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BRIDGE STRUCTURE MONITORING SYSTEM BASED ON THE FBG SENSOR NETWORK

K.T. Park
Korea Institute ofConstruction Technology,
South Korea

Y.K. Hwang
Korea Institute ofConstruction Technology,
South Korea

W.S. Lee
Korea Institute ofConstruction Technology,
South Korea

Abstract

This study is to address a bridge structure monitoring system based on a fiber communication network and fiber optic sensor network. The applied optical fiber sensor deployed the FBG (Fiber Bragg Grating) type, which makes it possible to measure multiple points from one cable. Since the fiber sensor uses the principle of light, it features some advantages in that it is not influenced by electromagnetic waves and it provides excellent durability. The data obtained from the measuring results of the bridge structure measuring system are designed to be transferred to the applicable maintenance control office via the pre-established fiber communication network. Pre-investigation results indicated that it is possible to effectively construct a structure safety management network based on the optical communication network and fiber bragg grating sensor system. It is anticipated that the data transmission methodology using the optical communication network will be effectively applied into the measurement of other major infrastructures based on this methodology.

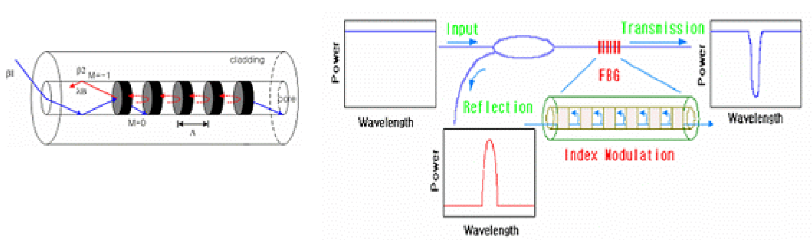
INTRODUCTION

In addition to the reasonable and accurate design and construction of civil and building structures, measurement for safety inspection, reinforcement and maintenance after construction is very important to improve serviceability, maintain optimal conditions, and extend service life of structures. In general, structures in service gradually lose original performance with time due to initial defects in design and construction, or exposure to unfavorable external conditions such as repeated loading or deteriorating environment, and in extreme cases, may collapse in a large disaster. Therefore, in order to maintain the serviceability of structures at optimal level, advanced structure measuring system which can inform optimal time point and method of maintenance is required in addition to accurate prediction of residual life of the structure by periodic inspection.

Optical fiber sensors are attracting attentions for the next generation sensing technology for civil structures due to their merits of endurance, workability and free from electric wave interference. In this study, a long-term bridge monitoring system is suggested using optical fiber bragg grating sensor which enables multiplexing and multi-detecting, a plan for establishing network by integrating each system is presented, and the trend of R&D activities and practical use of optical fiber sensor in Korea is introduced.

FEATURES OF FBG SENSORS

The optical fiber sensor introduced in this paper is the optical Fiber Bragg Grating(FBG) sensor. Since FBG is composed of germanium and silica glass, it is free from electric wave interference and resistant against corrosion by moisture or humidity. FBG can have multiple sensing points on a single strand of optical fiber by forming multiple bragg gratings, and the optical fiber can be extended to tens of kilometers due to their low transmission loss, which is less than 0.2dB per kilometer.

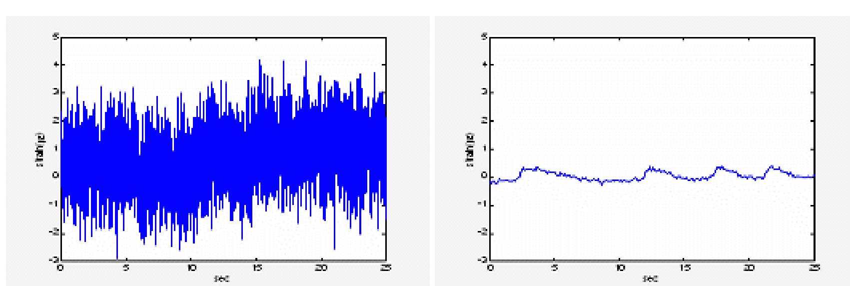


(a) Structure of Optical FBG (b) Characteristics of Optical FBG

Figure 1. Structure and Characteristics of Optical FBG

Due to such low loss in light transmission, they are suitable for long structure such as bridge, railroad, and pipeline. This feature of optical fiber grating sensor can solve various demerits of the conventional electric resistance type sensors, attracting attentions as a measuring device that can substitute conventional measuring device by their capability of measuring minute strain and temperature of structures.

As a representative example, Figure 2 shows the comparison of noise to signal ratio between electric resistance type strain gauge and optical fiber grating strain sensor. It can be seen that the electric noise of optical fiber grating sensor is significantly lower.



