Application of reinforced soil wall having self monitoring system to actual embankment construction project

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ABSTRACT: This paper reports that the reinforced soil wall having the monitoring system using optical fiber sensor is applied to the actual highway embankment project and high embankment of land improvement project. Authors developed an "optical fiber sensor geogrid" in which an optical fiber sensor is installed within a longitudinal member of the geogrid reinforcement. The system allows the stability of reinforced soil walls to be monitored continuously during and after construction and to assign a stability evaluation index to the walls based on peak strain readings.

1 INTRODUCTION

Many types of reinforced soil wall, which the gradient of wall can grow steep, have been proposed and have been applied worldwide. Since the reinforced soil structures were undamaged due to the powerful earthquake such as the South Hyogo Prefecture Earthquake in 1995, the Mid Niigata Prefecture Earthquake in 2004, etc., it was verified that the reinforced soil structure has high quake resistance. However, the assessment technique for the stability of the soil structure during and after construction or after the earthquake and heavy rainfall is not established. In order to assess the stability of the soil structure, authors developed the reinforced soil wall having self monitoring system in which the stress state of soil is monitored by installing the sensor geogrid. The reinforced soil wall consists of facing material, reinforced backfill and intermediate vertical layer which absorbs the earth pressure from backfill to wall surface. The sensor geogrid is used as the reinforcement of soil and the optical fiber is inserted in vertical strand of the geogrid. Optical fiber can be continuously monitored the strain distribution in the entire geogrid, so that it is possible to assess the stability of the reinforced soil wall by monitoring the strain distribution of geogrid. This paper reports that the reinforced soil wall having self monitoring system is applied to the actual highway embankment project and high embankment of land improvement project.

2 REINFORCED SOIL WALL HAVING SELF MONITORING SYSTEM

2.1 *Structure of reinforced soil wall*

The structure of the geogrid reinforced soil wall is illustrated in Figure 1. The wall has a double facing system with a layer to absorb deformation between the facing concrete blocks and the reinforced backfill. The absorption layer consists of single sized crushed stone. The facing concrete blocks and the reinforced backfill are connected by polyester fiber straps (Yoshida *et al*. 2006).

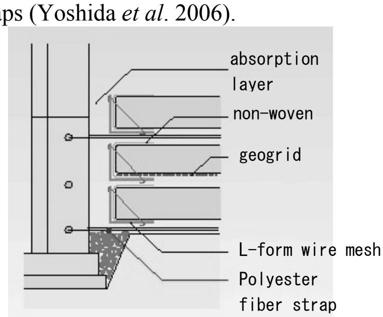


Figure 1. Structure of reinforced soil wall

The construction procedure is as follows; 1) grading the foundation surface to enable the facing concrete blocks to be placed horizontally, spreading of the crushed stone over the prepared foundation, and building the concrete footing, 2) installing the facing concrete panels on the footing and installing the polyester connection belts, 3) installing the geogrid layers, 4) backfilling and compacting the soil, and 5) filling the gap behind the concrete facing units with single sized crushed stone to create the absorption layer. When the foundation ground is soft, the concrete facing units can be constructed after consolidation of the foundation ground.

2.2 *Optical fiber sensor geogrid*

The structure of the optical fiber sensor geogrid is shown in Figure 2. The geogrid is manufactured from Aramid fiber and high-density polyethylene resin. The optical fiber sensor geogrid is manufactured as follows; 1) a stainless steel pipe with an inside diameter of 1.6 mm is inserted into a longitudinal member of the geogrid, 2) a single mode optical fiber sensor with a diameter of 0.9 mm is inserted into the stainless steel pipe, and 3) the optical fiber sensor is secured in the stainless steel pipe using an adhesive injected into the pipe. Since the stiffness of the stainless steel pipe is much lower than the stiffness of the Aramid fiber, the stainless steel pipe does not effect strain measurement.

