APPLICATION OF NEW LANDSLIDE MONITORING TECHNIQUE USING OPTICAL FIBER SENSOR AT TAKISAKA LANDSLIDE, JAPAN

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Abstract: A joint research project on new techniques of landslide monitoring is being carried out between the Public Works Research Institute in Japan and Institute di Recerca per la Protezione Idrogeologica, Consiglio Nazionale delle Ricerche in Italy. As one of the new techniques, an optical fiber sensing system was installed in the Takisaka Landslide, which was selected as a test site in Japan.

The Takisaka Landslide is located in Fukushima Prefecture in eastern Japan, at north latitude 37° 38 – 39' and east longitude 139° 38 – 39'. It is 2,100 m long (south-north direction) and 1,300 m wide (east-west direction). The volume of the moving soil mass is 4.8×10^7 m^3, and the maximum depth of the moving soil mass is about 140 m. The optical fiber sensing system has 18 sensors and was installed at the end of the Takisaka Landslide facing the Aga River.

Of the various methods of optical fiber sensing, the OTDR (Optical Time Domain Reflectometry) method was selected at this site. The sensor is a mechanical device in which part of an optical fiber bends in response to landslide displacement. Several sensors are installed along the optical fiber measurement line, and the OTDR detector detects the transmission loss of the light caused by bending of the optical fiber, at the locations of several sensors simultaneously. The landslide displacement is calculated from the change of transmission loss. Measurement was started manually in December 2004, but is now controlled automatically by a computer. As a result of measurement, tensile displacement was detected; this is similar to the tensile displacement of an adjacent extensometer, but an error of several mm is also observed. Therefore, ways of improving the measurement precision are now being studied.

INTRODUCTION

Figure 1. Logo

Electrical sensors are commonly used for monitoring devices of landslides such as extensometers, although they are easily damaged by lightning and electromagnetic noise. In contrast, optical fibers are free from such flaws, and devices using optical fibers have been developed in recent years. The sensors basically work by detecting changes in transmission light due to bending or warping of the optical fiber when the ground moves.

In recent years, the Public Works Research Institute (PWRI) in Japan has been developing a sensor to detect landslide displacement using the OTDR method. The applicability of the developed sensor was tested in the Takisaka Landslide area, as reported in this paper. This study was conducted under the Joint Laboratory on "Research, Training and Documentation on

Hydro-geological Risks" project, which is an international joint research program between Japan and Italy, as shown by the logo in Figure 1.

OUTLINE OF TAKISAKA LANDSLIDE

The Takisaka Landslide is located in Fukushima Prefecture in eastern Japan, at north latitude 37° 38 – 39' and east longitude 139° 38 – 39'. It is 2,100 m long (south-north direction) and 1,300 m wide (east-west direction). The volume of the moving soil mass is 4.8×10^7 m^3, and the maximum depth is about 140 m (Figure 2). This landslide has been under the direct control of the Ministry of Construction (presently the Ministry of Land, Infrastructure, and Transport) in view of the magnitude of the impact on the Aga River system due to its location and behavior. Detailed researches and measures have been conducted by the Ministry since 1996.

The geology is composed of Tertiary granite, Arkose sandstone, tuff, mudstone, fluvial sediment, and colluvium sediment in order from the lowest layer. The slide face is near the boundary between Arkose sandstone and tuff. The landslide movement is thought to be triggered by the inflow of groundwater by snowmelt as well as bank erosion during flooding of the Aga River. The landslide is divided into northern and southern blocks on a large scale, and each block is subdivided into several smaller blocks (Figure 3). The northern block is moving from north to south and the southern block is moving from east to west.

The sites for the test measurement were the neighboring Numata and Tokiwa blocks at the lower part of the southern block, facing the Aga River. The Numata block, which is 250 m long (east-west direction) and 600 m wide (south-north direction), is moving from east to west. The Tokiwa block, which lies on the northwest side of the Numata block, is 200 m long and 50 m wide, and moving from northeast to southwest. Monitoring and investigation of both blocks have continuously been carried out by the Agano River Management Office.

