogrid arrangement was designed so that it would be extremely close in order to verify the effectiveness of concrete block wall facing, and so that when stability calculations were performed according to the PWRI design manual (1992), however, the safety factor against circular slip was set Fs≒ 1.0 as critical condition.

Immediately after completion of the banking work, an overburden embankment equivalent to the surcharge traffic load considered for the design (10kN/m^2) was constructed on top of Type 3 wall.

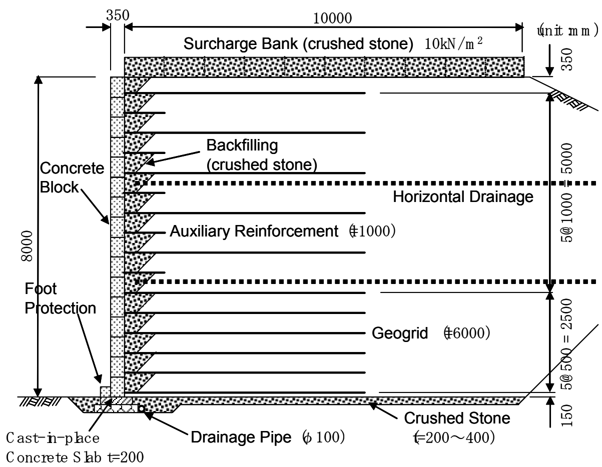


Figure 5 Cross-section of Type 3 Wall

2.2.2 *Outline of the measurement results*

Type 3 was measured, and the instrumentations were the vertical and horizontal displacement of the wall, settlement of the foundation ground, displacement of the ground in front of the reinforced soil wall, strain of the geogrids, the horizontal earth pressures acting on the wall facing, and the vertical earth pressures at the bottom of the reinforced soil wall.

Figure 6 shows the horizontal displacement of the wall after completion on Type 3 wall. The form of displacement is, like that of Type 1, an arc-shaped distribution with its peak close to the middle of the wall height, that is assumed to be a typical displacement pattern obtained by using relatively stiff wall material.

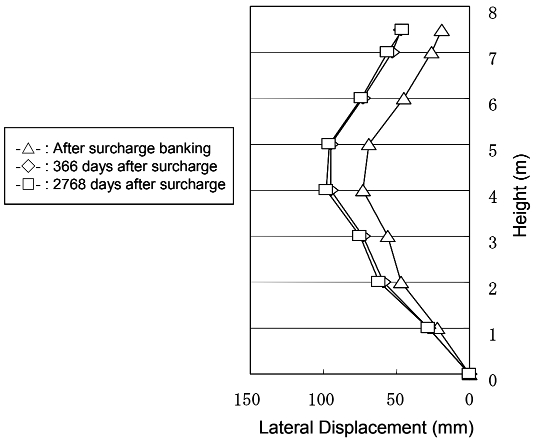


Figure 6 Lateral Displacement of Type 3 Wall

Figure 7 shows the strain distributions of the geogrids in Type 3. Overall it is a triangular distribution with its peak near the wall facing, and like Type 1, it is assumed to be a distribution shape characteristic of cases with relatively stiff wall materials. Even after completion of the banking, as time passed, strain near the wall facing tends to increase and a rise in local tension is confirmed.

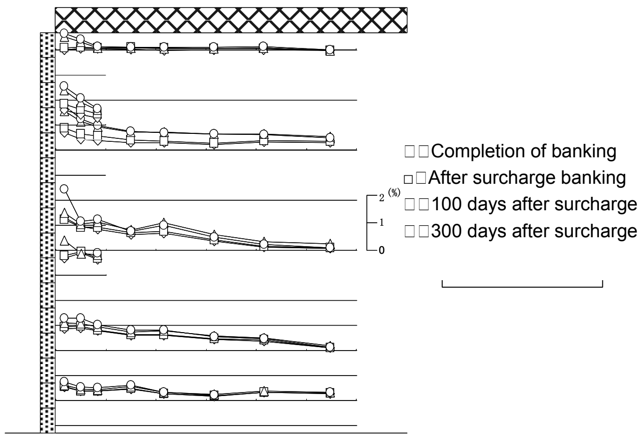
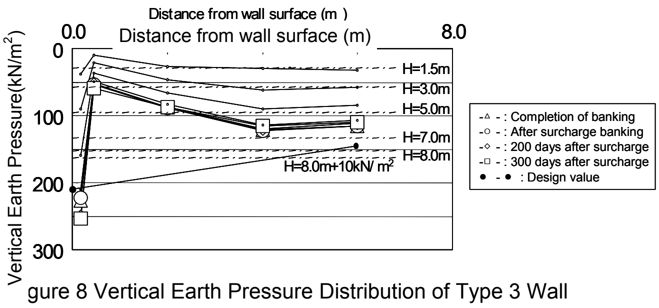


