Development of Borehole Multiple Deformation Sensor System

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ABSTRACT

The multiple deformation sensor system for small diameter borehole is required for the long term monitoring of deformation of rock mass of high-level radioactive waste disposal site. The conventional electric monitoring systems are difficult to apply for a long term monitoring in many cases because of the sensor failure caused by lowering of insulation or other problems and only available for the large borehole and for 6 or less measurement sections. The Borehole Multiple Deformation Sensor System was developed based on the **FBG** (Fiber Bragg Grating) sensor technology that is expected to have longer life time than electric systems. The developed system can be set in a **66 mm diameter borehole** and available for **9 or more measurement** sections that can be hardly achieved by electric systems. The sensor system is applying for the monitoring of ground deformation in **the Horonobe Underground Research Laboratory in Japan.**

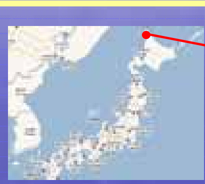
1.INTRODUCTION

Many precise computer simulations are being done for the ground deformation in the study for the geological disposal facility of high-level radioactive waste. But there are few appropriate verification means for these simulation results in the field for long term, because the conventional electric monitoring systems show rather short life time, and require a large size borehole that disturbing the ground conditions and allow only limited number of measurement sections of 6 or less that is not enough for verification for the precise simulation results. The optical fiber sensor system is a potential candidate for these kinds of long term monitoring for precise verification.

The Borehole Multiple Deformation Sensor System was developed based on the FBG sensor technology. The sensor is designed to be put inside the small diameter borehole of 66 mm instead of the large borehole of 86 mm or 100 mm in diameter for conventional systems. The sensor system is also designed to be available for 9 measurement sections. These improvements can be hardly achieved by conventional electric systems due to the difficulty of wiring thick electric cable in limited space.

One of the weak points for applying FBG sensors for a long term monitoring is its temperature dependency. **The self compensation mechanism** is examined and fundamental laboratory test was carried out. Based on the result temperature independent (i.e. self temperature compensate) deformation sensor units are developed.

The developed system was set in a horizontal borehole drilled from the tunnel wall of Horonobe Underground Research Laboratory in Japan. The successful monitoring result in early stage is shown in this paper.



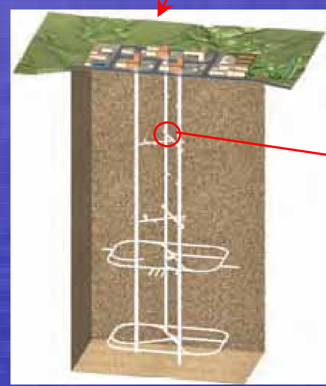
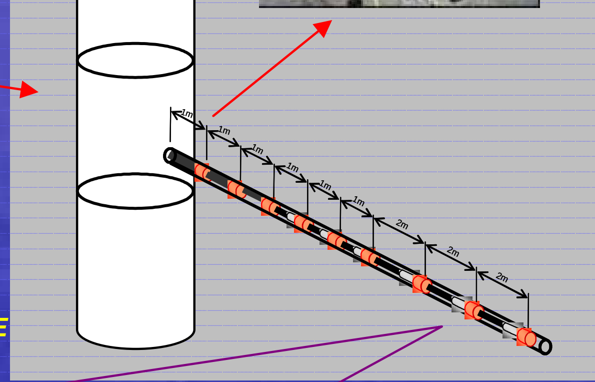
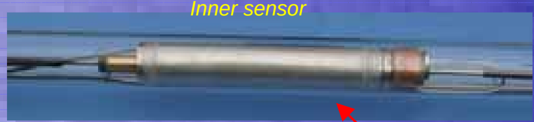


Fig.1. Schematic figure of HOROBE

Outer sensor



Inner sensor



1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 2000 | 2000 | 2000

(Unit:cm) Total:1200cm

Outer sensor (range: 50mm) | Inner sensor (range: 7mm) | Inner sensor (range: 1mm)

Tunnel wall

Photo. 1. Structure of Borehole Multiple Deformation Sensor System

2. BOREHOLE MULTIPLE DEFORMATION SENSOR SYSTEM

2.1 Structure

The structure of Borehole Multiple Deformation Sensor System is shown in Photo. 1. The ground deformation would be the biggest at the surface of the tunnel wall and becomes gradually small in the inner part. The maximum measurement range is 50 mm/pitch (pitch means between an anchor and another anchor) at the shallow part within 3 m from the face of the tunnel and the minimum range is 1 mm/pitch at the bottom of the borehole 12 m away from the face of the tunnel.

2.2 Inner sensor

2.2.1Examination for inner sensor units

Inner part units have two kinds of measurement range; 7 mm and 1 mm. These two sensors are similar structure except for size of sensor unit.

