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Field Test of Strain Fluctuation in the Experimental Reactive Powder Concrete Bridge at Shepherd's Creek

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Abstract

The newly built bridge made of novel reactive powder concrete at Shepherd's Creek, Lake Macquarie, NSW is tested for static strain activity over a two-day period. We developed a fibre grating-based experimental strain sensing system and employed an active interrogation scheme using a tuneable laser source. Four FBG sensor heads are surface-mounted in the middle of a girder and under the bridge deck to monitor the strain and temperature movement. The strain sensors have a resolution of approximately 1.5με. The observed strain fluctuations, which indicate the hogging and sagging behaviour of the bridge, are in agreement with the theoretical expectation.

Introduction. Fibre-optic strain sensors based on fibre Bragg gratings (FBGs) have found applications in the monitoring of large-scale concrete structures [1][2]. They have the primary advantage over conventional electrical strain gauges in that they are not subject to drift, thus making them ideal for the use in long term monitoring of large-scale structures. Furthermore, their small size gives them more flexibility in their use, allowing the potential for unobtrusively embedding them into the concrete so as to directly measure the bulk strains of the structure as well.

Our static strain system, comprising a tuneable laser (TL) and a computer, plus a required number of FBG sensor heads, is developed for installation on civil engineering structures such as bridges. The system is designed to automatically upload and download data so as to allow for its use in remote locations. In the initial field test at the bridge over Shepherd's Creek, Lake Macquarie, NSW, a 4 FBG sensor array is surface-mounted as shown in Fig.1. This bridge was selected as it is the first bridge in Australia to employ Reactive Powder Concrete (RPC) [3] in the casting of its girders. RPC has very high strength and is capable of withstanding compressive stresses in excess of 160 MPa. The bridge represents an advancement over the Magog River Pedestrian Bridge in Quebec [4], the first in the world to use reactive powder concrete, in that it is open to traffic and thus with the use of an intelligent monitoring system this new construction material can be field tested to its full extent.

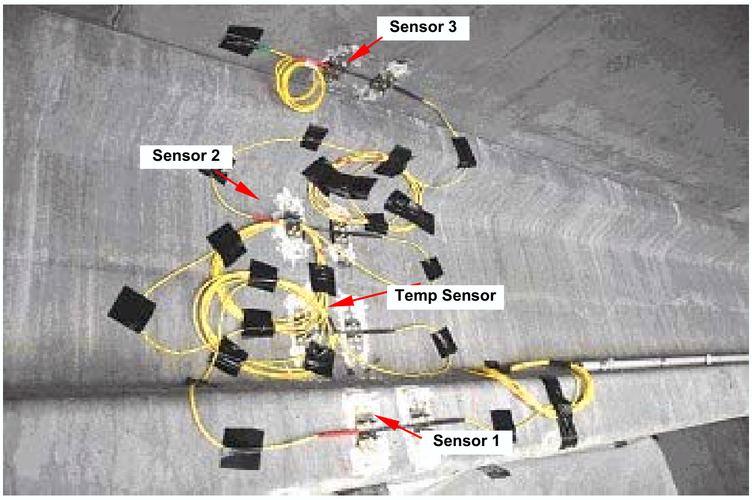


Fig.1 Surface-mounted sensor array at the Shepherd's Creek Bridge

FBG Sensors. Besides being sensitive to strain, FBGs are highly sensitive to temperature, especially when encapsulated in metal wires which have a higher thermal-expansion coefficient than that of silica glass. The change in the Bragg wavelength $\Delta\lambda_B$ in a grating depends on the applied strain and the ambient temperature, the governing equation being [1]

$$\frac{\Delta\lambda_B}{\lambda_B} = \left(1 - \frac{n^2}{2}\cdot\left[p_{12} - \nu\cdot\left(p_{11} + p_{12}\right)\right]\right)\cdot \varepsilon_z + \left(\frac{1}{\Lambda}\frac{\partial\Lambda}{\partial T} + \frac{1}{n}\frac{dn}{dT}\right)\cdot\Delta T$$
$$= \left(1 - E\right)\cdot\varepsilon_z + \left(\alpha_\Lambda + \alpha_n\right)\cdot\Delta T \qquad (1)$$