Figure 7 Strain Distributions of Geogrids (Type 3)

Figure 8 shows the vertical earth pressure distribution shape at the bottom of the Type 3 wall. From the first stage of the banking, a high earth pressure that exceeds the overburden pressure appears directly under the wall facing, while behind the wall, there is a unique distribution shape far less than the overburden pressure. These distribution shapes are assumed to be characteristic results of the structural form of the wall facing used in Type 3 wall.

Figure 9 shows the degree of increase of settlement of the ground surface in front of the reinforced soil wall, the bottom of the wall facing, and the foundation ground after execution of the surcharge banking. Because the foundation ground where Type 3 was constructed includes a soft layer with N-value of 10 or less near a depth of 10m from the surface layer, settlement tends to continue after banking. Under the effects of the concentrated earth pressure at the bottom of the wall facing in particular, the settlement has a more protruding distribution than at other locations. And there is a tendency for settlement to occur



gure 8 Vertical Earth Pressure Distribution of Type 3 Wall

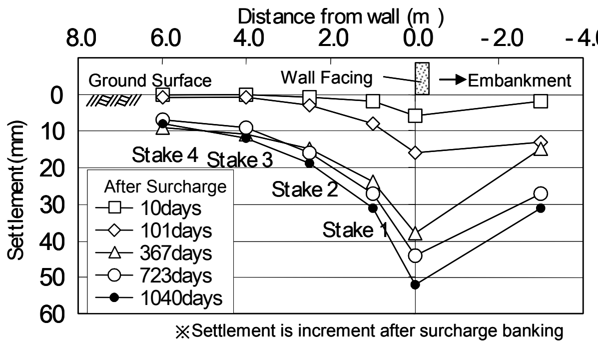


Figure 9 Settlement Distriburion of Foundation Ground

in the surrounding ground, pulling in the wall facing. But in the reinforced soil wall, the reinforced zone follows deformation as a block so that the reinforced soil wall retains its functions as a soil structure.

3 DURABILITY OF GEOGRIDS

Twelve years (4,570 days) after construction of the Type 1 and Type 2 and 7 years (2,768 days) after construction of the Type 3 and Type 4, part of embankment was excavated to sample the geogrid that is working as reinforcement to undergo tensile tests and chemical degradation tests.

3.1 *Geogrid sampling method*

As shown in Table 2, there are three kinds and 4 types of geogrid. The geogrid samples were obtained by the following method.

- Geogrid laid in the soil was sampled by excavating embankment from its top to obtain the quantity necessary for the testing from the top layer. After sampling, new geogrid was laid and the excavation was filled with the soil that had been removed.
- Geogrid exposed on the surface as wall facing on Type 2 wall was obtained by cutting off. After cutting, a grid-shaped steel frame was attached to restore the surface.
- When the embankments were excavated, the condition of the geogrid, the wall facing, connections between conrete block and geogrid etc. were visually inspected. The state of growth of vegetation was also inspected.
- When the geogrid samples were obtained, the pH of the surrounding soil was measured and on-site density testing was done.

3.2 *Survey and testing method*

The tensile test of the sampled geogrid was performed under the conditions shown in Table 3 in compliance with the standard test method in the PWRI manual to calculate the strength retention rate by comparing the test results with that of the geogrid in its original condition. The chemical degradation testing was also performed in compliance with the standard test method in the PWRI manual. After it was immersed in chemicals according to the specifications shown in Table 4, tensile testing was performed under the conditions in Table 3 to calculate the strength retention rate. This chemical degradation test was conducted to confirm the changes of the chemical properties of geogrid installed for a long period of time either underground or exposed on the surface under special conditions: strong acidity (pH≦ 4) and strong alkalinity (pH ≧ 10).