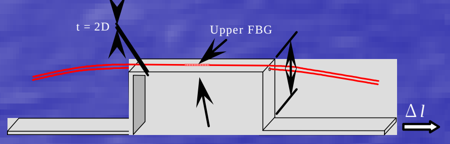


Fig. 2. The schematic figure of Inner sensor unit

$$\varepsilon = \frac{\sigma}{E} = \frac{3\,\Delta\, lD}{2\,r^{2}} \quad (1)$$

ε : Strain of FBG
σ: Stress to FBG
E: Elastic modulus
Δl, D ,r : see Fig. 2

The schematic figure of deep sensor unit is shown in Fig. 2. As the displacement occurred, the upper plate of sensor unit may bend and compression and extension strain are generated upper side and lower side of the plate respectively. The behavior of FBG is shown in Fig.3.The relation between the displacement and these strains is shown in equation (1).

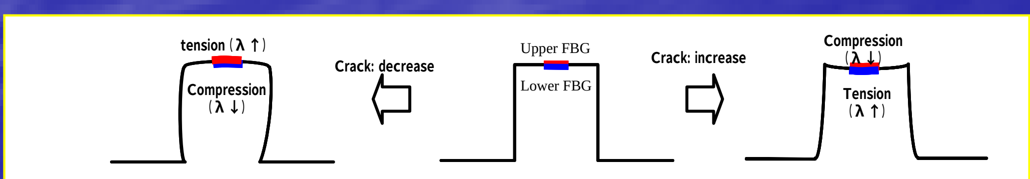
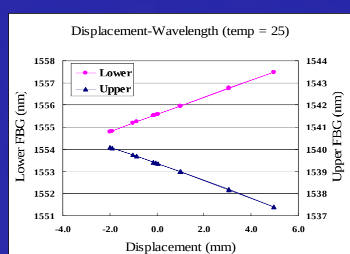


Fig. 3. The behavior of FBG

2.2.2Laboratory test results for inner sensor units

Laboratory test was carried out for the prototype of inner sensor. Fig.4 (a) shows the relation between the displacement and wavelengths of two FBGs; upper side and lower side. Both FBGs react symmetrically and the wavelength difference is in direct proportion to the displacement. Fig.4 (b) shows the behavior for the temperature change of two FBGs. The graph is parallel that means the wavelengths of two FBGs increase same amount. This result shows that temperature change does not affect the wavelengths difference of two FBGs; i.e. no need to temperature compensation. Thus this inner sensor unit has self temperature compensation function.



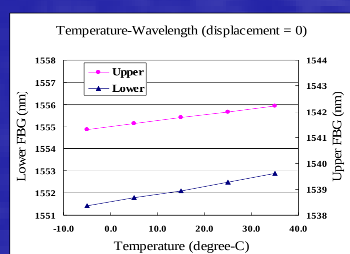


Fig. 4. The test results for inner sensor unit

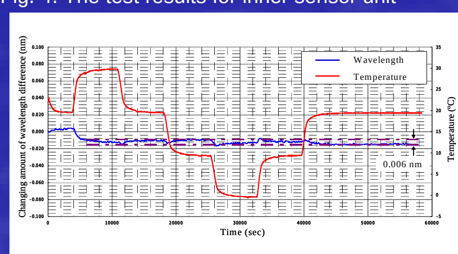


Fig. 5. Self compensation performance of inner sensor unit

2.2.3 Design and development of inner sensor

Fig.6 shows the design and the photo of an inner sensor. Two units are used symmetrically for canceling the imbalanced load, though a pair of FBGs is embedded to one unit only. The outer diameter of unit is 60.5 mm and can be set in the borehole of 66 mm in diameter.

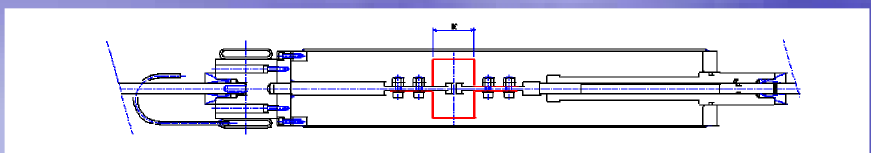


Fig. 6. The schematic figure of Inner sensor unit

2.3 Outer sensor

The basic design of outer sensor is similar to conventional sensors. The displacement is transmitted to the surface by connecting rod and measured by the displacement sensor. Photo.2. shows the main part of outer sensors.

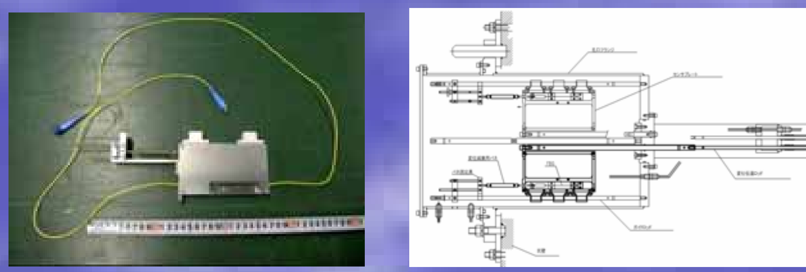


Photo. 2. The main part of outer sensor

3.THE RESULTS OF FIELD MEASUREMENT

3.1 Installation of the system

The developed system was set in a horizontal borehole drilled 12.7m from the tunnel wall 70m under the ground surface of Horonobe Underground Research Laboratory in Japan as shown in Fig.7. Three outer sensors and six inner sensors were successfully embedded in a 66mm diameter borehole and the monitoring was carried out.