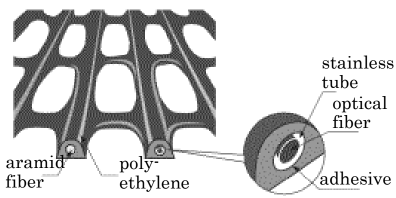


Figure 2. Structure of optical fiber sensor geogrid

The BOTDR (Brillouin Optical Time Domain Reflectometer) system measures strain along the geogrid using an optical fiber sensor. The BOTDR system can monitor the strain distribution along the entire length of the geogrid by measuring the frequency distribution of Brillouin scattered light. Moreover, this system can identify the position of the strain measurement by measuring the return time. For strain measurement using the BOTDR system, the average strain over a length of 1 m of the optical fiber sensor is measured at 0.2 m intervals.

2.3 *Stability evaluation index*

The design tensile strength of the geogrid is based on maximum tensile strength reduced by creep, durability and installation damage factors. The rupture strain of geogrid used in this study is about 5% and the strain corresponding to the design tensile strength is about 3%. When the measured strain is less than 3%, the tensile force acting in the geogrid is less than the design tensile strength and the reinforced soil wall is considered stable. When the measured strain is greater than 3%, the tensile force acting in the geogrid is greater than the design tensile strength and the reinforced soil wall is considered unstable or close to being unstable. A stability evaluation index based on the measured strain was developed by authors and is shown in Table 1 (Tsuji *et al*. 2006).

Table 1. Stability evaluation index to measured strain

State	Maximum value of measured strain (%)
Stable	0.0～3.0
Warning	3.0～4.0
Unstable	greater than 4.0

3 APPLICATION OF REINFORCED SOIL WALL TO ACTUAL CASE STUDIES

3.1 *Case study 1*

The optical fiber sensor geogrid was applied to a reinforced soil wall with a maximum height of 10.2 m and a width of 6.5 m in an embankment project at an exit ramp of an expressway junction. Figure 3 shows the cross section of the reinforced soil wall. Geogrids were installed throughout the respective levels to ensure the monolithic condition and facilitate construction of the reinforced embankments.

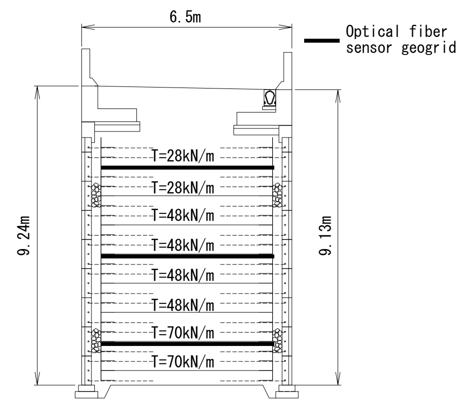


Figure 3. Cross section of reinforced soil wall (case study 1)

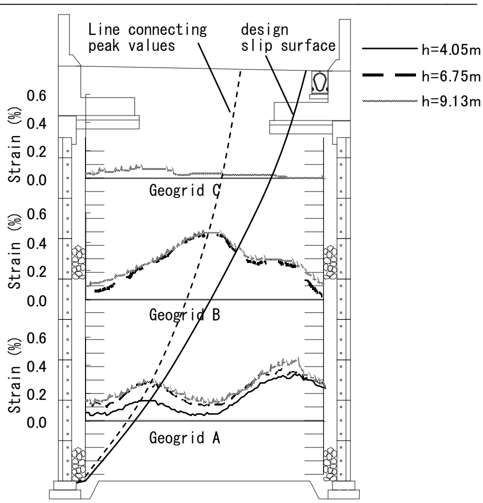
In the foundation of the reinforced soil wall, an alluvial clayey soil (N-value of approximately 1) was deposited for a thickness of approximately 7m over the bedrock. Part of foundation ground was stabilized by the deep mixing method to secure the bearing capacity of the foundation and to prevent the settlement of the wall. The soil properties of the banking material are listed in Table 2. The banking material was classified as clayey sandy gravel. Soil was stabilized using lime to control the water content of the banking material during construction.