Table 3 Condition of Tensile Test

Items	Condition
Testing machine	Constant rate extension type tensile testing machine
Testing atomosphere (standard condition)	Temperature 23±2℃ Humidity 50±20%
Adjusting time	16 hours and more
Tensile rate	20 %/min
Number of specimen	N = 5

Table 4 Condition of Immersion in Chemicals

Items	Condition
Geogrid	Geogrid T (SR2 & SR55)
Chemicals	1. Distilled water 2. Sodium chloride solution (3.0%) 3. Calcium hydroxide solution (saturated) 4. Sodium hydroxide solution (10%) 5. Hydrochloric acid solution (10%) 6. Sulfuric acid solution (10%)
Immersed Temperature	50±2℃
Immersed time	500、1,000 hours

3.2 *Results of tensile test of the geogrids*

Figure 10 shows the maximum tensile strength after sampling of geogrid N used as reinforcement of Type 1 wall and the strain at the time of this maximum strength. Because the initial tensile strength of geogrid N is now not clear, the comparison of scattering was done using the results of products performed immediately after their manufacture to obtain approval by the Public Works Research Center.

The strength retention rate of the maximum tensile strength is unknown, but it has been confirmed to be tensile strength far greater than the design tensile strength (40kN/m) that accounts for the safety factor of each type of material.

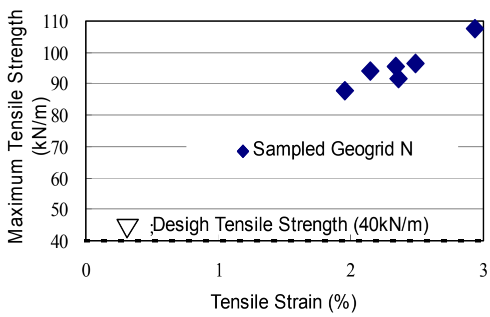


Figure 10 Tensile Strength and Strain of Geogrid N

Figure 11 shows the coefficients of variation of the maximum tensile strength of each sample. For Geogrid N, it is 3.5% according to the results of approval testing, but when it was sampled after 12 years, it was higher at 6.9%, revealing wide scattering.

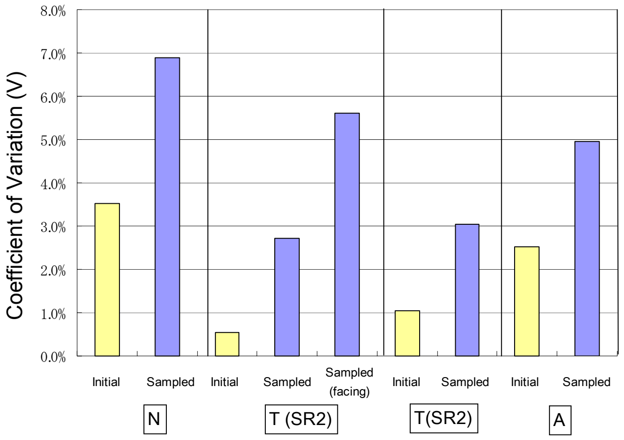


Figure 11 Coefficient of Variation of Each Geogrid

Figure 12 shows the results of tensile testing after sampling of geogrid T (SR2) used for the Type 2 reinforced soil wall. The figure also shows the results for exposed geogrid that was used on the wall surface.

The result is almost identical to the initial maximum tensile strength, with no decline of strength observed. Scattering of the maximum tensile strength is higher than the initial value, but its coefficient of variation is 2.7% as shown in Figure 11.

The maximum tensile strength results of the geogrid exposed on the wall surface work of the Type 2 Wall include some lower than the initial value, but averaging the results obtains strength equal to the initial value, However, scattering of the maximum tensile strength is approximately twice that of the buried samples, the scattering of strain is large, and the coefficient of variation of the maximum tensile strength is 5.6% that is about twice that of the buried samples.

