Smart Concrete Structures with Optical Fiber Sensors

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ABSTRACT

Recently, the interest in the safety assessment of civil infrastructures has increased. As bridge structures become large-scale, it is necessary to monitor and maintain the safety of large bridges, which requires smart systems that can make long-term monitoring a reality.

Civil engineers have applied monitoring systems to several bridges, such as the New Haeng-Ju Bridge and Riverside Urban Highway Bridge, but these applications have some problems with the sensors for long-term measurement, setup techniques for the bridge monitoring system and the assessment of measured data.

In the present study, an optical fiber sensor smart system was tested and confirmed in laboratory tests on the concrete members. By Attaching optical fiber sensors to the structural parts of the Sung-San Bridge, the bridge load test was measured.

These smart concrete structure systems can be applied to bridges and the load capacity of the bridge can assessed.

Keywords : smart structure, bridge, optical fiber sensor

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1. INTRODUCTION

Optical fiber sensors having advantages of no electromagnetic interference, good resolution, good durability, good efficiency of remote signal transmission, they can be a useful measure for displacements of bridges.[1)2)3)]

In Korea, there has been no example of the application of optical fiber sensors to civil structures. Therefore, we developed the optical fiber sensor and its signal processing system. To assess the applicability of optical fiber sensors to bridge monitoring system, we have performed laboratory test of reinforced concrete member and applied these system to the existing real bridges.

2. SENSOR CONSTRUCTION

An intrinsic Fabry-Perot fiber optic sensor with circular cross-section is, mainly, composed of two parallel, partially reflecting mirrors spliced into the optical fiber at L_0 distance apart. After cleaving the fiber, the end of fiber is coated by TiO_2 film with the thickness of 500-1000Å, and then the TiO_2 film become partially reflecting mirror. The two mirrors in the fiber made by previously explained manner compose the Fabry-Perot interferometric system.

A coherent laser beam of light passed along the optical fiber, the light intensity reflected from the first and second mirror is measured.

Fig.1 shows the diagram of Fabry-Perot fiber sensor developed in this study.

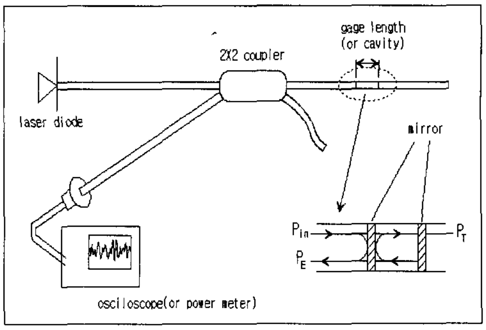


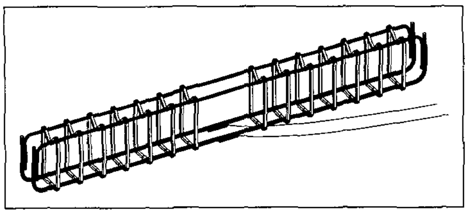
Fig.1 Diagram of Fabry-Perot fiber sensor

3. LABORATORY BEAM TEST

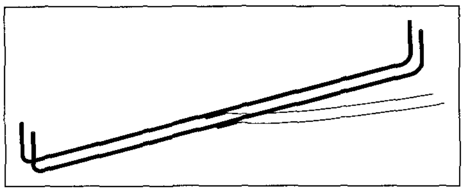
3.1. Test Procedure

Laboratory tests were performed to compare the data from fiber optic sensor with those from conventional strain gauges and to verify the effectiveness of optical fiber sensor.

The cavity length L_0 between two mirrors in optical fiber sensor is about 1cm. The sensors were embedded in 20cm ×20cm×150cm cement concrete specimens. We attached an intrinsic Fabry-Perot sensor on a reinforcing steel bar in specimens and strain gauges on the other steel bar near the Fabry-Perot sensor (Fig.2). We placed these steel bars in the wooden mold and poured the concrete mixtures. After curing these specimens for one month in the air, we put it on the UTM(universal Testing Machine) and carried out 4 point bending test. Data from Fabry-Perot sensor were measured with peak counting method using eye detection and with X-Y Plotter.



