Long span cable-stayed bridge monitoring system using distributed optical fiber strain sensor

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ABSTRACT

Structural health monitoring system using distributed optical fiber strain sensor in a long-span cable-stayed bridge was described. The system was implemented for monitoring the deformation entire the bridge throughout the construction process.

Twelve lines and over 2,500M of distributed optical fiber strain sensors were embedded in concrete of the bridge. Optical measurement equipment based Brillouin Optical Time Domain Reflectometry (B-OTDR) was installed, and data transmit system using the Internet was also installed. The distributed strains were measured and recorded all around construction stage. The calculated deformation results obtained showed a good correspondence to the progress of construction.

INTRODUCTION

Structural Health Monitoring (SHM) system using optical fiber sensors has been successfully applied in the large-scale and long-lifetime structure [1].

In particular, distributed optical fiber strain sensing system based on Brillouin scattering is most deployed on buildings and civil infrastructure to monitor deformation in the entire structure in a simple yet effective manner [2].

Long span cable-stayed bridge requires a high level of accuracy against the effects of the construction work, environmental threat, traffic volumes, etc. during construction stage to in-use stage.

The SHM system using distributed optical fiber sensor was installed a bridge under construction for monitoring the deformation in the towers and girders as construction progressed.

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SYSTEM SETUP

The long span cable-stayed bridge equipped with the distributed optical fiber sensing system is shown in Figure 1. The bridge was constructed out of pre-stressed concrete; the main span has a length of 435m, and the bridge spans an international strait.

In order to prevent environmental impact and maintain a navigation clearance that was sufficiently wide (200m) and high (50m) for ships to pass under the bridge, the bridge was constructed on land using balanced cantilever system based the climbing formwork (for towers) and formwork traveler (for girders), as shown in Figure 2.