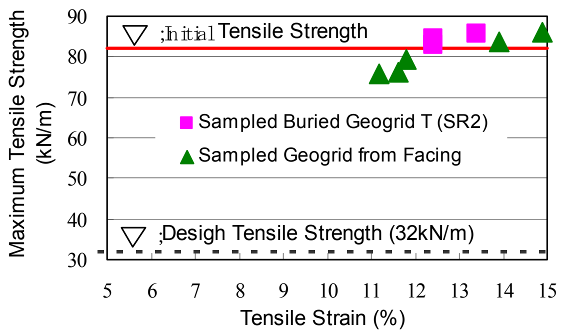


Figure 12 Tensile Strength and Strain of Geogrid T (SR2)

Figure 13 shows the results of tensile testing after sampling of geogrid T (SR55) used to build the Type 3 wall.

A comparison with the initial maximum tensile strength reveals a strength retention rate of about 90%, but strength in excess of the design tensile strength of 30kN/m was confirmed. Scattering of the maximum tensile strength is larger than that of the initial values but the coefficient of variation is 3.1% as shown in Figure 11.

Figure 14 shows the results of tensile testing after sampling of geogrid A used to build the Type 4 reinforced soil wall. The initial tensile strength of geogrid A is now unknown, but scattering was compared with the results of

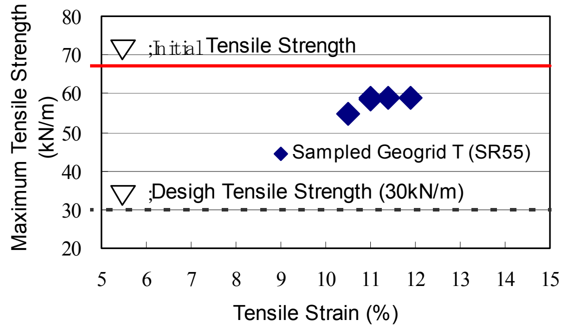


Figure 13 Tensile Strength and Strain of Geogrid T (SR55)

tensile testing performed to obtain approval by the Public Works Research Center.

The strength retention rate of the maximum tensile strength is unknown, but it has been confirmed that it is tensile strength far higher than the design tensile strength (24kN/m). Scattering of the maximum tensile strength was obtained by a comparison with the results of testing for approval, and the coefficient of variation was 2.5% in the approval test results, but 5.0% after sampling as shown in Figure 11.

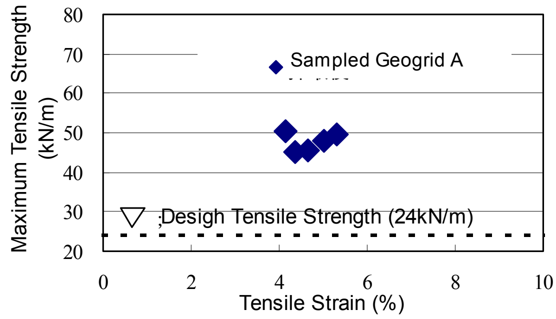


Figure 14 Tensile Strength and Strain of Geogrid A

3.3 *Results of chemical degradation test of the geogrids*

Figure 15 shows the results of chemical degradation tests after sampling of geogrid T used to construct Type 2 and Type 3 walls. The strength retention rate was calculated by equation (1) after 500 hours and 1000 hours of immersion in chemicals, treating the maximum tensile strength of samples that were not immersed in chemicals after sampling as the initial maximum tensile strength.

$$R_T = T_i / Ta \times 100\% \qquad (1)$$

where R_T : Strength retention rate
T_i : Tensile strength after immersion
T_a : Tensile strength after sampling

The figure shows that the strength retention rates were high for all chemicals after 500 hours and after 1,000 hours. It is, therefore, assumed that the chemical immersion after sampling had little effect on the samples and that they maintained their durability. The exposed geogrid used as Type 2 wall facing was also evaluated as not affected by chemical immersion.

Figure 16 plots the maximum tensile strength and its standard deviation by the distance from the slope surface in the results for the buried sample obtained at the Type 2 wall. It confirms that there is small change in strength and in the scale of the scattering according to the distance from the slope.