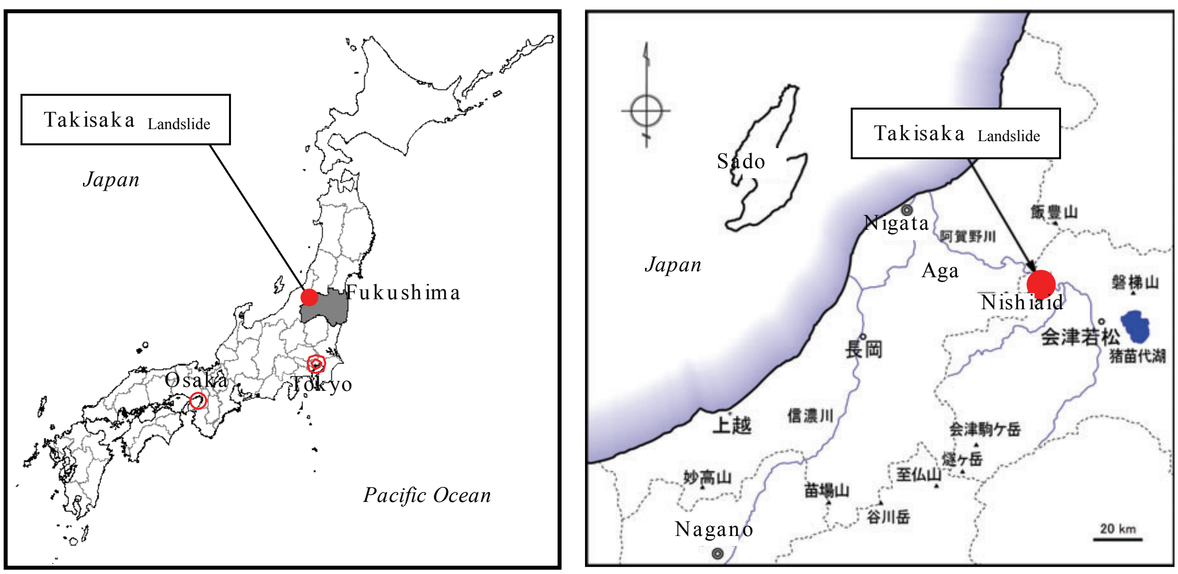

Figure 2. Location of Takisaka Landslide

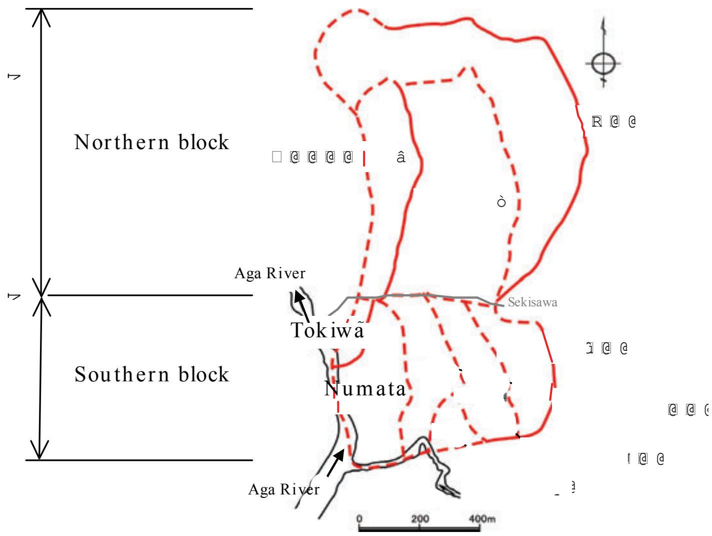

Figure 3. Blocks of Takisaka Landslide

OUTLINE OF THE LANDSLIDE DISPLACEMENT DETECTION SENSORS USING OPTICAL FIBER AND THE OTDR METHOD

The OTDR (Optical Time Domain Reflectometry) method measures the amount of loss of traveling light and identifies where the loss occurs in the optical fiber. The mechanism works by detecting the amount of backscattering of light and analyzing the time domain of reflected light when the optical fiber is bent due to some cause. Usually, OTDR is used for the management of optical fiber networks as well as the production and inspection of optical fiber. The cost is lower than other methods such as BOTDR, FBG and SOFO.

The sensor developed in this study uses OTDR to detect and monitor landslide displacement which causes bending of the optical fiber (Figure 4).

The sensors are installed in a line similarly to conventional extensometers, thus enabling measurement of the amount of displacement for the intervals between them (Figure 5).