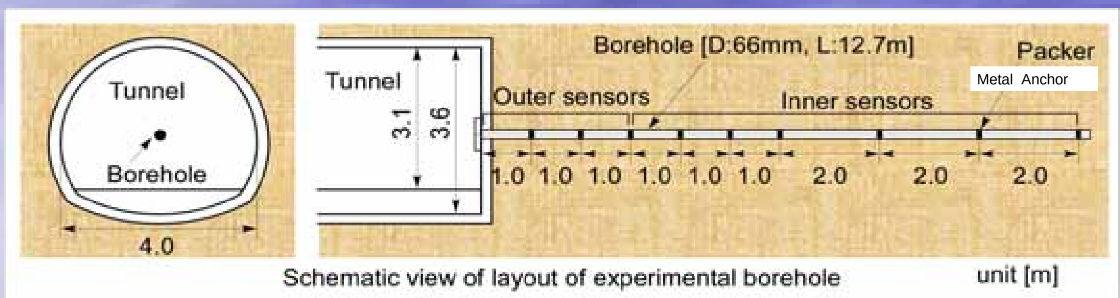


Fig. 7. The schematic figure of Inner sensor unit

Photo. 3. The core of HORONOBE borehole

3.2 Monitoring result

Fig.8 shows the variation with time of the cumulative deformation in the early stage of monitoring in the case that the anchor at 12m depth is fixed point. Plus means tensile and minus means compression in displacement are summarized in Fig.8. The compressive deformation had been occurred because of the effect of the rock bolts from the tunnel wall to 3m depth. And creep deformation of rock mass had been occurred from the tunnel wall to 12m depth. Fig.8 shows only 7 weeks of the beginning stage, and the monitoring will be continued coming several years.

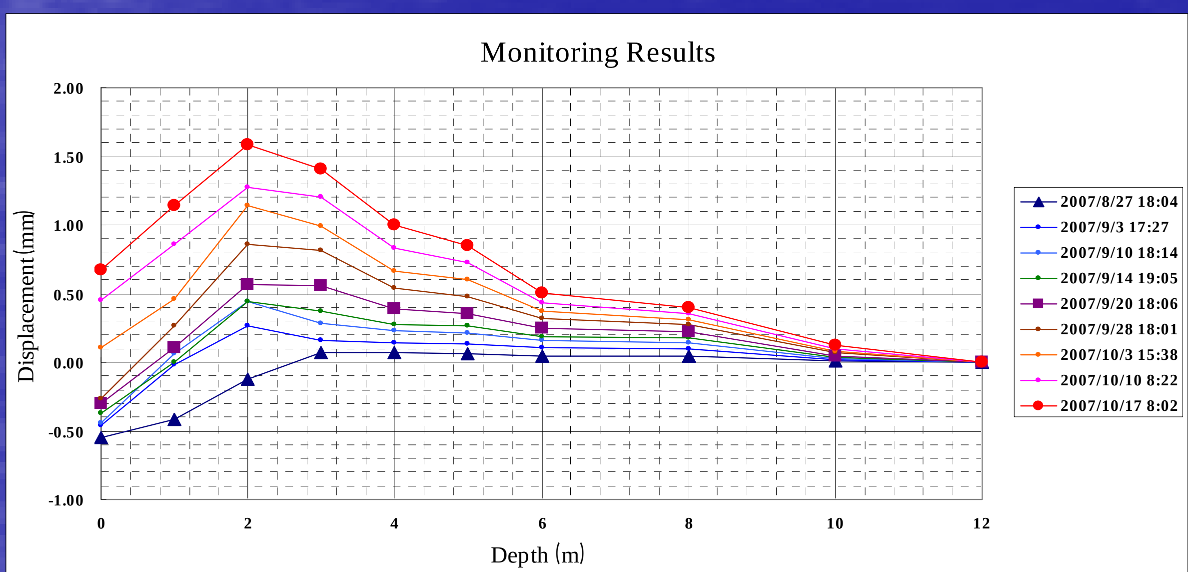


Fig. 8. The monitoring result

4.Conclusion

The multiple deformation sensor system for 66 mm diameter borehole is developed based on the FBG sensor technology. The inner sensors for this system have self compensation mechanism for temperature variation. The monitoring was carried out using this system and the result of early stage shows an availability of this system. This development could be a breakthrough for the ground monitoring techniques, because conventional electric systems are difficult to apply for long term monitoring and for such multi stages in a small size borehole. It is planed that the developed system will be applied to the monitoring for deeper part of Horonobe Underground Research Laboratory, and will be verified long term durability and accuracy for the minute deformation.