(a) Embedded sensor in bending test



(b) Embedded sensor in shear test

Fig.2 Diagram of test specimen

3.2. Experiment Results

Two types of tests were carried out. First, load test was performed to induce the failure of specimen by bending force. The specimen had several steel stirrups across the tensile steel bars to prevent the shear failure(Fig.2(a)). We measured data from Fabry-Perot sensors and strain gauges. From the analysis of data, they showed good linearity as shown in Fig.3

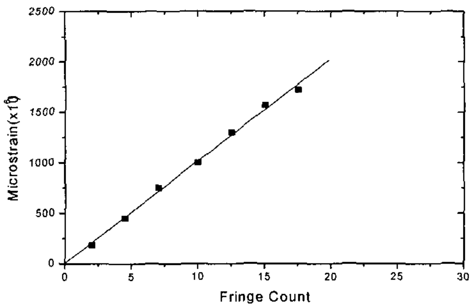


Fig.3 Correlation between optical fiber sensor and strain gauge data

Second, to induce the shear failure of concrete specimen, the other specimen had only two tensile steel bars without any stirrups and the sensors were attached to the tensile steel bars(Fig.2(b)). The specimens were failed by shear force, and data from strain gauges and Fabry-Perot sensors were obtained as shown in Fig.4 and Fig.5 Data from Fabry-Perot sensors were recorded by X-Y plotter, and they showed small fluctuations due to the crack propagation and the amplitude change according to increasing load. The phenomenon due to shear strain in the cross-sectional plane of the sensor occurs, and it was predicted by K. Kim, et'.al.[4] The conventional strain gauges cannot measure any strain after the failure of the specimen, but the Fabry-Perot sensors showed good response even after failure.

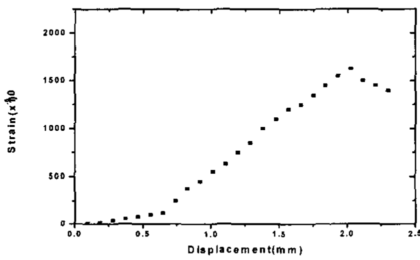


Fig.4 Data from conventional strain gauges

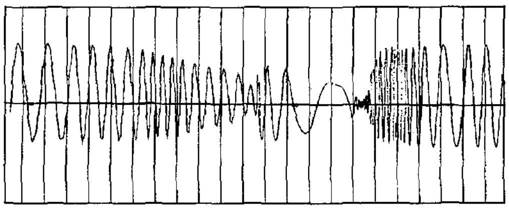


Fig.5 Data from Fabry-Perot sensor(by X-Y plotter)

4. APPLICATION TO EXISTING REAL BRIDGE

4.1. Test Procedure

From the results of laboratory tests, outputs from Fabry-Perot sensors showed good linearity to output from conventional strain gauges, so we can apply Fabry-erot sensors to monitor the behaviour of a real bridge.

Therefore, we chose Sungsan Bridge, which is one of the longest bridges in Korea, to apply these system to real bridge, and attached intrinsic Fabry-Perot sensors to steel girders of this bridge. We applied numbers of strain gauges, acceleration sensors and deflection sensors as well as optical fiber sensors. In this study, we will discuss the application of Fabry-Perot sensors. After the execution of visual inspection, three spans of the bridge were chosen, then optical fiber sensors as well as conventional strain gauges were attached to a steel girder at midspan. Static and dynamic loads were applied to the bridge by 30ton trucks.

4.2. Structure of the System

Fig.6 shows the applied optical fiber sensor system, which consists of sensor, laser source, detector, data processor, and control and display subsystem.

Laser diode transforms electric signal into laser beam, then the laser transfers to the sensors. The laser in the sensor part varies by the changes in strains and temperatures of the material surrounding the sensor. The laser changed into electric signals by detector, and then the Processor changes the signals to readable data to the computer. Obtained data are analyzed by data processor, and finally the structural safety of bridge is assessed.