Figure 4 shows the measured strain distribution. It shows the distribution of strain increases due to construction relative to the initial value (0%) at the time of geogrid installation. In geogrid A, strain peaked at points 1.5 to 2.0 m from either wall surface. In geogrid B, strain peaked at the middle of the embankment. In geogrid C, peak strain is not outstanding. This is because the earth cover was only 0.3 m and low tensile force acted on the geogrid. Strain was 0.1 to 0.5%, indicating the stable state shown in Table 1 that presents stability evaluation indexes. Thus, the geogrid and reinforced soil wall were determined to be sound. Figure 4 shows a slip surface with the minimum safety factor obtained by the circular slip surface method at the time of design and a line connecting the measured peak strains. Shear stress seems to be potentially predominant in an area closer to the wall than to the design slip surface identified in the design phase.

Figure 3. Cross section of reinforced soil wall (case study 1)

Table 2. Soil parameters

Classification		Clayey sandy gravel
Density		2.710g/cm^3
Optimum water content		16.3%
Maximum dry density		1.837 g/cm^3
	Gravel	45%
Particle size	Sand	31%
distribution	Silt	15%
	Clay	9%
Cohesion		13.0kN/m^2
Internal friction angle		31.4deg.



Fgiure 4. Strain distribution (case study 1)

3.2 *Case study 2*

The reinforced soil wall with the monitoring system using optical fiber sensor was applied to a highway embankment construction because the wall was 15m high and soil produced by excavating a tunnel was used for the backfill. Figure 5 shows the cross section of the wall and the placement of geogrids. To examine the accuracy of geogrid strain measurement using an optical fiber sensor, comparison with strain gauge readings was carried out (Geogrids A and B). The banking material is classified the sandy soil containing some fines as shown in Table 3.

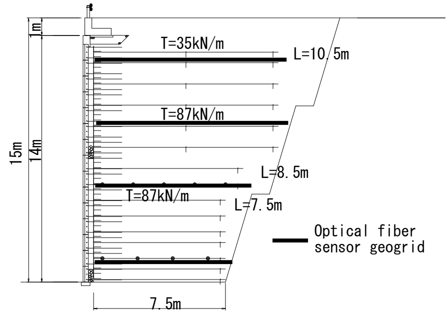


Figure 5. Cross section of reinforced soil wall (case study 2)

Table 3. Soil parameters

Classification		sandy soil containing fines
Density		2.639g/cm^3
Optimum water content		14.2%
Maximum dry density		1.767 g/cm^3
	Gravel	0%
Particle size	Sand	88%
distribution	Silt	4%
	Clay	8%
Cohesion		0kN/m^2
Internal friction angle		30.0deg.

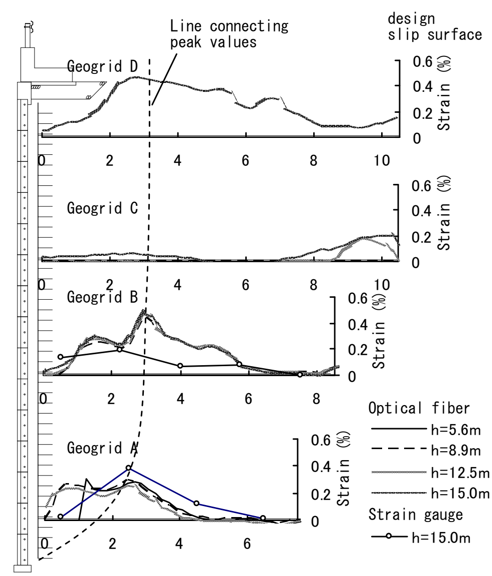


Figure 6. Strain distribution (case study 2)

Figure 6 shows the measured strain distribution. The strain is largest near the wall on Geogrid A, which is located close to the bottom of the wall, and in the middle to the rear on Geogrids B and C, which are located at intermediate heights. The strain distributions monitored by the optical fibers and strain gauges are slightly different from each other but showed similar trend. The maximum value of strain is about 0.5%, which shows that the wall is considered stable based on the proposed evaluation stability index. The line connecting the peak strain values consists of two straight lines with an inflection point. It seems that shear stress is potentially predominant in an area closer to the wall than to the design slip surface identified in the design phase.

