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Deformation measurement technology of geomembrane at controlled landfills using optical fiber sensors

Nakamura, J.
Aomori Railway Construction Branch, Japan Railway construction, Transport and Technology Agency

Sakanishi, M. & Kitazawa, A.
Maeda Corporation

Kumagai, K.
Hachinohe Institute of Technology

Fujihashi, K. & Ogasawara, T.
NTT Infranet Corporation

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ABSTRACT: Distortions occur in the sheets that are laid to low ground or used as capping to prevent seepage at controlled landfills. These distortions vary depending on the contents, displacement when filling capping materials, and subsequent compaction. As one of the methods to recognize and evaluate deformation during construction or while in service, measurements of the sheet elongation strain have been attempted. However, only the point where the gauge was attached could be measured using a conventional strain gauge. Therefore, it was difficult to determine linear or surface distortions necessary in evaluating geomembrane deformation. In this research, the ability of optical fibers to register distortions in meter increments was utilized, a method to determine and evaluate geomembrane linear and surface deformation was studied, capping was attempted, and its applicability was confirmed. Brillouin Optical Time Domain Reflectmeter (BOTDR) method capable of measuring distortions in meter increments using optic fiber sensors was used.

1 INTRODUCTION

Mineralized rocks were discovered during the construction work at the Hakkoda Tunnel (Nashinoki section). The impact on the environment was a concern as mineralized rocks exposed to wind and water are easily oxidized. The mineralized rocks in this section were wrapped using capping sheets. This construction site was in the forest park operated by the city, so it was necessary to recover the soil and replant the trees once the capping sheets were used.

When covering the sheets with soil, there is the possibility for deformation to occur as a result of displacement or compaction. As one of the methods to determine and evaluate such deformation, measurements of sheet elongation/strain were attempted. With conventional strain gauges, measurements were taken at several points, but it was difficult to make linear or surface measurements required for evaluating deformation.

Then we focused on the optic fiber sensors' ability to determine deformation in meter increments, considered its applicability, tried to develop a method to determine geomembrane deformation in lines or on surface, and installed optic fiber sensors on the capping sheet and the covering soil. The following are the results of our distortion measurements.

2 OPTIC FIBER MEASUREMENT PRINCIPLE APPLIED TO MEASUREMENT

Optic fiber continuous distortion measurement technology, BOTDR, is a measurement method utilizing the principle that when light pulses through an optic fiber, the frequency of the Brillouin scattering light in the backscattered light returning to the incident side of the optic fiber, changes as shown in Figure 1.

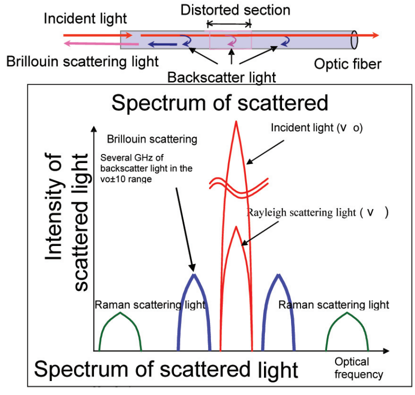

Figure 1. Strain measurement principle of BOTDR.

The frequency shift of Brillouin scattered-light power spectrum (Δ) is linear to strain produced in an optical fiber in its longitudinal direction, as shown in Figure 2.

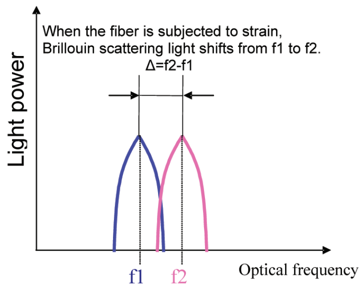

Figure 2. Optical frequency shift due to strain.

3 INSTALLATION OUTLINE

During the snow season, the covering soil of controlled landfills is subjected to the heaviest loads and often results in the covering soil to slide. At the beginning of spring when the snow cover load moves over the covering soil such as in an all layer-snow slide or surface snow slide, the covering soil is considered to become most unstable.

Regarding the final shape of filling, height of each slope is 5.0 m for the first slope, 5.0 m for the second slope, and 3.5 m for the third slope, and the slope inclination is 1:3. Considering the influence of snow accumulation, the first slope can be influenced by drifting snow, and the slide of snow cover may be small due to flat slope bottom. Therefore, we judge that it is the most economical to set the measuring sensors to the second and third slope as the position is effective for evaluating the influence of snow accumulation.