(a) Electric Resistance Type (b) Optical Fiber Sensor

Figure 2. Comparison of Noise to Signal Ratio

ANALYSIS ON THE PROBLEM OF CONVENTIONAL SENSORS

Most social infrastructures aim at convenience and comfort of life, therefore, functionality and safety are important factors for design and construction of such structures. However, most of the structures lose their functionality and performance by ceaseless changes in loading conditions and deterioration of structural members. The result may even be a disaster giving serious damage to human life and properties(see Fig. 3).

Bridges, buildings, and railroads which are important social infrastructures can be damaged by unwanted environmental changes such as earthquake, typhoon, or flood, resulting in a reduced life period or even a collapse.

In Korea, in response to the collapse accidents including the Seongsu Grand Bridge and Sampoong Department Store, the procedures of verifying the measures taken by facility owner for maintenance or reinforcement was formulated in 1995. And the FMS (Facility Management System) was established and operated by the Korea Infrastructure Safety and Technology Corporation(KISTEC) to integrate and manage safety and maintenance information of facilities.

(a) Sampoong Department Store (1995, Korea)   (b) Tacoma Bridge (1940, USA)
Figure 3. Collapse of Infrastructures

According to such trend, short and long-term monitoring systems have been introduced to bridge, building, and railroad structures in order to obtain basic data for judging the degree of damage or deterioration, or structural problems. Figure 4 shows an example of short-term measurement system for the evaluation of railroad track status, which is the core facility of railway. Long-term monitoring systems have been introduced to special bridges including Namhae, Dolsan, and Jindo bridge in Korea since 1997. These days, many social infrastructures such as bridges, dams, buildings, and railroad structures are equipped with the system. Figure 5 shows the bridge type by section of Seohae Grand Bridge which is known to have a well-operated long-term monitoring system in Korea.

Figure 4. Track Measurement for Status Evaluation (Korea)

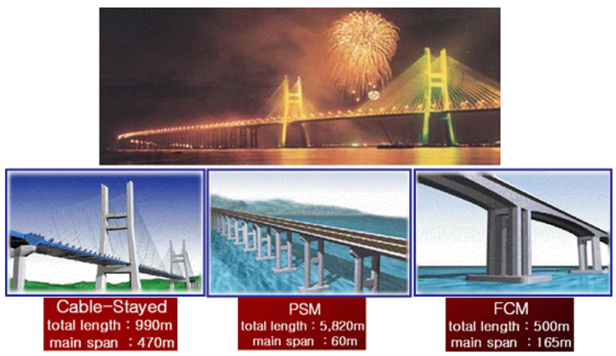


Figure 5. Bride Type by Section, Seohae Grand Bridge (Korea)

However, according to the Highway & Transportation Technology Institute (2003), although the measurement systems were introduced to bridges to grasp long-term behaviors for the purpose of evaluating the status and life span of bridges, as shown in Table 1, at the investigation conducted after installation, most of the systems had errors in computer systems or measurement systems, or systems have not been in operation for a long time. As shown in Table 1, which shows operation status of 5 representative bridge sensors, 31-66% of the systems were found out to be responseless or provide abnormal signals.

Most of the measurement equipments and sensors were electric resistance type which are subject to corrosion, electric wave interference, or problems in workability. In addition, even in short-term measurement, a lot of time and cost are required due to excessive lead cable work, or the reliability of measurement signal is insufficient. Due to the liability to electric wave interference, measurement near high electric voltage structures such as pylons, subways, or high speed railways is almost impossible or subject to significant influence of noise.

Table 1. Operation Status of Measurement Sensors on Bridges

Bridge	Installed in	Operation Status of Measurement Sensor			
		Number of Sensors	Normal Operation	Abnormal Operation	Rate of Faulty Sensors (%)
I	11. 2001	52	36	16	31
E	11. 2001	52	29	23	44
F	11. 2001	56	28	28	50
G	11. 2001	59	20	39	66
J	11. 2001	61	27	34	56

R&D OF OPTICAL FIBER SENSORS

In Korea, R&D of optical fiber sensors had begun later than advanced countries. Since the late 1990s, studies in optical fiber sensor application in civil structures were started (KICT, 2002), and recently, some businesses are developing and manufacturing optical fiber sensors by themselves. Recently, KISTEC(2006) has installed optical fiber sensor system on PSC box girder bridge, and there was a case of railroad monitoring according to temperature. The national R&D project, which is the matrix of this study, has started since 2006(Ministry of Construction and Transportation) and study on constructing a test bed for bridge using optical fiber sensors for 4 years until 2010.
Figure 6 shows measuring processes with optical fiber sensors on PSC girder bridges, and Figure 7 shows the measurement of railroad track behavior according to temperature.