The cost of the sensor is the same as a conventional extensometer, because OTDR monitors and optical fiber cables are commonly available. Furthermore, the sensor can measure landslide displacement, as five sensors can be attached to one optical fiber cable. The error of this sensor is estimated to be 1–2 mm, so the minimum limit of detection is a displacement of 1 mm.

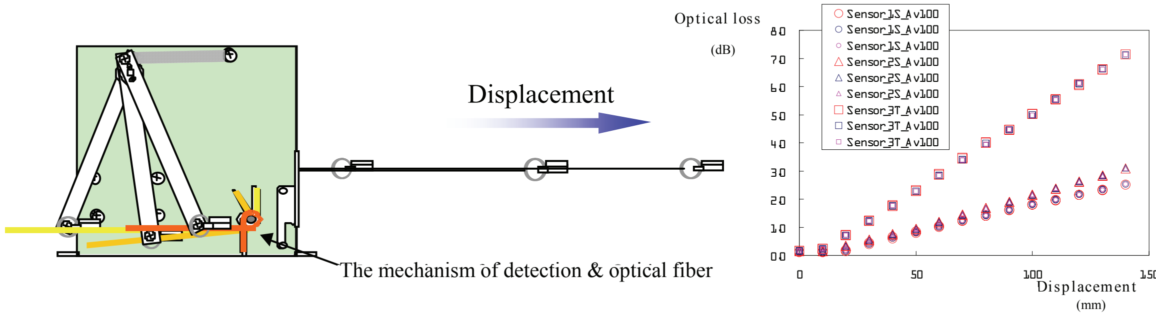

Figure 4. Landslide displacement detection sensor using optical fiber

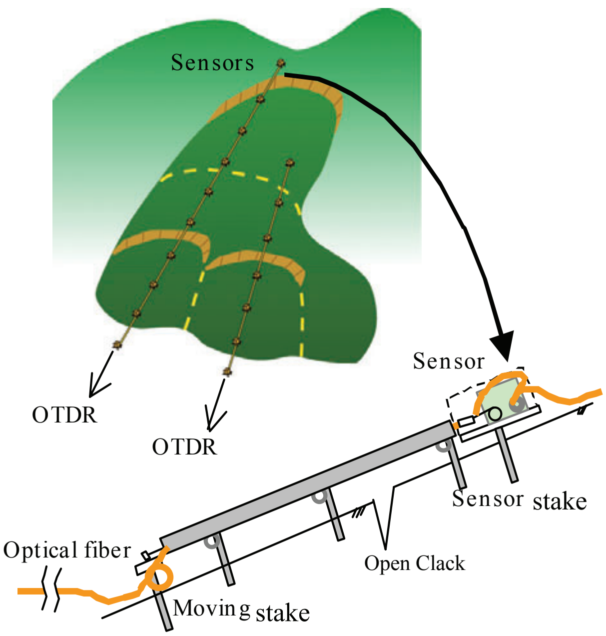

Figure 5. Example of install of Optical fiber sensor

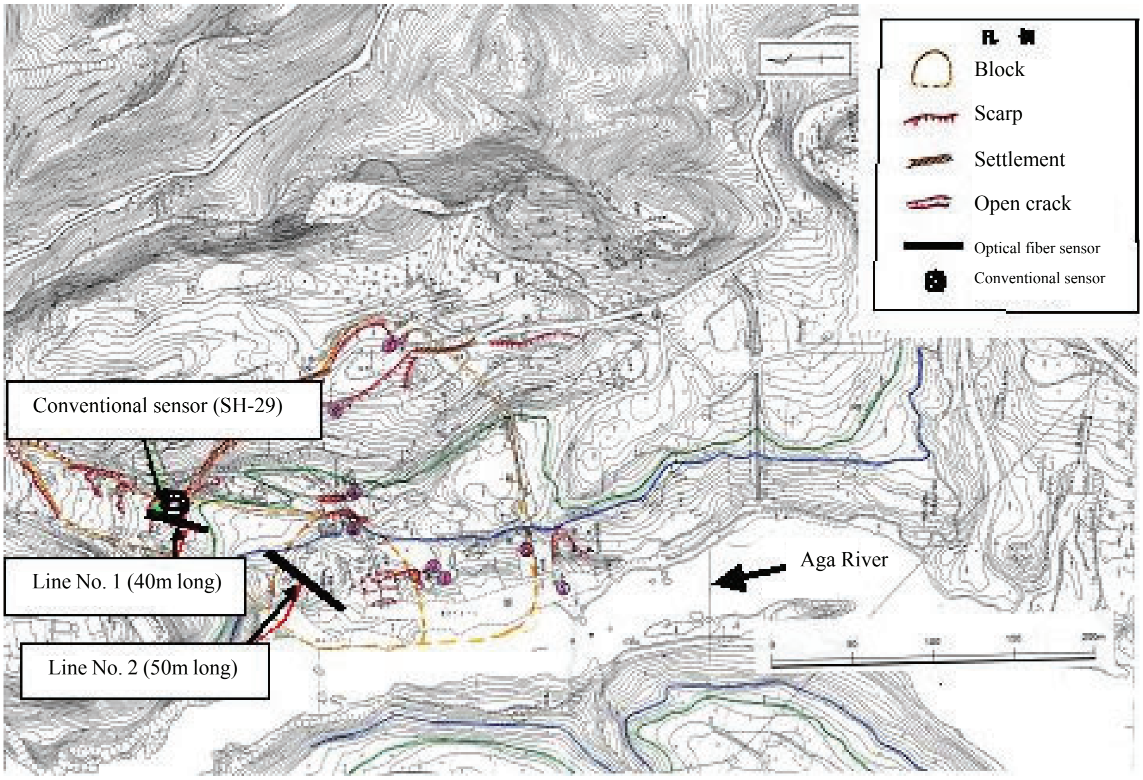

Figure 6. Location of optical fiber sensor in Takisaka Landslide

INSTALLATION OF SENSORS AND MONITORING SYSTEM

Two lines with 18 sensors in total were set up at the test measurement site (Figure 6). Figure 7 shows the monitoring system.

Measuring line No. 1 was 40 m long with 8 sensors attached at 5-meter intervals. A conventional sensor was also installed along part of line No. 1 for comparison. The second line, No. 2, was 50 m long and installed in the direction of landslide movement, with 10 sensors attached at 5-meter intervals. The diameter of the optical fiber cables used in the sensors was 2.8 mm, which is commonly used in the field. The diameter of the optical fiber cables between the sensors, which also acted as invar wires, was also 2.8 mm. Concerning the relationship between the range of the amount of transmission loss available for monitoring, and the amount of loss produced by each sensor, each cable line was composed of two lines, i.e., four subsystems were established in the monitoring system (Figure 7).

Measurement by OTDR monitoring was initially carried out manually at the site on December 16 and 25, 2004. Automatic hourly monitoring then started on February 3, by installing a computer to control the OTDR and a channel selector for selecting the four subsystems in turn in the observing station.