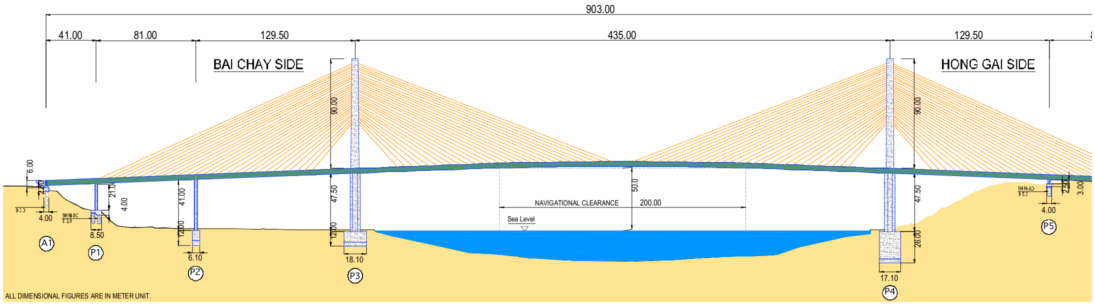


Figure 1. Overview of the long span cable-stayed bridge

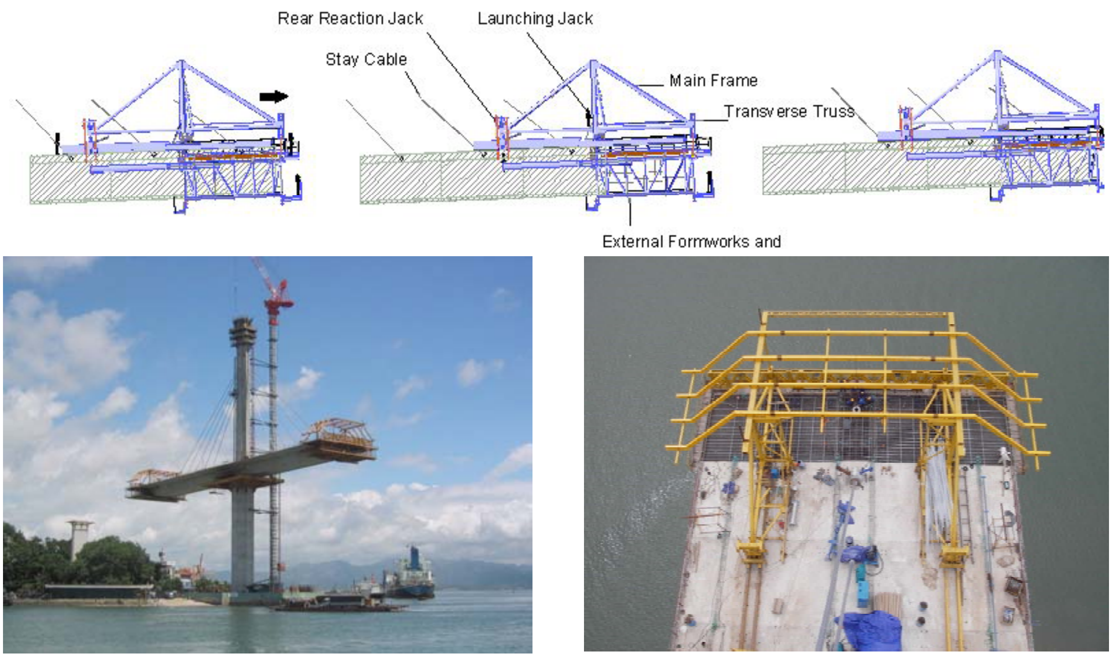


Figure 2. Construction process using balanced cantilever

Ordinary, the visual observation method is used to control bridge camber deformation during the construction works. However, the method is time and cost consuming since it is human intensive; further, only a limited number of points can be measured by this method.

In order to monitor deformation of the entire of the bridge, four lines of optical fiber sensor were embedded in the concrete at each edge of the towers and girders, as shown in Figure 3 and Figure 4. The total number of sensor is twelve, and the total length of sensors was around 2,500m. Each sensor is connected through an optical switch to the equipment the Brillouin scattering measurement (B-OTDR).

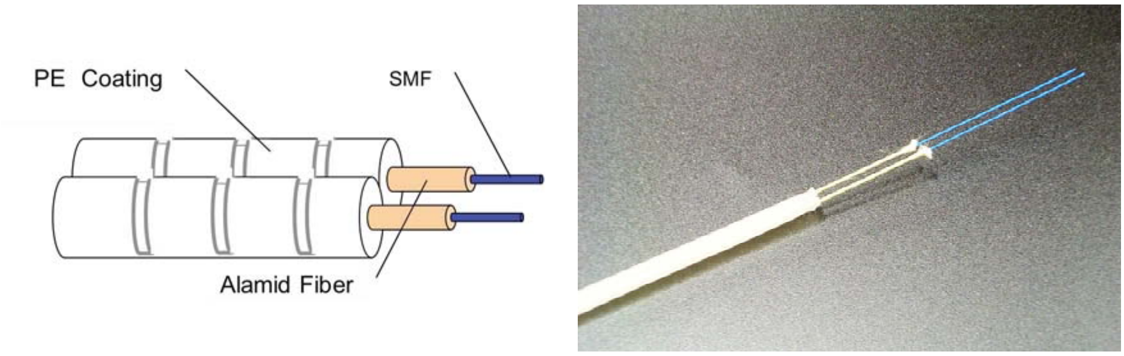


Figure 3. Optical Fiber Strain Sensor

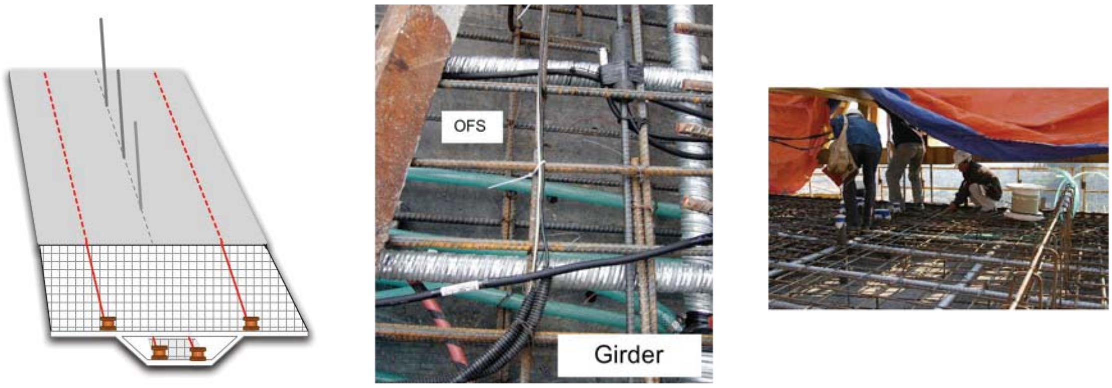


Figure 4. Installation of optical fiber sensor to concrete

The deformations can be calculated from the strain distribution values. The towers and girders act as rigid supported cantilever. Their relative displacements are given as follows:

$$d(x) = \int_0^x \frac{S(\varepsilon_1(x) - \varepsilon_2(x))}{D} dx \qquad (1)$$

where $d(x)$ is the relative displacement of the tower or girder; $\varepsilon_1(x)$ and $\varepsilon_2(x)$ the strain values of two sensors; D, the interval of each sensor; and S, the spatial resolution of distributed strain sensor.