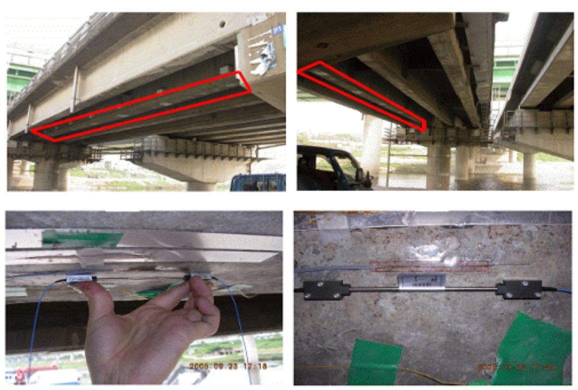


Figure 6. Experiment on Kia Grand Bridge (Korea)

Figure 7. Track Behavior Monitoring Using Optical Fiber Sensors between Pyeongnae-Hopyeong Stations (Korea)

In foreign countries, positive studies are actively in progress. Studies on the effectiveness are being conducted by inserting FBG sensors in FRP, and on the basis of the study results, studies on the development of FRP bars having FBG sensors inside and tensile members having sensing function using FRP bars have been performed(Chuan Wang *et al*, 2005).

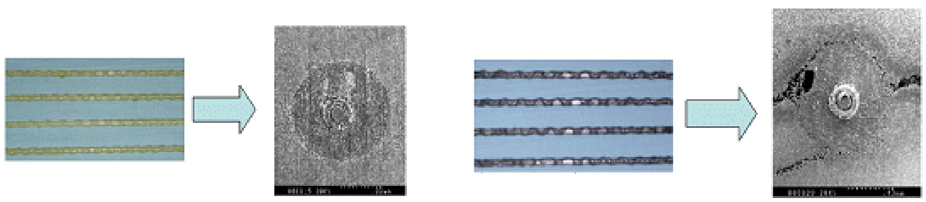


Figure 8. FRP Bar Having FBG Sensor Inside

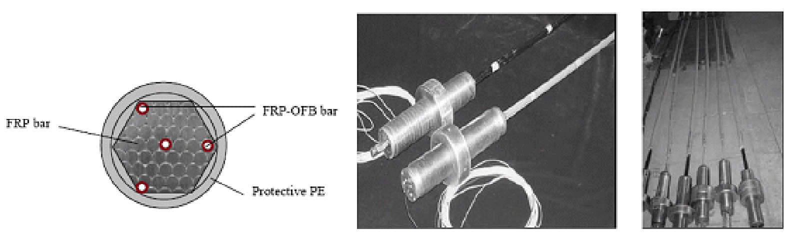


Figure 9. Smart FRP-OFBG Based Bridge Cable

Studies on measuring tensile force of cable without additional endeavors by inserting FBG sensors in bridge structure cables, which are made of conventional steel cable has been conducted (Zhi Zhou *et al*, 2004, 2005). Overseas, studies for providing sensing functionality to cable by inserting bare optical fiber sensor or FBG sensor in FRP are being actively carried out, resulting in actual implementation in some bridges.

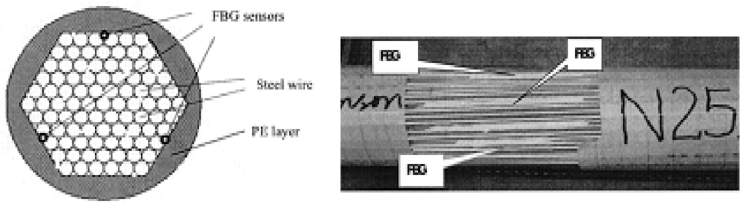


Figure 10. Steel Wire Cable Inserted with FBG Sensor

BRIDGE TEST BED CONSTRUCTION PLAN

In this study, objective bridges selection plan was set up for various cases in order to provide efficiency and practicality of the study subject. 5 bridges were selected having 5 different superstructure types, including cable stayed bridge and arch bridge which are special typeS, and steel box girder bridge, PSC box girder bridge, and steel plate girder bridge, which take major portion of the bridges having maximum span of 50m or longer. The bridges will be installed with mixed systems of optical fiber sensor and conventional systems, which will be networked with existing optical communication network. Figure 11 shows the system structure on test bed construction.

Use of optical fiber sensors will be limited to strain gauges and temperature gauges considering the level of development state. For conventional sensors, several kinds of sensors including acceleration sensor, tiltimeter, and expansion joint gauge will be introduced. For measuring deflection, sensors which make use of GPS which is classified as a next generation sensing technology will be introduced and tested for operation.

