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Stability assessment of geogrid reinforced soil wall by using optical fiber sensor

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ABSTRACT: This paper reports that we can assess a total stability of a geogrid reinforced soil wall during and after construction by using an optical fiber sensor. We developed an "optical fiber sensor geogrid" in which an optical fiber sensor was installed in geogrid. We applied the optical fiber sensor geogrid to measure the strain distributions of an actual reinforced soil wall. The stability of the reinforced soil wall can be evaluated during and after construction continuously.

1 INTRODUCTION

To assess the total stability of geogrid reinforced soil wall during and after construction, field observation is carried out. However, it is difficult to assess the total stability from the result of field observation. We try to get a clear picture of strain distribution of geogrid during and after the construction of a geogrid reinforced soil wall to understand the total stability of the structure. A strain gauge has been widely used for strain measurement of geogrid inside the soil. However the strain gauge lacks durability, continuity of measuring point and ease of installing. In order to resolve these practical problems within a strain gauge, we have newly developed an "optical fiber sensor geogrid" in which optical fiber sensor was installed in geogrid. We applied the optical fiber sensor geogrid to measure the strain distributions of an actual reinforced soil wall. The reinforced soil wall consists of facing material, geogrid reinforced backfill and intermediate vertical layer which absorbs earth pressure from backfill to wall surface. To verify the reliability of optical fiber sensor, the strain gauges were also equipped at the same time. Results of strain measurement reveals as follows: 1) optical fiber sensor is more sensitive than the strain gauge, 2) it can measure a continuous strain distribution of geogrid and detect a local abnormality, and 3) we can provide the stability level of measured strain to assess the stability of reinforced soil wall, so that the stability of the reinforced soil wall can be evaluated during and after construction continuously. This paper reports the measuring system of an optical fiber sensor, manufacturing method of senor geogrid and real measuring results of geogrid reinforced soil wall.

2 OPTICAL FIBER SENSOR GEOGRID

The structure of the optical fiber sensor geogrid is shown in Figure 1. A single mode optical fiber of a diameter of 0.9 mm is fixed by adhesives in a protecting stainless tube of an inner diameter of 1.6 mm. Since the stiffness of stainless tube is lower than the stiffness of aramid fiber, the stainless tube does not influence on strain measuring. The optical fiber monitors strain using the BOTDR method, which is irradiating light pulses through the fiber and monitoring changes in the frequency of Berlian scattered light, which changes its frequency proportionally to the strain of the optical fiber (Tatta, N. et al., 2005). Optical fibers have

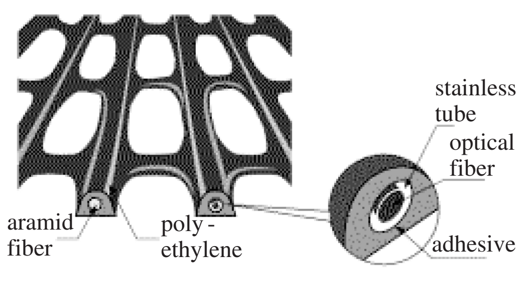

Figure 1. Optical fiber sensor geogrid.

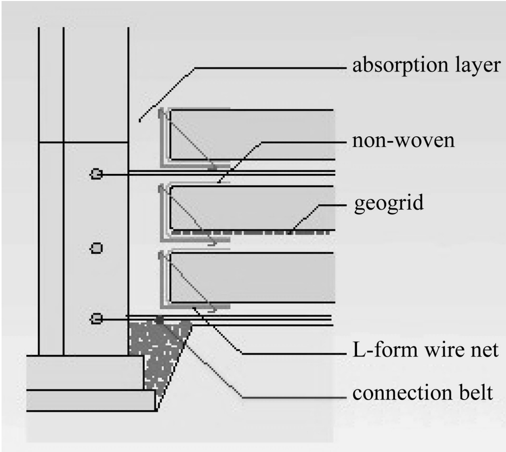

Figure 2. Structure of geogrid reinforced soil wall.

various advantages in monitoring strain distribution, such as 1) optical fiber is durable and it can be used to measure strains over a long period of time compared to strain gauges, and 2) the fibers can measure the strain in the entire geogrid.

