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Monitoring Seasonal Strain Changes with Distributed Fiber Optic Sensing at a Landslide Site

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Abstract: Strain changes were measured at 6-hour intervals using TW-COTDR (Tunable Wavelength Coherent Optical Time Domain Reflectometry) in a landslide area in Shimane Prefecture, Japan, from March 2018 to March 2019. A total length of 364 m of optical fiber cable was installed in two ways: 1) vertically within a 16-m-deep borehole and 2) horizontally along the ground surface in a trench 30 cm deep dug into the surface layer of the landslide mass. The measurement results revealed that strain changes measured in the borehole near the surface are more sensitive to the presence or absence of precipitation. In contrast, in the deeper section near the slip surface (approximately 8 m deep) and below, the correlation with precipitation was weaker, but the strain gradually increased throughout the year, reaching a maximum increase of about 750 $\mu\varepsilon$. Along the ground surface, some areas showed an unclear relationship with the presence or absence of precipitation, and local differences were observed in the magnitude of strain change.

Keywords: ***Distributed fiber optic Sensing, Strain measurement, Monitoring, Seasonal change.***

Introduction

In recent years, Distributed Fiber Optic Sensing (DFOS) has gained attention as a technique capable of measuring slope deformation. DFOS allows us to detect slope deformation with high spatial resolution (< 10 cm) (Kogure and Okuda, 2018). Although the number of studies with DFOS increases, we still have less knowledge about the configuration of cable installations because many of the studies used vertical boreholes. Understanding the strain distribution on the slope surface is important in detecting the strain anomaly that results in the initiation of landslides. Applicability of DFOS to long-term slope monitoring should also be addressed because DFOS will be used in an early-warning system for slope disasters in the near future. Therefore, this study aims to measure annual strain change along a cable installed both in a borehole and buried in the shallow ground surface to confirm the long-term availability of the DFOS system and to explore the applicability to different cable alignments, following the work by Kogure and Okuda (2018).

Study site

Figure 1 shows the plan and cross-section of the studied landslide in Japan (Kogure and Okuda, 2018). The landslide mass is approximately 30 m wide and 80 m long. The bedrock surrounding the landslide is Neogene Miocene rhyolite pyroclastic rock, which is overlain by mudstone, which is then covered by tuff. The strike and dip of the boundary between the tuff and mudstone is N70°-85°W30°-60°N, making it a dip slope relative to the inclined ground surface.

The subject landslide began activity over 28 years ago, and landslide countermeasure works have already been carried out by the local government. As of the end of the 2016 fiscal year, landslide countermeasures such as collector wells, drainage boreholes, and steel pipe piles had been completed on and around the study slope. Since no deformation has been observed on the slope or its surrounding topography since the completion of the work, the landslide movement is considered to have stopped.

Methodology

Cable installation

At this location, it was possible to use existing investigation boreholes and measurement holes for steel pipe piles that were established during the landslide event. An optical fiber cable was installed within these holes for this study: a 16 m-deep borehole and two steel pipe piles, 7.5 m and 10.5 m deep. The backscattering light analysis device was housed in an observation hut installed outside the landslide mass, and the cable ran from the device to the bottom of the borehole and steel pipe pile holes and back, resulting in a total cable length of 364 m. In areas other than the observation hut, borehole, and steel pipe piles, the cable was placed in a 30 cm deep trench dug along the ground surface and fixed only by backfilling the excavated soil.

Backscattering light analysis

The backscattering light analysis device was the NBX-7020 manufactured by Neubrex Co., Ltd. In this study, Rayleigh backscattering light was analyzed by Tunable Wavelength Coherent Optical Time Domain Reflectometry (TW-COTDR). The spatial resolution for the measurements was set to 10 cm every 6 hours. The spectral shift of the Rayleigh backscattering light during the measurements was converted to a strain change (or a temperature change) with the equations by Kogure and Okuda (2018).