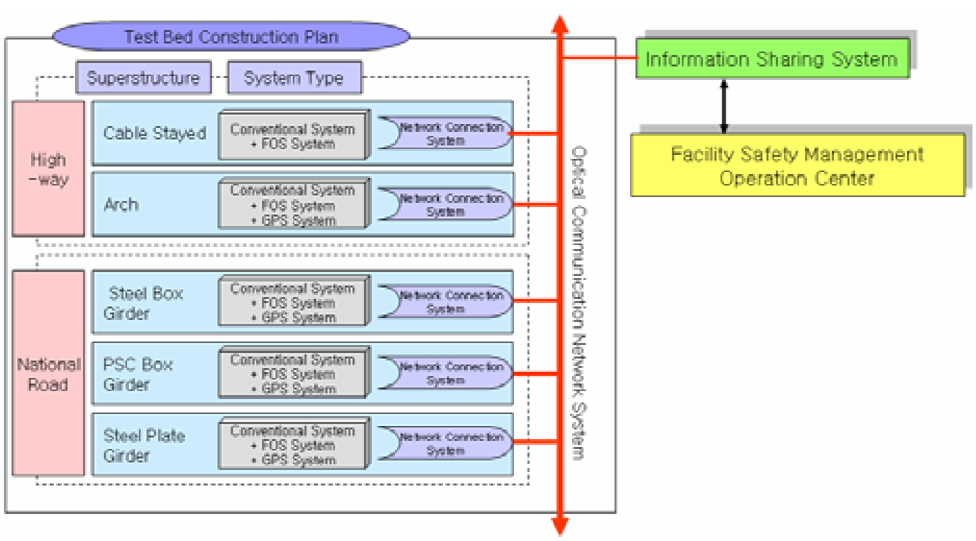


Figure 11. Bridge Test Bed Construction Plan

The research system for the present study is summarized as belows. The Korea Institute of Construction Technology(KICT) and a related company will jointly carry out the study in addition to two companies which will apply the research results and actual road structure management authorities, KMC.

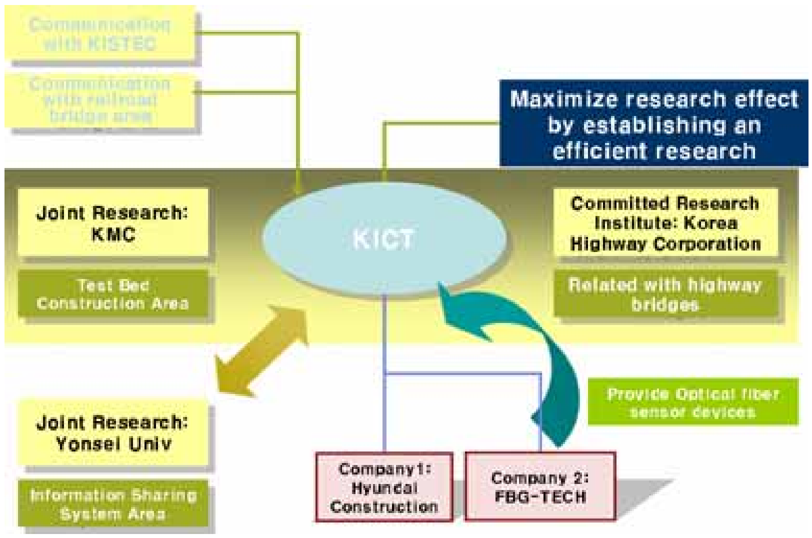


Figure 12. Research System

SAFETY CONTROL NETWORK CONSTRUCTION PLAN

The test beds will be constructed by introducing optical fiber sensors to civil structures including tunnels and cut slopes, railway facilities including railway bridges, tunnels, and railroad slopes, and irrigation facilities including dams and banks, in addition to the bridges on roads, all of which will be integrated with the optical communication network mentioned above. All will be connected to the facility safety management network operation center for the safety management of major national facilities.

CONCLUSIONS

In this study, the progress in the studies on the utilization of optical fiber sensors in Korea was presented, in addition to the conceptual scheme of infrastructure safety management network construction plan using optical fiber sensor. Contents of the present study can be summarized as follows:

1) FBG sensors are attracting attention as the next generation sensing technology due to their ability of multiplexing and multi-detecting, immunity to electromagnetic interference, and excellent endurance. Considering the active positive studies on introducing optical fiber sensors in bridge structures, bridge structure monitoring systems using optical fiber sensors will be increased in a near future.
2) It was found out that some of the conventional sensors have inferior endurance and are subject to electromagnetic wave interference by comparison with optical fiber sensors. Therefore, it is desirable to replace conventional type sensors with optical fiber sensor systems, gradually.
3) For the safety management of major infrastructures in Korea, long term monitoring systems on bridges with optical fiber sensors are suggested, and a plan for networking the systems with existing optical communication network is proposed.
4) Studies on safety management of major national structures including railway and irrigation facilities, in addition to road facilities, by constructing a network similar to that of bridges are being carried out. The objects of the studies will be extended on the basis of the test bed construction results presented in this study. The various results obtained by this study will be presented to international academic societies in the future.

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