The structure of reinforced soil wall is shown in Figure 2 (Yoshida, K. et al., 2006). The wall has a double wall system with a vertical layer (called absorption layer) between a wall of facing concrete blocks and a reinforced backfill. The absorption layer consists of single sized crushed stones. The facing concrete blocks and the reinforced backfill are connected with many belts of polyester fiber (called connection belt). The procedure of construction is follows: 1) grading the foundation ground to enable the facing concrete blocks to be horizontally installed, spreading crushed stones for the foundation, and building concrete foundation, 2) installing the facing concrete blocks on the foundation concrete, installing the connection belts and geogrids, backfilling and compacting soil, and 3) filling the absorption layer with single sized crushed stones. When the foundation ground is soft, the wall can be constructed after banking the reinforced backfill. The facing concrete blocks are installed after consolidation of ground. The installation of the optical sensor geogrid is shown in Figure 3. Considering that strain would be about 3% for the design tensile strength of the geogrid, the stability assessment index is established for assessing the stability of the measured strain values as shown in Table 1 (Yoshida, K. et al., 2006).

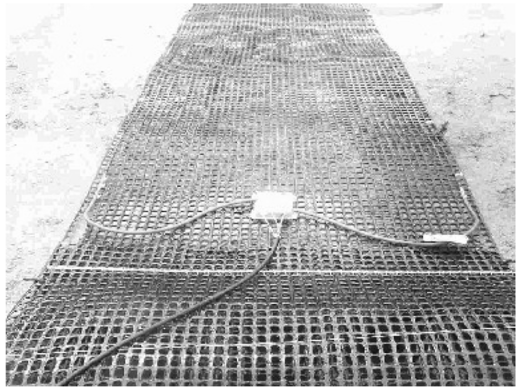

Figure 3. Installation of optical fiber sensor geogrid.

Table 1. Stability assessment index.

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

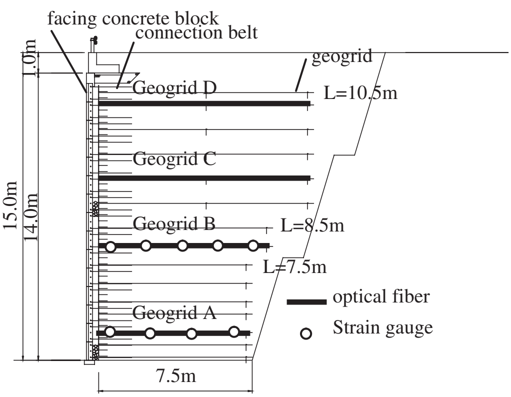

Figure 4. Cross-section.

3 EXAMPLES OF STRAIN MONITORING

3.1 *Example 1*

A cross section of the reinforced soil wall and the placement of geogrids are shown in Figure 4, where *L* is the length of geogrid. The wall was 15 m high and soil produced by excavating a tunnel was used for the backfill. The strain of geogrids during the construction of the wall was monitored to assess the stability of the wall during construction. The strains were monitored using optical fibers on Geogrids A, B, C and D shown in Figure 4. To verify the reliability of strain monitoring using optical fibers, the strain was also measured on Geogrids A and B using strain gauges.

The strain distribution monitored using optical fiber is shown in Figure 5, and the strain distribution

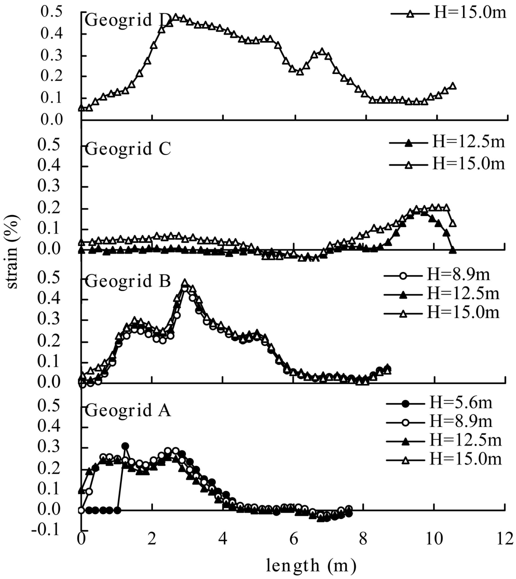

Figure 5. Strain distribution measured by optical fiber.

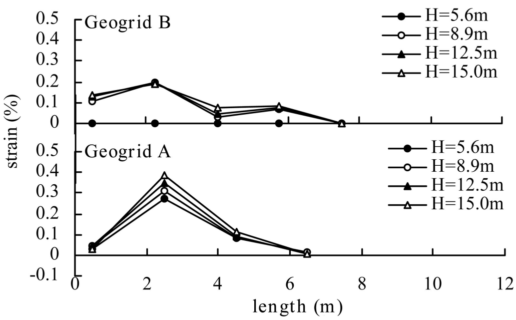

Figure 6. Strain distribution measured by strain gauge.

monitored using strain gauge is shown in Figure 6. It shows the increment in strain from the initial values monitored immediately after installing the geogrids, and *H* is the construction height of the wall. The optical fibers monitored the strain continuously throughout the geogrids. As banking progressed, the strain increased. The strain is largest near the wall on Geogrid A, which is installed low, and in the middle to the rear on Geogrids B and C, which are installed at intermediate heights. Stains of Geogrid C measured by optical fiber are small compared with other geogrid, because of error of measuring initial value of strain. The values monitored by the optical fibers and strain gauges are slightly different from each other but showed similar strain distributions. The maximum value of strain is about 0.5%, which shows that the wall is stable state.