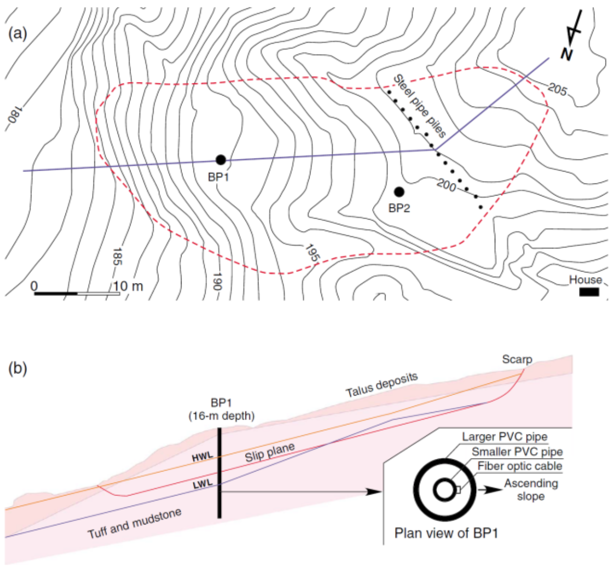

Figure 1, Geological setting of the investigated landslide: (a) plan view and (b) cross section along the blue line in Figure 1a. HWL = high water level; LWL = low water level (Figure 1 in Kogure and Okuda 2018).

Results and discussions

Strain change in the borehole

The results are shown in Figure 2. Positive strain represents tensile strain (downslope extension), and negative strain represents compressive strain (upslope contraction). The maximum strain value at these depths was approximately 750 $\mu\varepsilon$ at 7.57 m. The difference between the maximum and minimum strain change at 1.98 m was also approximately 750 $\mu\varepsilon$, but the strain at the end of the measurement in March 2019 was nearly equal to the strain at the beginning of the measurement. Therefore, it was found that while the near-surface layer frequently deforms upslope or downslope depending on the presence or absence of rainfall, it appears to exhibit virtually no net deformation over the course of a year.

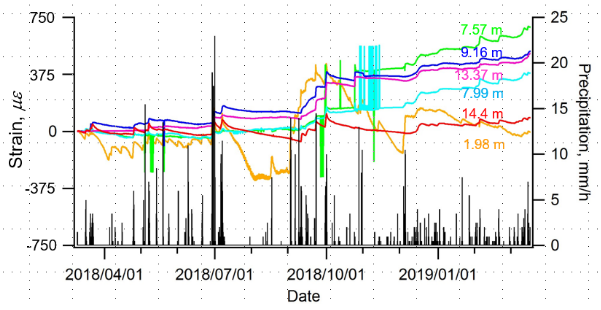

Figure 2, The relationship between strain change and precipitation at specific depths in the borehole.

Strain change along the ground surface

Figure 3 shows the spectral shift measured by the cable buried at a depth of 30 cm and the air temperature changes around the landslide site. The spectral shift measured at 30 cm deep is due to changes in ground temperature. Figure 3 shows the spectral shift at several selected locations along the cable. The spectral shift and air temperature change are harmonic at many locations, indicating that the cable captured ground temperature changes reflecting air temperature changes. However, locations like 268.3 m and 283.19 m showed a spectral shift trend that differs from the air temperature trend. This change in spectral shift is considered to be caused by a change in strain. However, since the characteristics of the change at the two locations differ, the cause of the strain change is also thought to differ from one location to another. Therefore, investigating the characteristics of these spectral shifts is expected to allow for a detailed discussion of the deformation process that has conventionally been categorized generally as slope deformation.

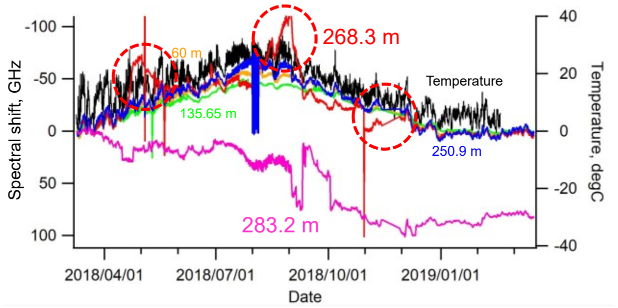

Figure 3, Annual spectral change measured by the cable buried at 30 cm deep at some locations along the slope surface, and temperature change.

Conclusion

Through the annual strain measurements with a cable installed in a borehole and buried along the slope surface in a landslide site, this study concludes that:

- The near-surface layer frequently deforms upslope or downslope, depending on the presence or absence of rainfall; it appears to exhibit virtually no net deformation over the course of a year
- The cable buried at a depth of 30 cm along the slope surface captured ground temperature changes reflecting air temperature changes, although some locations show anomalies.

Acknowledgement

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References

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