RESULTS

Figure 8 shows the measurement results of lines No. 1 and No. 2 and the conventional sensor (SH-29), together with the data of rainfall and snowfall during the monitoring period. The tension displacement of SH-29 recorded active behavior of the landslide during the snowmelt season (10 mm from February to the beginning of May) and during the rainy season (13 mm from July to September). On the other hand, each sensor of line No. 1 recorded continuous tension displacement, although the values fluctuated at each sensor and varied among them (from 5 mm to 20 mm in total). In particular, sensors No. 1-1-4 and No. 1-2-1 recorded higher displacement than the others. The displacement trends monitored by these sensors did not always agree. In addition, many data were missing, the cause of which was assumed to be the computer and/or OTDR monitor. This computer and/or OTDR trouble was identified the interruption of power supply in the system check. After that, an uninterruptible power supply was added to the monitoring system.

Each sensor of line No. 2 also recorded continuous tension displacement, and the values fluctuated like those of line No. 1. The displacements monitored by sensors No. 2-1-1, 2-1-2, 2-1-5 and 2-2-4 were relatively large compared to the others (>20 mm after December 2004). On the other hand, the compression displacement at No. 2-1-3 and 2-1-4 was 5–10 mm. The displacement accelerated at all the sensors after April.

The displacement recorded by the conventional sensor and sensors No. 1-2-1 and 1-2-2, which were lined up in parallel, almost coincided (Figure 9). According to this chart, the displacement trend of each sensor matched between the existing conventional sensor and sensors No. 1-2-1 and 1-2-2.