3.3 *Case study 3*

A reinforced soil wall with a monitoring system using optical fiber sensors was constructed in an embankment project at an expressway interchange. The cross section is shown in Figure 7. A reinforced embankment was constructed by the Terre Armee method over a geogrid-reinforced soil wall constructed earlier. The geogrid-reinforced soil wall was composed of concrete panels at the lower level and of a steel frame at the upper level in view of the surrounding environment. The steel frame was expected to enable vegetation on wall surface. For embankment materials, the soil classified as gravel was used (Table 4).

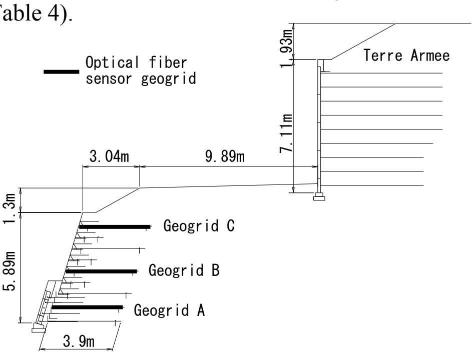


Figure 7. Cross section of reinforced soil wall (case study 3)

Table 4. Soil parameters

Classification		Gravel
Density		2.847g/cm^3
Optimum water content		15.9%
Maximum dry density		1.823 g/cm^3
	Gravel	78%
Particle size	Sand	18%
distribution	Silt	3%
	Clay	1%
Cohesion		8.4kN/m^2
Internal friction angle		35.6deg.

The measurements of strain are shown in Figure 8. The peak strain was reached at a point nearly one meter from the wall surface. The measurements by optical fiber sensors were similar to those by strain gauges. The peak strain was 0.3%. It was thus verified that the result was on the safe side. The line connecting the peak strain values is located ahead of the design slip surface. It seems to indicate that shear stress is potentially predominant in an area closer to the wall than to the design slip surface identified in the design phase.

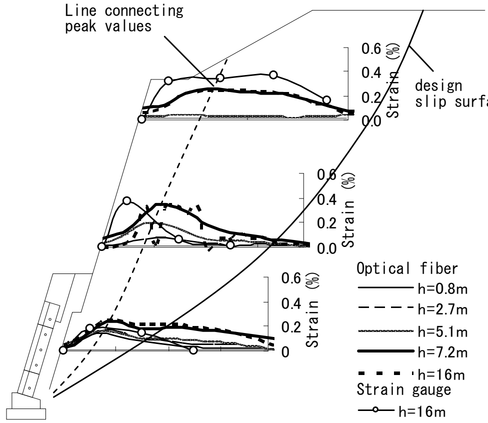


Figure 8. Strain distribution (case study 3)

4 CONCLUSION

In this study, reinforced soil walls with a monitoring system using "optical fiber sensor geogrid", geogrid in which optical fibers are installed, were applied to actual highway embankment projects to evaluate the stability of the reinforced soil wall during and at the end of construction, and after a disaster. The following results were obtained; 1) "Optical fiber sensor geogrid" was developed that enables continuous and long-term monitoring of the strain of geogrid. 2) Stability evaluation indexes were proposed based on the tensile properties of geogrid to evaluate the stability of the wall based on the strain measurements. 3) As a result of application of reinforced soil walls with a monitoring system to actual embankment projects, it was verified that the strain in the geogrid was small and that stable reinforced soil walls were constructed. 4) It was verified that continuous measurement of the strain of geogrid and the identification of the stress condition in the reinforced soil wall were possible.

In the future, this monitoring method will be applied to more construction projects for long-term measurement.

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