RESULTS AND ANALYSIS

Figure 5 shows the example of distributed strain result. And figure 6 shows calculated deformations during one cycle involving the construction of the girder section. It is assumed that during the progress of construction, the distributed strain in each part of girder changes. And the marked position of the girder moved downward after concrete casting; it moved further downward during movement of the formwork traveler. Finally, after cable stressing was completed the girder was lifted up.

Relative displacement values are obtained, which were from the monitoring system, successfully agreed with the expected values. Figure 7 shows the comparison between the settling value consequences before and after casting concrete, measured by observation method and calculated from distributed strain.

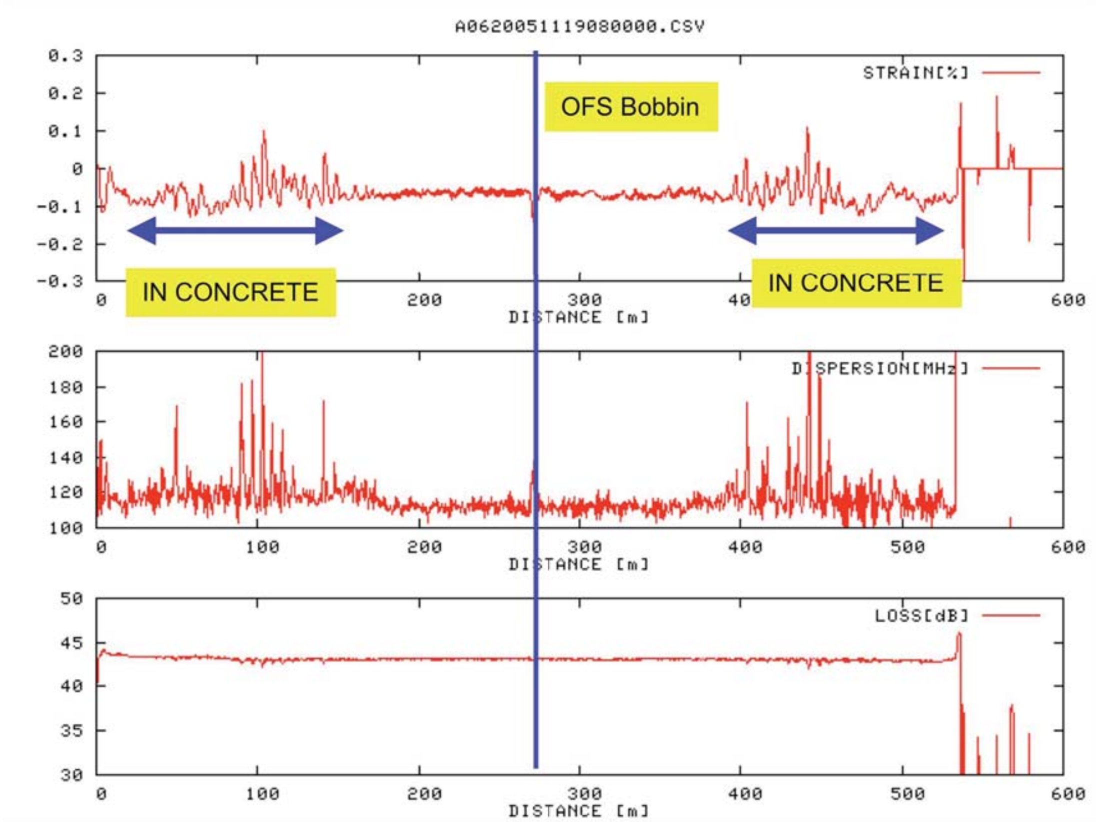
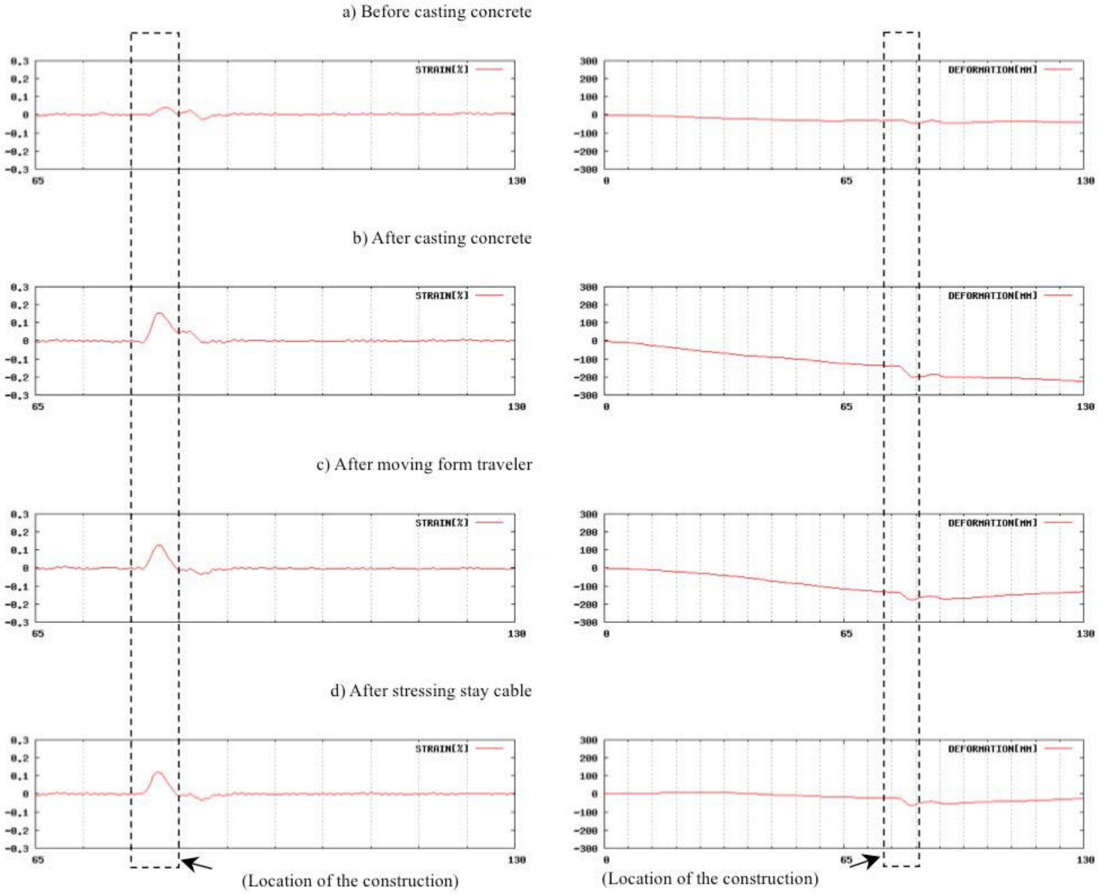
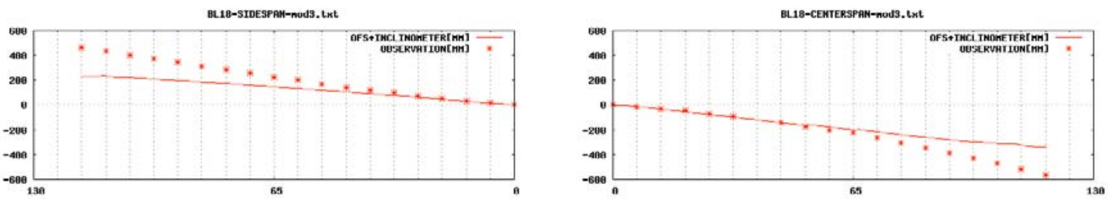