These results indicated that optical fiber and the OTDR method are practical for monitoring landslide displacement in the field. The amounts of displacement monitored by the sensors are plotted in Figure 7, showing the two-dimensional behavior of the landslide. This result also suggests that the behavior of landslides can be understood more accurately and landslide blocks can be identified by installing several sensors in areas thought to be block boundaries.

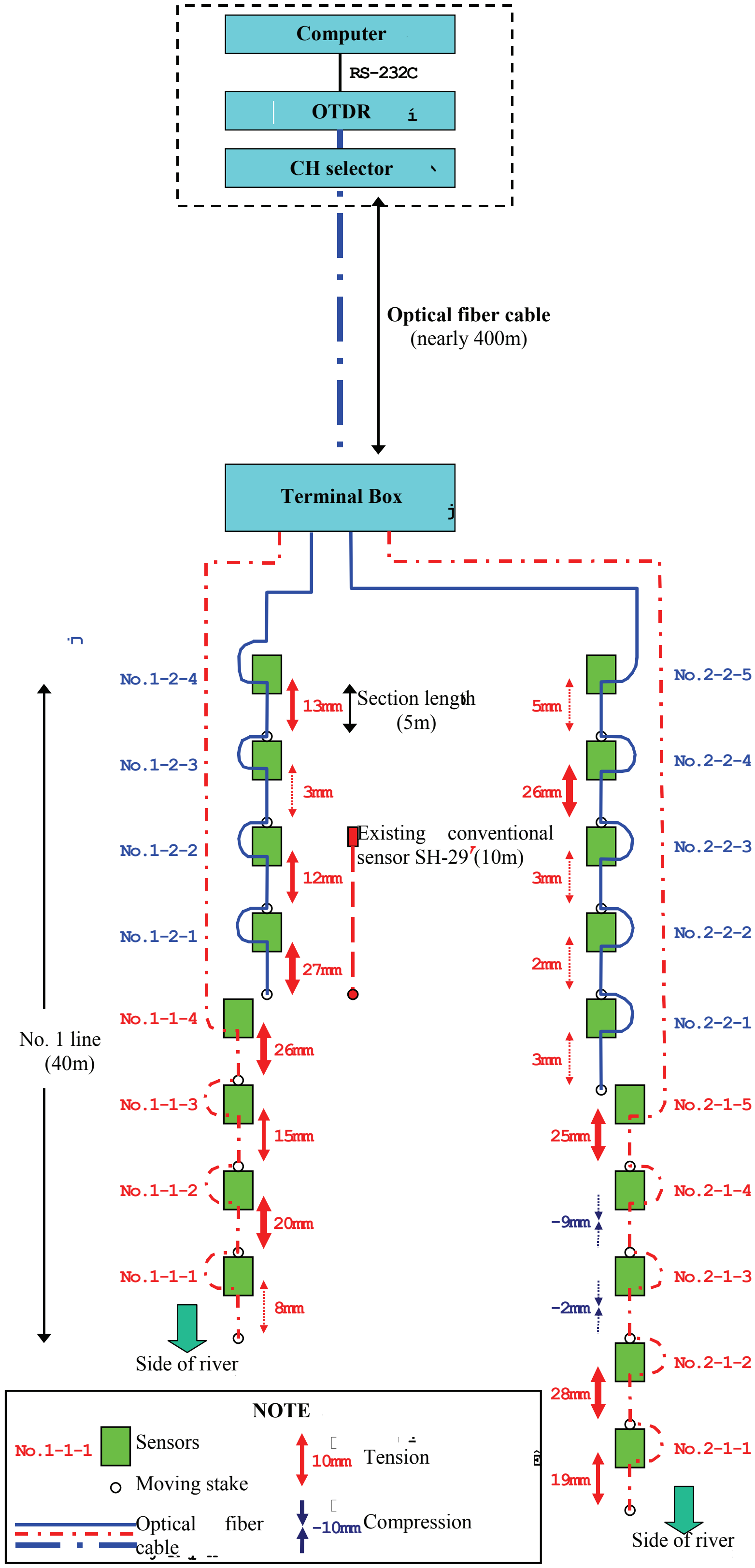

Figure 7. Outline of monitoring system

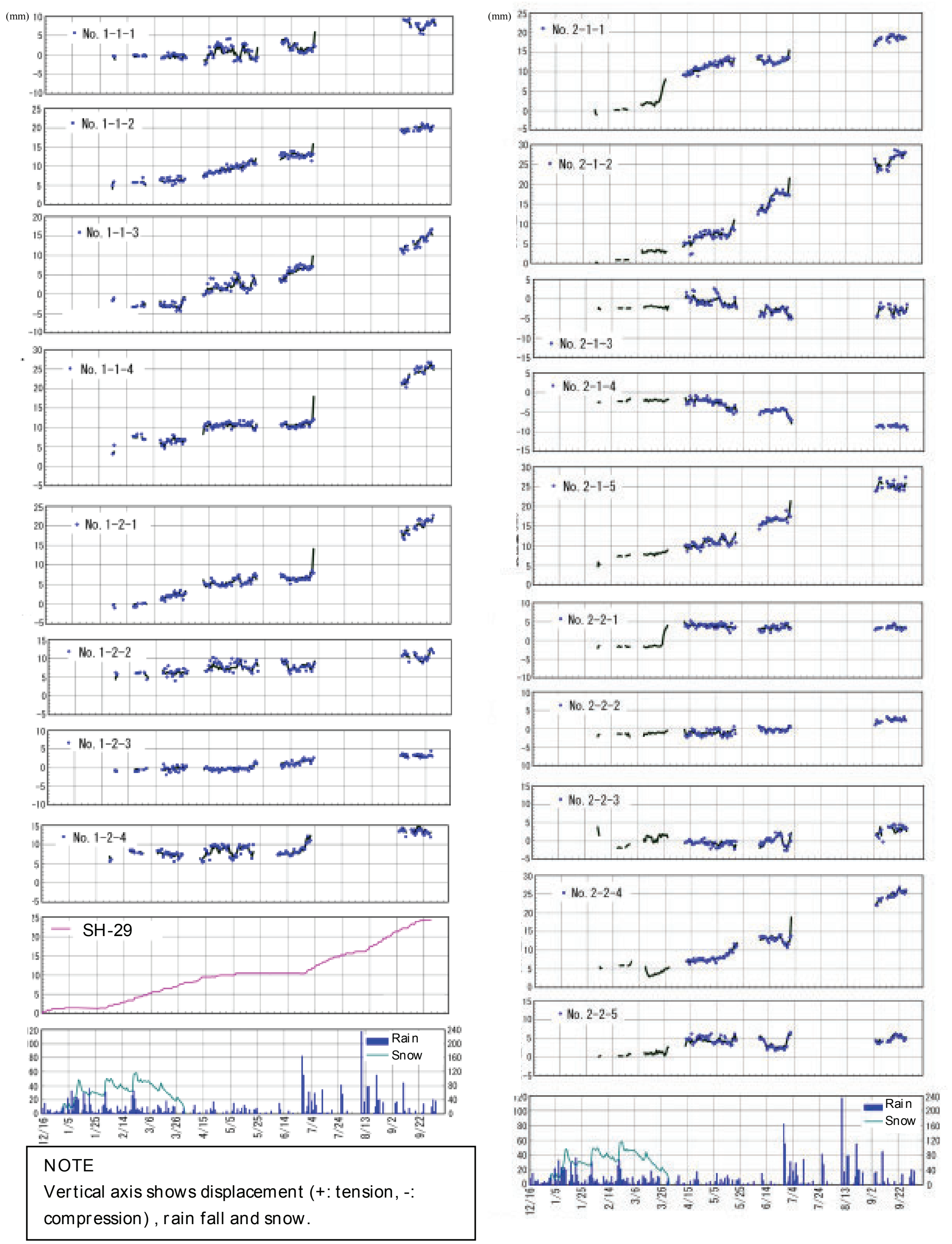

Figure 8. Results of measurement

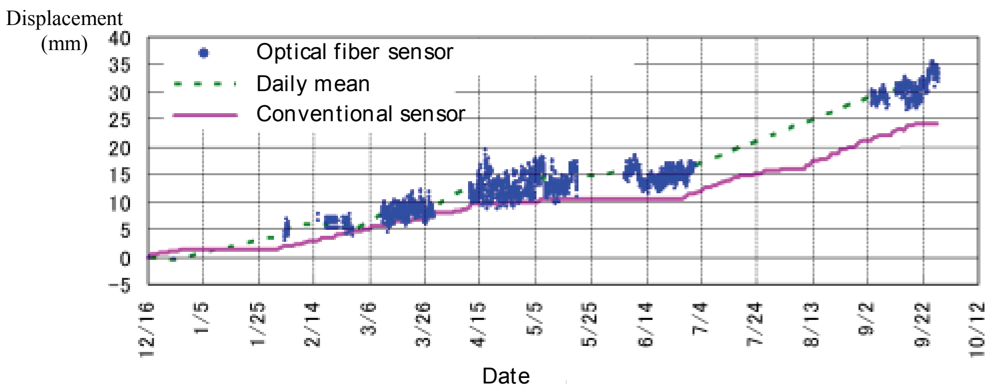

Figure 9. Comparison between optical fiber sensor and conventional sensor

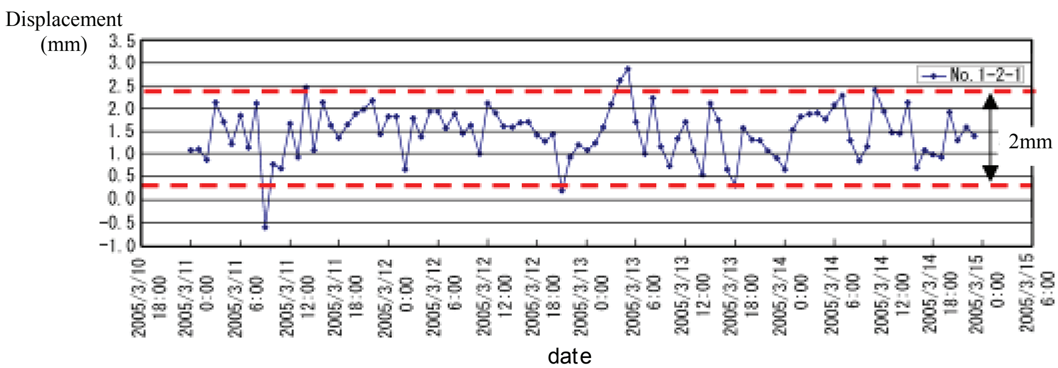

Figure 10. Measurement result of No. 1-2-1 (Expanded scale)

PROBLEMS AND SOLUTIONS

In order to make the sensor reported in this study more practical, the fluctuations of the monitoring values induced by optical fiber must be reduced first. For example, a part of the measurement result at