As for the displacement of sheet, we decided to measure relative displacement. As for the displacement of covering soil, we decided to set the fixed end to the upper third slope and measure there. Distance between sensors on the sheet is to be 1.7 m. In consideration of elongation and compression due to sliding covering soil, we decided to set no tension sensor and 1000μ strain sensor in 2 measuring lines. Figure 3 shows the outline of sensor installation. The same sheet was welded to glue sensors of the sheet. Figure 4 shows operations for installing sensor cable on the sheets. In order to measure sliding of covering soil, sensors with 1000μ strain tension were set at 0.2 m high from the covering soil surface at a distance of 5.0 m, as shown in Figure 5.

The detail of sensor setting on the sheet is shown in the Figure 6.

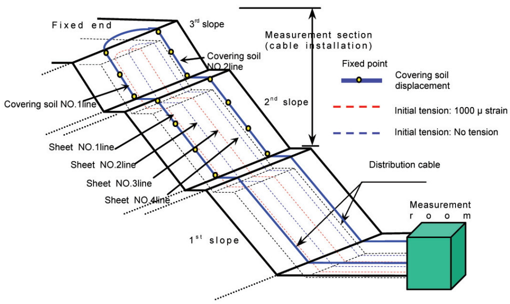

Figure 3. Outline of Sensor installation.

Figure 4. Sheet installation condition.

Figure 5. Covering soil sensor installation condition.

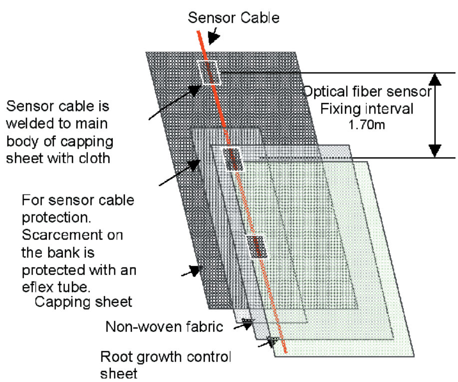

Figure 6. Sheet installation detail.

4 MEASUREMENT RESULT AND CONSIDERATION

Regarding this matter, we report on snow accumulation distribution and measurement results of the second sheet during the measurement period. Snow accumulation distribution in the period is shown in Figure 7. Figure 8 shows the sensor position of each measurement line.

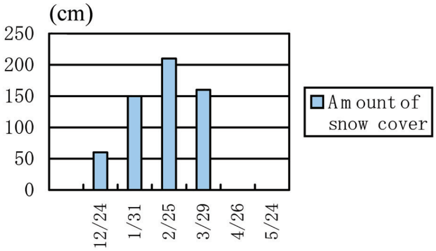

Figure 7. Amount of snow cover distribution chart.

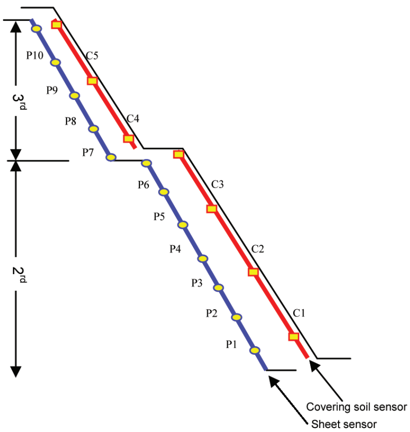

Figure 8. Sensor position of sensor cables.

The measurement was executed six times. Figures 9, 10, 11, 12 show the relative displacement of the sheets, and Figure 13 and 14 show the relative displacement of covering soil. According to the measurement results, the biggest sheet displacement is at the point P6 at upper slope, where the sheet is pulled down. It matches the displacements at points C3 and C4 of the covering soil, and is considered to be the result of covering soil sliding on the third slope. The effectiveness of tension on the measuring line could not be confirmed due to the very small displacements. Displacements of the sheet and covering soil were quite small (a few mm), and it can be considered as consolidation of covering soil. Therefore, the slope seems to be stable.

4.1 *Measurement results*

(1) Distortions resulting from pulling toward the upper

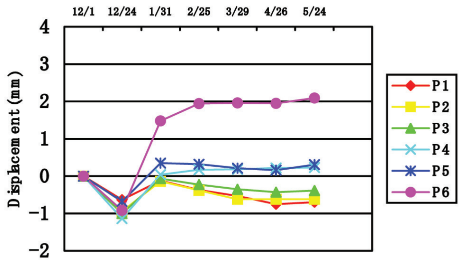

Figure 9. Sheet No 1 line on the 2nd slope.

