Development of a Road Disaster Monitoring System Using Optical Fiber Sensing Technology

Kazuhiko Fujihashi, Hideki Uehara†, Masaru Okutsu, and Koji Komatsu

Abstract

NTT Access Network Service Systems Laboratories has developed a system for monitoring road disasters by using optical fiber sensing technology. This technology allows linear measurement over long distances, which is advantageous when the length to manage is long and risk locations are difficult to determine in advance. This article describes various sensors developed for monitoring road disasters and software for controlling the measuring devices, processing data, and performing other tasks.

1. What is optical fiber sensing technology?

Optical fiber sensing technology is for measuring strain, temperature, optical loss, and other phenomena by inputting a laser beam into an optical fiber and analyzing the characteristics of the reflected or transmitted light. It covers several methods. NTT has developed the Brillouin optical time domain reflectometer (BOTDR) and currently uses it [1], [2]. This method allows continuous measurement of the strain along an optical fiber based on the characteristic that the frequency distribution of the Brillouin scattered light, which is one type of backward scattered light generated when an optical pulse is input into an optical fiber, shifts in proportion to the axial strain of the optical fiber (**Fig. 1**). On the other hand, the OTDR

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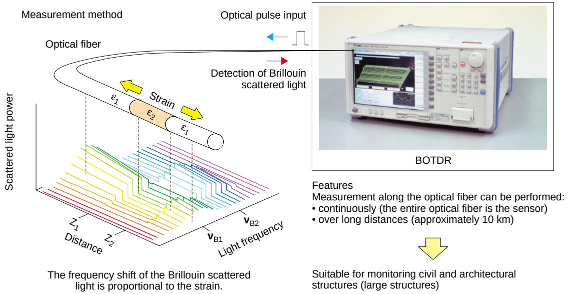

Fig. 1. Overview of system using the BOTDR method.

system measures the optical power of the Rayleigh scattered light, making it possible to measure loss in the longitudinal direction of the optical fiber, determine connection point positions, and calculate the optical fiber length, etc.

2. Development background and current themes

Japan is a mountainous country with a harsh natural environment that includes typhoons, snowfall, and earthquakes, so it regularly experiences various disasters. Roads can be affected and disasters can have a serious impact on people's lives and the economy. Countermeasures have been implemented in some areas, but the lengths to manage are long and it is difficult to determine the locations of risks, so these measures cannot be considered complete. Remote monitoring using sensors and other devices is performed in some places, but most management relies on human inspectors, so this is insufficient in terms of safety and speed of response. Furthermore, sensor and other monitoring data is intermittent, maintenance and renewal cycles are short, and running costs are a burden. To resolve these issues, NTT started to develop a system using optical fiber sensing technology, which allows remote and linear monitoring over long distances and which has superior weather and environmental resistance. This technology is thought to be suitable for monitoring road disasters because the Ministry of Land, Infrastructure and Transport and other road managers are currently installing information boxes alongside roads and are laying optical fibers for road management. If this optical fiber network is used as the basic infrastructure, the optical fibers can be branched for sensors at the necessary locations, which should be advantageous for constructing a system covering a wide area. This development project was undertaken by NTT Access Network Service Systems Laboratories (AS Labs).

3. System overview

The road disaster monitoring system includes four functions for monitoring the collapse of sloping surface layers, disasters involving snow and ice, bridges, and tunnels (**Fig. 2**). Various sensors were developed; installation methods, workability, and durability were investigated; and software for controlling measuring devices, processing data, and performing other tasks was developed, as described below.

3.1 Monitoring the collapse of a sloping surface layer

Sloping surface layers can collapse in various different ways depending on the topography, soil quality, vegetation, and other conditions. Locations where collapse might occur are difficult to determine. Optical fiber sensing technology should be able to cover a

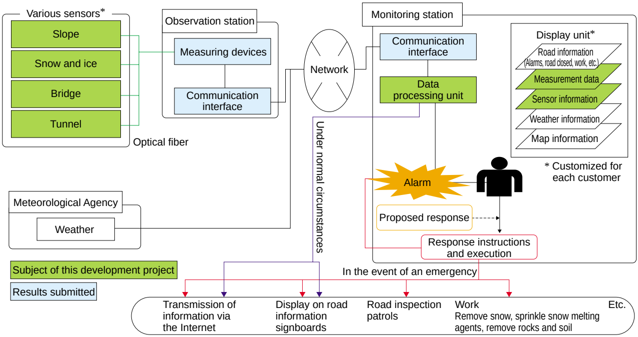

Fig. 2. Road disaster monitoring system.

wide area and detect even small-scale collapses, letting road managers quickly understand the scope of disasters. Prior to this development project, AS Labs was already participating in the "Joint Research on Monitoring Roadside Slope Collapse by Using Optical Fiber Sensors" with more than ten other private sector companies led by the Incorporated Administrative Agency Public Works Research Institute (PWRI). In that joint research, AS Labs worked with NTT InfraNet Co., Ltd. and Airec Engineering Corporation to develop optical fiber slope displacement sensors, optical fiber underground displacement sensors, and optical fiber water level sensors, and carried out field measurements on slopes alongside national road No. 19 on the outskirts of Nagano City (**Fig. 3**). During this period there were no surface layer collapses due to rainfall or other factors, but the workability and durability were confirmed. In addition, on-site tests were conducted using forcible displacement, and the results confirmed excellent measurement characteristics.