where the first term accounts for the change in longitudinal strain, and the second term the change in temperature. n is the refractive index of the core, p_{ij} are Pockel's coefficients, and ν is the Poisson's ratio. $\Delta\varepsilon_z$ is the change in applied longitudinal strain, Λ is the grating period and T is the temperature. The coefficient E is measured to be 0.22 [1], so the strain dependence is simplified to

$$\frac{\partial\lambda_B}{\partial\varepsilon_z} = \lambda_B \cdot 0.78\cdot 10^{-6}\,\mu\varepsilon^{-1} \qquad (2)$$

Thus a change in strain of 1με results in a shift of λ_B of around 1.2pm at 1550nm. The tuneable laser scans the reflection spectrum with 5pm between consecutive points. This would give a resolution of 4.16με, but as we monitor the location of an edge in the reflection spectrum by fitting a curve to the result of each scan, this inaccuracy vanishes. The measured standard deviation of the strain in the absence of any applied strain and temperature variation is determined to be 1με.

When the sensors are unstrained, minor fluctuations in temperature could introduce significant changes in the Bragg wavelength $\Delta\lambda_B$. However, when the sensors are mounted and under strain, the effects of thermal expansion would be largely suppressed, and the thermo-optic effect would become significant. In order to suppress the influence of temperature on the results, we use one FBG as a temperature sensor. As the gratings are installed near each other, and the bridge acts as a big heat reservoir, the temperature is assumed to be same at all four points where FBGs are installed.

As shown in Fig.2, $\Delta\lambda_B$ of the FBG temperature sensor changes linearly with temperature. As mentioned above, we need to distinguish between the thermo-optic (TO) effect from the thermal-expansion (TE) effect. The two effects are represented by constants α_Λ and α_n in equation (1), respectively. TO originates from the change of refractive index of silica glass in the fibre core due to the temperature dependence of refractive index. The change of the effective refractive index alters the Bragg constant and thus the Bragg wavelength. The thermo-optic coefficient α_n of a silica fibre is measured to be $6.67\times10^{-6}\,K^{-1}$ [1]. TO is the dominant effect for free FBGs, as the TE constant $\alpha_\Lambda=0.35\cdot10^{-6}K^{-1}$. Encapsulating the fibre with stainless steel rods, gives additional contribution to temperature dependence. Namely, the thermal expansion of free stainless steel is around $10\cdot10^{-6}K^{-1}$ and thus a certain strain is induced in the fibre by expansion of the rods. From curve in Fig. 2, which shows a linear fit of the measured temperature vs. Bragg-wavelength shift for the temperature compensating FBG, we find the slope to be 17.121pm/K, i.e. at λ_B=1533nm, $\alpha_\Sigma=11.17\cdot10^{-6}K^{-1}$. Thus, the expansion of the rods induces a strain of 5.35με/K. This coefficient is measured with repeatability of 5% in other three gratings.