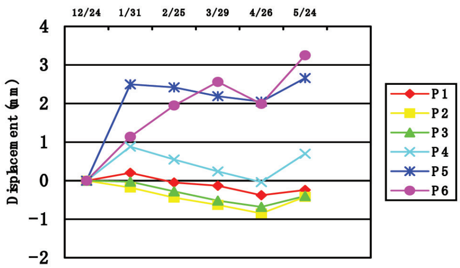

Figure 10. Sheet No 2 line on the 2nd slope.

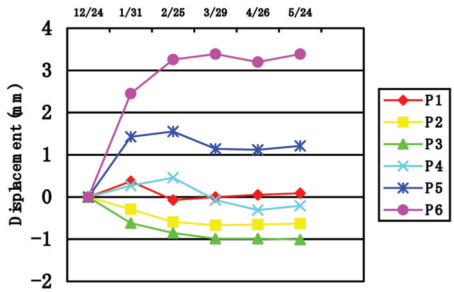

Figure 11. Sheet No 3 line on the 2nd slope.

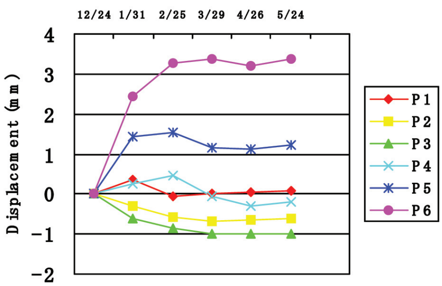

Figure 12. Sheet No 4 line on the 2nd slope.

slope were detected by sheet and covering soil sensors. They were small displacements (several mm).

(2) The maximum displacement on the sheet was approximately 3.39 mm. Measured by P6 sensor on May 24. (Refer to the Figure 12.)

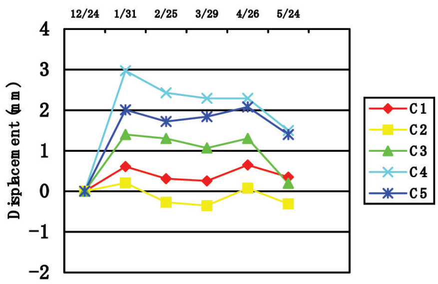

Figure 13. Covering soil No 1 line on the 2nd and 3rd slope.

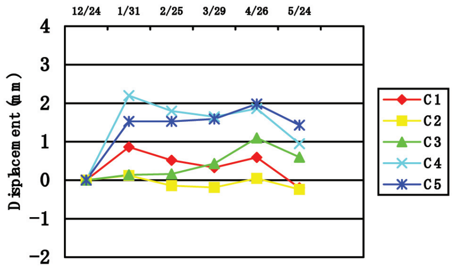

Figure 14. Covering soil No 2 line on the 2nd and 3rd slope.

(3) The maximum displacement on the covering soil was about 3.0 mm. Measured by sensor C4 on January 31. (Refer to the Figure 13.)
(4) Bigger displacements were found in December and January than other months. The amount of snow cover was also the highest during this period. (Amount of snow cover: approximately 100 cm difference) (Refer to the Figure 7.)
(5) Regarding the data of January and the following months, large displacements are not recognized, and data is stable. (The greatest displacement was 2.0 mm for the 5 month period starting from January.)
(6) No slow fell in April and no change in displacement was found.

4.2 *Consideration*

(1) According to measurement results of sheet sensors, displacement was only 3.39 mm (0.19%) maximum. It is a small elongation compared with the capping sheet's maximum elongation percentage (430%). The sheet appears to be sound.
(2) Since the 3rd slope of sheet sensor could not be measured, further examination on how to install and protect optical fibers is required.
(3) The optic fiber sensor is corrosion resistant and be able to provide measurements for several years.

5 SUMMARY

Elongation and distortion of sheets that used to be measured at points could be measured. Furthermore, regarding behavior on the ground with accumulation of snow, influence of snow coverage to behavior of underground and sheet could be figured out by combining measurements.

Therefore, it was confirmed that optic fiber sensing can be used as an effective method for evaluating geomembrane deformation.

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