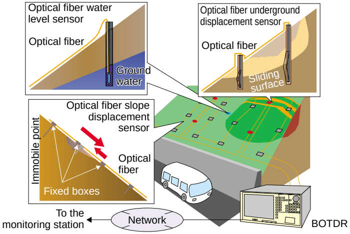

Fig. 3. Monitoring the collapse of a sloping surface layer.

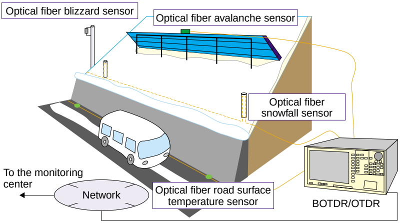

Fig. 4. Monitoring disasters involving snow and ice.

3.2 Monitoring disasters involving snow and ice

Approximately 60% of Japan experiences snow and cold weather, so winter road management is an important issue. Road upkeep management costs and environmental loads must be reduced while at the same time maintaining safety by appropriately removing snow or melting it (by sprinkling snow melting agents or heating the road). BOTDR snowfall and road surface temperature sensors and OTDR avalanche and blizzard sensors were developed to detect avalanches and freezing road surfaces and report them to managers (**Fig. 4**). To confirm the functions of these newly developed sensors, field tests were conducted in cooperation with the Hokkaido Otaru Civil Works Field Office from December 2002 to May 2003 alongside prefecture road No. 998 (Shakotan peninsula). The results confirmed that all sensors satisfied the target performance for the most part.

3.3 Monitoring bridges

Bridges are focal points for transport not only under ordinary circumstances, but also in the event of disasters. Managing their upkeep, ensuring safety, and improving earthquake resistance are important themes for road managers. Bridge monitoring consists of monitoring the deterioration of the upper structure and monitoring bridge deformation (girder movement, bridge pier tilting, etc.) after an earthquake. However, considering the accuracy required for each of these tasks and the accuracy of current measuring devices, deformation was selected as the development subject (**Fig. 5**). Displacement sensors were developed to measure and detect the magnitude of bridge girder movement to judge bridge soundness and the feasibility of using them to transport goods immediately after earthquakes. Specifically, we fabricated prototype sensors that quantitatively measure displacement using the BOTDR method and simultaneously use the OTDR method to judge whether management reference values have been exceeded. Their functions were confirmed through indoor tests and heat cycle tests, etc.

3.4 Monitoring tunnels

Recently, incidents of concrete peeling or dropping from railway tunnels and other locations have been reported. The structure monitoring function uses optical fiber sensing technology (BOTDR method) to monitor these types of structural changes to tunnels owned by NTT Group companies. This function was added to the Tunnel Management System from fiscal year 2001. In NTT tunnels, sensor cables are fixed to the inner surface of the tunnel in the axial direction at 2-m intervals, and they mainly monitor the occurrence of cracking. This technology has also been applied to road tunnels. In addition, prototype water-level-type subsidence sensors, which use optical fiber sensors to monitor tunnel sloping, were fabricated and their performance was confirmed through indoor tests (**Fig. 6**).

3.5 Road disaster monitoring software

Software was developed to control the various measuring devices described above and to gather, analyze, and display the data from the various sensors (**Fig. 7**). The overall monitoring system consists of the various sensors, optical switches, the BOTDR and OTDR, a control PC, a monitor PC, and this software. The main functions of this software are listed in **Table 1**.

4. Conclusion

NTT Access Network Service Systems Laboratories has developed a road disaster monitoring system using optical fiber sensing technology. This system was designed mainly for roads, but it can also be applied to other civil structures. We expect NTT group companies to continue developing it for various other fields.

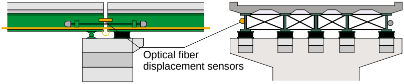

Fig. 5. Monitoring bridges.

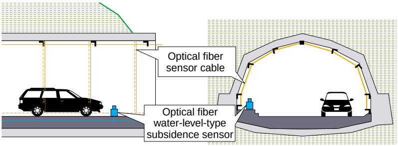

Fig. 6. Monitoring tunnels.

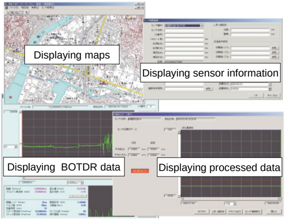

Fig. 7. Example screen-shot of road disaster monitoring system.

References

[1] H. Naruse, “Application of Optical Fiber Strain Gauge Technology to Civil Structures,” NTT Technical Journal, Vol. 11, No. 5, pp. 69-71 1999 (in Japanese).

[2] T. Kurashima, “Non-destructive Measurement of Optical Fiber Strain and Loss from One End,” NTT Technical Journal, Vol. 9, No. 6, pp. 87-89, 1997 (in Japanese).

Table 1. Outline of road disaster monitoring software functions.

Function	Description
Controlling measuring devices	Setting measurement conditions for each measuring device (BOTDR, OTDR) and setting the timetable for periodic measurement
Displaying measurement data	Displaying measurement data (strain, loss), loading and displaying stored data, and converting displayed data to .txt format
Registering and displaying sensor information	Registering and displaying various information regarding individual sensors including sensor type, sensor name, number of channels, route length, sensor section, compensation section, management reference values, and calibration coefficients.
Displaying maps	Displaying maps of the monitored area (zoom in/out, move up/down/left/right) and displaying registered sensors on the map
Processing and displaying data	Processing physical quantities (displacement, temperature, etc.) or making various judgments based on measured data and displaying them as time series.
Giving alarms	Displaying on the map in conspicuous colors any locations where the management reference values have been exceeded and sounding an alarm. “Caution” and “Warning” histories are stored.

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