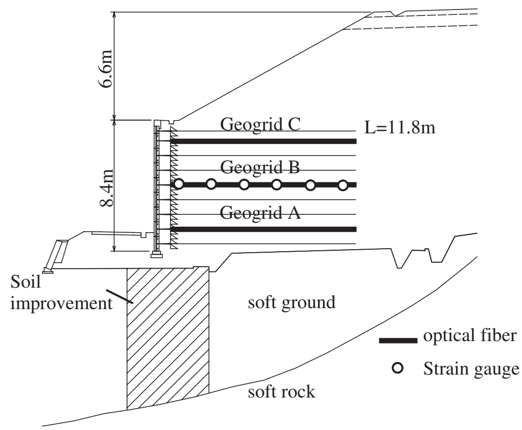

Figure 7. Cross-section.

3.2 *Example 2*

A cross section of the reinforced soil wall and the placement of geogrids are shown in Figure 7. The foundation ground consisted of an alluvial clayey soil layer (SPT N-value is about 1) of a thickness of about 5 m and a layer of sandy soil (SPT N-value is about 6) of a thickness of 5 m. Under the soft alluvial layer, the bed rock exists. Since the foundation ground was soft, there were risks of sliding failure of the foundation ground, liquefaction of the saturated sandy soil layers during an earthquake and immediate settlement of the foundation ground. To overcome these risks, the soil was stabilized using the deep mixing method at the site on which the facing concrete block wall was to be constructed. After the compression and consolidation of the non-stabilized ground section, which were caused by the construction of the geogrid reinforced backfill, ceased, the facing concrete blocks were piled up. Strain was monitored using optical fibers on Geogrids A, B, and C in Figure 7, and using strain gauges on Geogrid B.

The strain distribution monitored using optical fiber is shown in Figure 8, and the strain distribution monitored using strain gauge is shown in Figure 9. As banking progressed, the strain increased. Local large strain is observed on Geogrid A at about 3.5 m. This is likely attributable to the difference in settlement between the backfill built on stabilized and non-stabilized ground sections. The strain gauges cannot detect this behavior. Local increases in strain are observed in the reinforced backfill on non-stabilized ground. The maximum value of strain is about 1.8%, which shows that the wall is stable state.

3.3 *Example 3*

A cross section of the reinforced soil wall and the placement of geogrids are shown in Figure 10. After

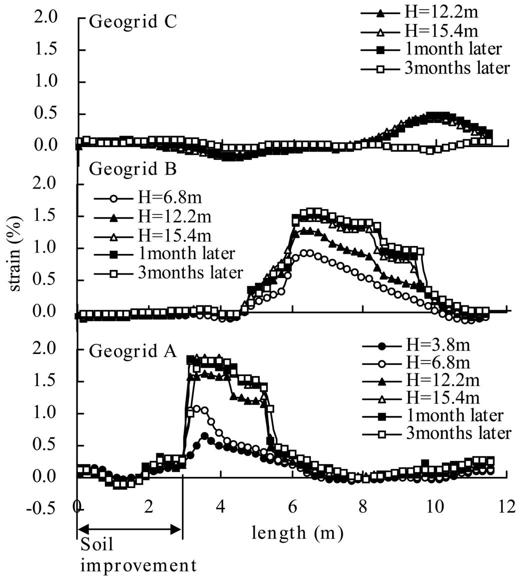

Figure 8. Strain distribution measured by optical fiber.

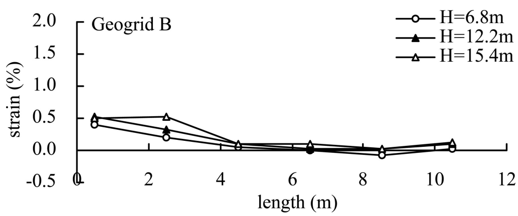

Figure 9. Strain distribution measured by strain gauge.