Figure 5. Example result of distributed strain

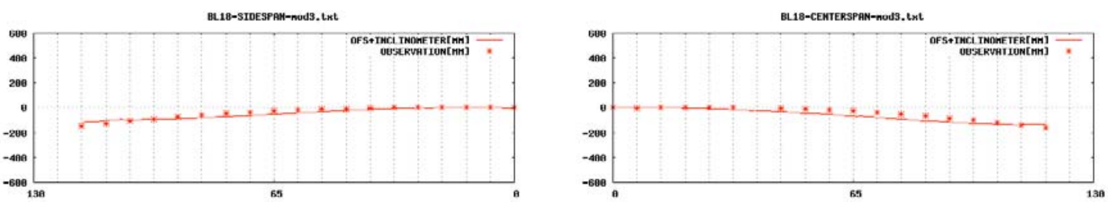


a) Distributed Strain b) Calculated Deformation

Figure 6. Deformation in progress of construction



a) After Center Span Casting



b) After Side Span Casting

Figure 7. Comparison between Observation Method and Optical Fiber Sensor

SUMMARY – FUTURE WORK

SHM system using distributed optical fiber sensor was successfully applied to keep accuracy and to check the structural deformation as the long span cable-stayed bridge. And results are shown good relativity in progress to construction. The system has the potential to achieve more precise management of the construction quality with the advantage of performance; further, the system can easily acquire a large amount of distributed strain data.

The future work will involve the extension of the system to monitor degradation and apply to maintenance after completion, in-use stage of the bridge.

REFERENCES

1. F. Ansari, "Fiber optic health monitoring of civil structures", Structural Health Monitoring and Intelligent Infrastructure, p.19, 2003.
2. L. Thevenaz, "Monitoring of Large Structures for safety Issues Using Brillouin Distributed Sensing", OFS-16, p.506, 2003.