No. 1-2-1 from March 10 to 15 shows fluctuations of nearly 2 mm/day (Figure 10). Furthermore, there was a difference of several millimeters in the daily mean of displacement between the sensor and the conventional one. Hence, the errors of the measurement were estimated at several mm to 10 mm in total.

The causes of the errors and ways of overcoming them are currently being examined. One possible cause is hysteresis occurring in the relation between the amount of loss of traveling light and the displacement of the ground observed in the laboratory. This hysteresis is caused by the coating of the optical fiber cable. Following the result of this experiment, the diameter of the optical fiber cable in the sensor was changed from 2.8 mm to 0.25 mm in order to reduce errors. A monitoring test using the improved sensors was started at the Takisaka Landslide in December 2005.

Another improvement to the monitoring system was to replace the optical fiber cables with conventional invar wires for setting tension lines between moving stakes and sensors. Previously, optical fiber cables were used instead of invar wires because they do not warp even in the long term. However, the sensors were hard to install in the field, as special attention was needed to stretch the cables taut.

CONCLUSION

The authors have developed a sensor for detecting landslide displacement using optical fiber. Based on the OTDR method, the sensor is more economical and easier to use than those employing other methods. The validity of the sensor was tested at the Takisaka Landslide area under an international joint research program between Italy and Japan. While the potential for future use was clearly confirmed, there are some problems to be resolved, e.g. the monitoring errors caused by optical fiber cables. Currently, the sensor is being improved through a series of experiments.

Although the international joint research program between Italy and Japan finished in 2005, the Public Works Research Institute is still pursuing this research in collaboration with five private companies.

REFERENCES

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