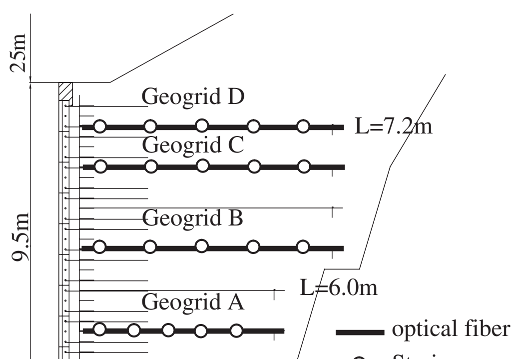

Figure 10. Cross-section view.

constructing the reinforced soil wall of 9.5 m high, the embankment slope of 25 m high was constructed. Strain was monitored using optical fibers and strain gauges on Geogrids A, B, C, and D in Figure 10.

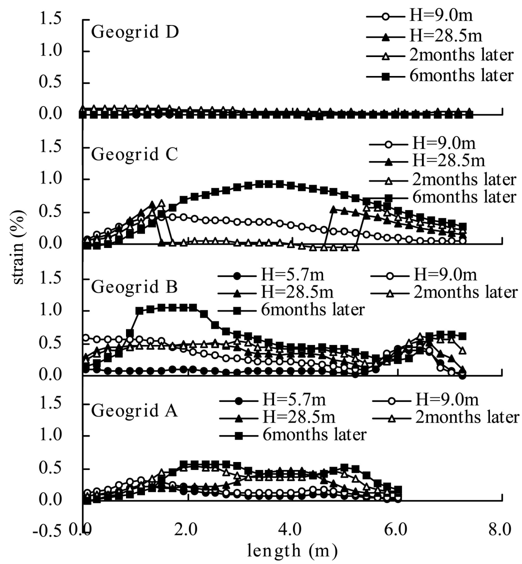

Figure 11. Strain distribution measured by optical fiber.

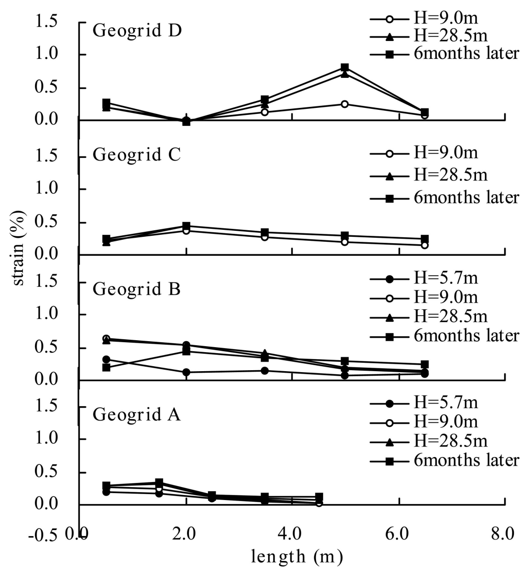

Figure 12. Strain distribution measured by strain gauge.

The strain distribution monitored using optical fiber is shown in Figure 11, and the strain distribution monitored using strain gauge is shown in Figure 12. The strain value equal to 0 on Geogrid C is attributable to mistaken setting of the frequency range to monitor. The strain is the largest near the wall on Geogrids A and B and in the middle on Geogrids C and D. Stains of Geogrid D measured by optical fiber are small compared with other geogrid, because of break at the part of fusion splice of optical fiber. The monitoring using optical fibers shows a trend similar to that of values monitored using strain gauges. The maximum value of strain is about 1.0%, which shows that the wall is stable state.

4 CONCLUSIONS

To assess the stability of geogrid reinforced soil walls during and after construction, strain of geogrid is monitored using optical fiber. The results are: 1) Optical fiber sensor geogrid can monitor the strain of geogrid during and after construction. 2) Optical fiber sensor geogrid is effective in monitoring strain on geogrid more continuously than strain gauge and identifying points of local deformation. 3) The stability of the geogrid reinforced soil walls can be assessed from monitored strain values using the stability assessment index of geogrid. 4) Strain monitoring using optical fiber sensor geogrid is effective in precisely detecting deformations inside of reinforced backfill. 5) The geogrid reinforced soil walls subjected in this paper are stable state without abnormality, such as deformation of wall.

Thus, the monitoring method using optical fiber sensor geogrids is shown to be an effective method for assessing the stability and deformation of reinforced soil walls during and after construction and after long service. This method will be used in a number of projects and long-term monitoring will be conducted. The reliability of optical fibers will be thoroughly examined by also installing strain gauges since some data monitored using optical fibers in this study did not agree with the strain monitored by using strain gauges.

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