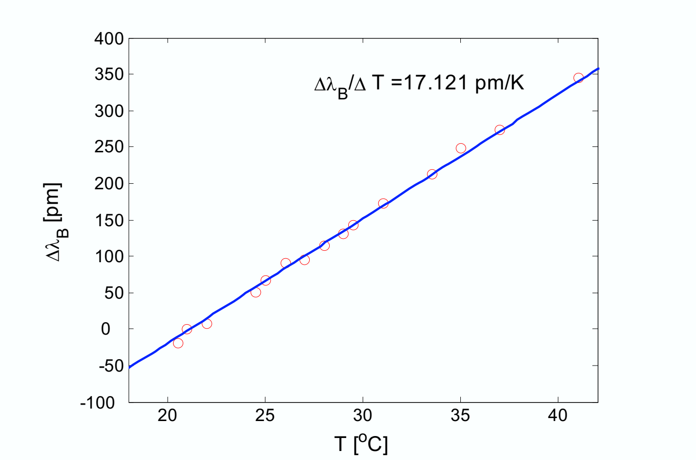
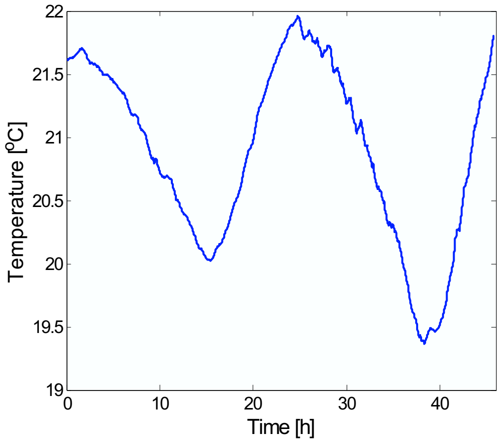
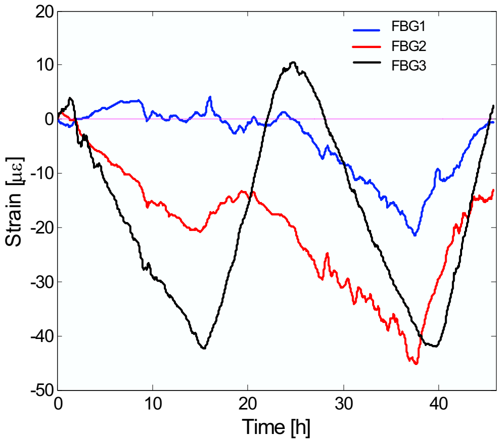


Fig.2 Linear temperature response of the encapsulated unstrained FBG sensor.

The inaccuracy in determining the ambient temperature contributes to the inaccuracy of strain measured in an uncontrolled environment. Because the two errors are uncorrelated, the total standard



(a)



(b)

Fig.3 a) Measured temperature variations during the cycle of 46 hours. b) Measured strain on the three gratings mounted on a girder (FBG1 and FBG2) and under the bridge deck (FBG3) .

deviation is estimated to 1.5με. The output power is also monitored constantly, but TL offers a very good control of this parameter, so it is expected that power variations do not have an effect on final results.

Results. Fig.3(a) shows the calculated temperature under the bridge, using the calibration curve. The temperature has modest variations - the difference in maximum and minimum is only 2.6ºC. Once the temperature is determined, we are able to remove the thermo-optic effect from the strain-measuring FBGs. Fig.3(b) shows the strain as function of time at the three measurement points. The measurement started Friday at 17.30, and lasted 46 hours. The data are averaged (moving average) in order to remove spikes. These spikes are of magnitude (peak-to-peak) up to 15με and are not registered in the temperature-measuring FBG. Furthermore, they occur mostly in intervals Friday and Saturday night i.e. when the traffic is intensified. Hence, we may attribute these fluctuations to strain caused by vibrations in the bridge. Temperature curve is also filtered by a moving average filter, the high-frequency spikes here were of magnitude up to 0.15ºC.

Strain in the deck follows closely the temperature variations, while the strain in the girder, which is perpendicular to and below the deck, is slightly out of phase with the temperature function. Peak-to-peak strain in the bridge material is 50με.

Conclusion. We have successfully tested an FBG-based strain sensor system utilising a tuneable diode laser. The estimated accuracy of the sensors is ±1.5με, while the repetition rate of measurements is one minute. The presented results are, though, averaged over 29 minutes. The test results and observed behaviour of the newly built RPC bridge agree well with the theoretical expectation with respect to maximum strain variations of 50με, and correlation to the ambient temperature.

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References

[1] Allan D. Kersey *et al.*, *Journal of Lightwave Technology* **15**, pp. 1442-1463, (1997).
[2] Allan D. Kersey *et al.*, *Spie* **2456**, pp. 262-268, (1995).
[3] Nadarajah Gowripalan *et al.*, Concrete in the 3rd Millenium, 21st Biennial Conference, Concrete Institute of Australia, Brisbane, July 2003, pp. 99-108.
[4] Eric Dallaire *et al.*, C*ivil Engineering* **68**, pp. 48-51, (1998).
[5] J. Lauzon *et al.*, Optics Letters **19**, pp. 2027-2029, (1994).