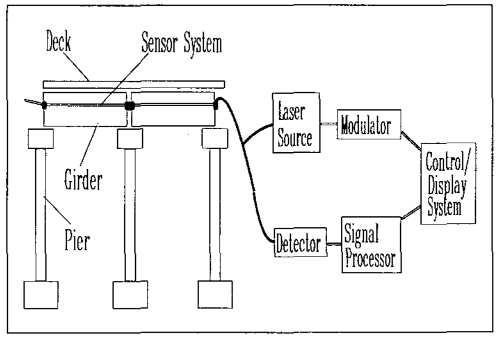


Fig.6 Bridge monitoring system of optional fiber sensor

4.3. Static Load Test

Fig.7 shows the results of static load test. The strain before test truck starts, and the strain when the truck is located at the sensor point, are measured. They showed stable response, and the sensor maintains constant output intensity. Also, it looks like almost no noise except natural vibration. The amount of length change of the sensor can be calculated approximately by Equation(1).

$$\Delta l = \frac{\Delta I}{I_{\max} - I_{\min}} \times \frac{\lambda}{2} \qquad (1)$$

If we suppose that 2π phase change means 1.3μm length change and the intensity change linearly, the strain when the truck is placed to the sensor point is about 12.3μ strain. Supposing that the accuracy of 1/10 can be read, the resolution is approximately 0.1μ strain. Therefore the optical fiber shows very good resolution.

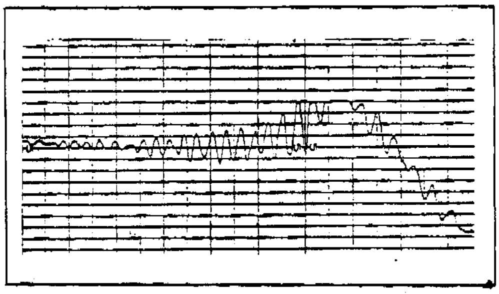


Fig.7 Response of Fbary-Perot sensor in static load test

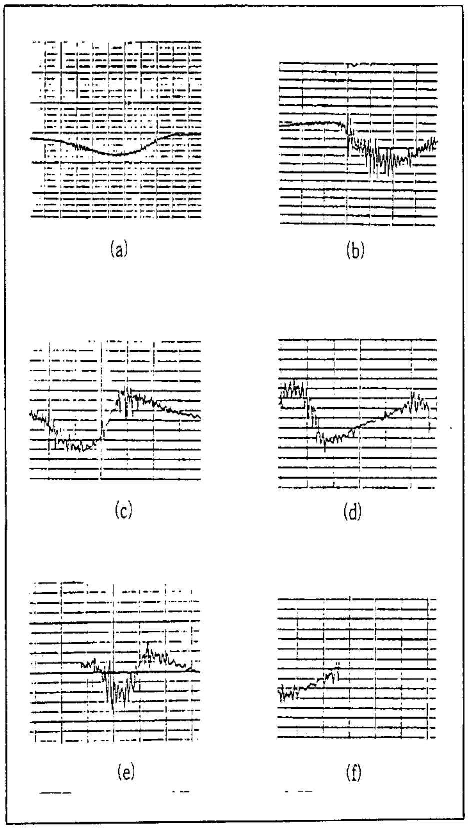


Fig.8 Response of Fabry-Perot sensor according to the change of truck velocity (x-axis ; time, y-axis ; strain)
(a) 10 km/h (b) 20 km/h (c) 30 km/h
(d) 40 km/h (e) 50 km/h (f) 60 km/h

4.4. Dynamic Load Test

Strain patterns were measured by Optical Fiber Sensors at each dynamic test step passing by the velocity from 10km/h to 60km/h with 30ton truck.

Fig.8 shows the change of measured strains by optical fiber sensors in dynamic load test according to the change of truck speed.

The bridge experiences similar amounts of stress at the truck speed of 20km~40km, and less amounts of stress when the truck speed is below or above the speed.

5. CONCLUSION

To develop the smart concrete structure with optical fiber sensor, we developed Fabry-Perot optical fiber sensor system and confirmed this system by laboratory test and the application to Sungsan Bridge.

Output from Fabry-Perot sensor embedded in concrete specimen showed good linearity to output from the conventional strain gauge, and so Fabry-Perot sensors can be applied to maintenance and control system instead of strain gauges.

Measurement by Fabry-Perot optical fiber sensors was performed as a part of safety diagnosis of Sungsan Bridge, and showed good applicability. In the static load test, optical fiber sensor system showed the high resolution of approximately 0.1μ strain. In the dynamic load test, it clearly shows the tendency of strain in the bridge with the change of truck velocity.

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