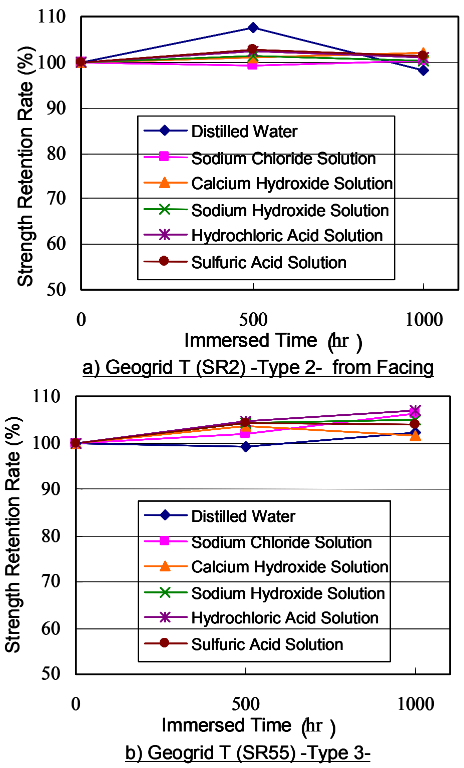


Figure 15 Strength Retention Rate after Immersion

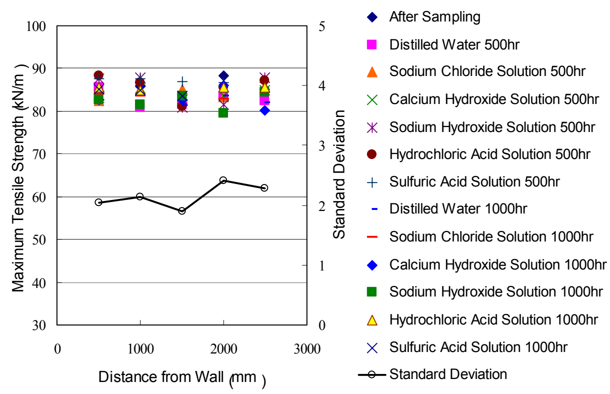


Figure 16 Tensile Strength and Distance from Wall (Type 2 Wall)

3.4 *Propeties of the soil*

The pH values of the all soil resulted in almost neutral, pH 7, indicating that this soil has no an impact on the durability of geogrids. The on-site density was also confirmed to be compaction of 90% or higher, indicating that the degree of compaction at the time of the banking was maintained.

4 CONCLUSION

This study has obtained the following knowledge concerning the behavior of geogrid reinforced soil walls over a long period of time and the durability of geogrids used to build such soil walls.

[1] Concerning deformation of the wall of a reinforced soil wall after it is constructed, in a case of soft wall surface work, displacement advances in the top layer, but in the case of relatively stiff wall surface work, arc-shaped deformation with its peak close to the middle of the wall height appears.

[2] Strains of the geogrid are, in the case of flexible wall facing, distributed in the shape of a parabola with its peak close to the active failure line, and if relatively stiff wall facing is done, its distribution is shaped like a triangle with its peak close to the wall surface work.

[3] In the case of flexible wall facing, vertical earth pressures which are equivalent to the overburden pressure acts across the entire bottom surface of the reinforced zone, but in the case of stiff wall facing, the characteristic vertical earth pressure distribution shape is locally high pressure at the bottom edge of the wall surface.

[4] The results of observations of partial excavation of the reinforced soil walls after approximately 12 years and approximately 7 years confirmed that the geogrids used and the wall facing were in sound condition without any damage.

[5] The maximum tensile strength of buried geogrids was confirmed to have a high strength retention rate. But scattering of the maximum tensile strength was about twice as high as that of the initial values. The tensile strength of geogrids exposed on wall surface work is more scattered than that of buried geogrid.

[6] The chemical degradation test of geogrid T that was obtained after approximately 12 years and after approximately 7 years has confirmed that they have high strength retention rates. This has confirmed that the chemical properties of geogrid material (resin) does not change. And no evidence was found that the strength retention rate varies according to its distance from the slope surface.

Measurements of these reinforced soil walls will be continued to study their behavior over long periods of time and to predict future tests of durability of the geogrids that remain.

5 ACKNOWLEDGEMENTS

The authors would like to express sincere gratiitude to Dr. Naozo FUKUDA, Fukken Co. Ltd, and Mr. Atsushi NAKANE, Tekken Co. Ltd, for the cooperation and advice.

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