Simulation and Experimental Investigations on the Strain Measurement of the Uniform Strength Beam Using a FBG sensor

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Abstract The model of force analysis on a uniform strength beam is built by the general finite element program (ANSYS software). The flexivity profile produced by uniform strength beam with different forces is simulated by ANSYS software. In experiment, a fiber Bragg grating sensor is fixed on the uniform strength beam with modified acrylate. The flexivity and strain are varied by changing the load on the end of the beam. The strain of the uniform strength beam is measured with FBG when applied force is varied from 2.45N to 14.7N with a step of 2.45N. Both the simulated and experimental results show that, the strain induced by the uniform strength beam is linear with the load force. The sensitivity is 18.32με/N for experimental measurement, and 19.72με/N for simulation. The experimental results are consistent with the simulation results, with the maximum measurement error of strain being 7.4%. It indicates that, the FBG sensor fixed with modified acrylate is proved to be effectively and reliably in the applications of civil engineering.

Key words fiber Bragg grating sensor; simulation; uniform strength beam; strain measurement; flexivity

1. Introduction
The safety assessment of civil engineering becomes more important with the development of the society. Detecting the strain in the civil engineering correctly can realize structural health monitoring for a long time. Sensor technology is the foundation of the engineer security. In the field of fiber-optic sensors, FBG sensors are the most outstanding. Its sensing principle is based on the sensitive characteristic of its wavelength to the measurand, such as temperature and strain. FBG sensors have several inherent advantages over conventional electrical sensors, such as small size, light weight, non-conductivity, fast response, resistance to corrosion, higher temperature capability, and immunity to electromagnetic noise and radio frequency interference¹⁻⁵. When civil engineering is monitored by FBG sensor, sensing characteristics of FBG sensor are affected by different fixing methods. Therefore, it is necessary to investigate the difference between measurement value and true value. In this paper, finite element method is used, this is to say that, uniform strength beam is divided into a number of finite elements to analyze. The strain produced by uniform strength is simulated based on ANSYS 10.0 software, and measured by FBG. Finally, the difference of the measured value and the

¹ Foundation item: 浙江省科技厅重大科技专项（编号 2008C13041-1）
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simulated value is investigated [6].

2. Operating principle

The Bragg wavelength related to the grating period \( \Lambda \), and the effective refractive index \( n_{\text{eff}} \), which is given by

\[
\lambda_B = 2n_{\text{eff}} \Lambda
\]  

When the temperature is constant, both \( n_{\text{eff}} \) and \( \Lambda \) vary with the changes of the strain in the fiber. The Bragg wavelength shift caused by variation of the strain is given by is given by

\[
\frac{\Delta \lambda}{\lambda} = (1 - P) \Delta \varepsilon
\]  

Where \( P \) is the valid elastic-optic constant, \( \Delta \varepsilon \) is the variation of the strain[7]. The strain caused by uniform strength beam is given by

\[
\varepsilon = \frac{hX}{l^2}
\]  

Where \( h \) is the thickness, \( l \) is the length, and \( X \) is the maximal flexivity of the uniform strength beam. From the above equations, it is easy to find that the Bragg wavelength shift is linear with the strain caused by the uniform strength beam [8, 9].

3. ANSYS simulation

The ANSYS program is composed of PREP7, SOLUTION, and POST1. In the PREP7, the model of the uniform strength beam is built and meshed. The element type is defined solid95, which is a higher order version of the 3-D 8-node solid element solid45. It can tolerate irregular shapes without as much loss of accuracy, so it can be used to analyze the strain caused by uniform strength beam. The result is shown through the cloud picture.

The material of the uniform strength beam is iron, whose elastic modulus is 1.6e11pa. The left end of the beam is fixed, and the right end is applied some force, as shown in Fig.1. The flexivity of the uniform strength beam is simulated by ANSYS software, and the cloud pictures are acquired when applied force 2.45N, 4.9N, 7.35N, 9.8N, 12.25N, 14.7N, as shown in Fig.2. The strain can be calculated by equation (3), as shown in Fig.3. The results show that the strain caused by the uniform strength beam is linear with the applied force, which is consistent with the theory.
Figure 1: The model of the uniform strength beam

(a) applied force 2.45N
(b) applied force 4.9N
(c) applied force 7.35N
(d) applied force 9.8N
Figure 2 The flexivity of the uniform strength beam when applied different forces, the colors represent the values of the flexivity profiles.

Figure 3 The maximum flexivity and the strain obtained from simulation

4. Experiment
4.1 Experimental setup
We use the SM130 FBG demodulation produced by MICRON OPTICS Ltd, whose resolution is 2pm. The FBG sensor is produced by NINGGOBO SANGONG Ltd. Its center wavelength is 1547.799nm at temperature 17°C. The experimental setup is shown in Fig.4. The probing light is transmitted to the FBG sensor from the broadband source which is integrated in the demodulator. And then the reflected signal of the FBG sensor is transmitted back to the demodulator, which will be display on the computer. A fiber Bragg grating sensor was fixed on the uniform strength beam with modified acrylate.
In order to change the strain in the FBG sensor, the weight at the end of the uniform strength beam is varied.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure4.png}
\caption{Experimental setup}
\end{figure}

4.2 Experimental results and discussion

The wavelength shifts of FBG sensor fixed with modified acrylate are measured at the force 0, 2.45N, 4.9N, 7.35N, 9.8N, 12.25N, 14.7N when the temperature is 25℃. The strain can be obtained through the equation (2), as shown in the Fig.5. It shows that the strain caused by the uniform strength beam is linear with the load force. Also, in the three repetitive measured experiments, the error of the wavelength shift is less than 5pm, which shows that the temperature is constant.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure5.png}
\caption{FBG sensor wavelength and strain response under different applied forces}
\end{figure}

The strain comparison between the simulated and measured is shown in Fig.6. The strain of the uniform strength beam measured with FBG when applied force is 2.45N, 4.9N, 7.35N, 9.8N, 12.25N, and 14.7N. The corresponding strain is 48.46 με, 96.92 με, 143.38 με, 192.64 με, 242.20 με, 290.70 με by ANSYS simulation, and 45.33 με, 90.66 με, 135.08 με, 179.50 με, 223.92 με, 269.25 με by FBG demodulation. The strain obtained by simulation and measurement both has excellent linearity. The sensitivity is 19.72με/N for ANSYS simulation and 18.32με/N for measurement by FBG, respectively.
The linearly dependent coefficient is 0.99997 for ANSYS simulation and 0.99999 for measurement by FBG, respectively, which proves that the strain is excellent linear with the applied force. The experimental results are consistent with the simulation results, with the maximum measurement error of strain being 7.4%. The error is caused by the error of the elastic modulus between the parameter value and the real value, and by the stress transmission error caused by FBG fixing method.

![Figure.6 Strain of simulation and experimental measurement versus applied forces.](image)

5. Conclusions
The flexivity profile produced by uniform strength beam with different forces is simulated by ANSYS software. In experiment, a fiber Bragg grating sensor is fixed on the uniform strength beam with modified acrylate. The strain is measured by FBG. Both the simulation and experimental results show that, the strain induced by the uniform strength beam is linear with the load force. And the experimental results are consistent with the simulation results, with the maximum measurement error of strain being 7.4%, which is acceptable to the applications of the civil engineering. This paper indicates that, the FBG sensor fixed with modified acrylate is proved to be effective and reliable in the applications of civil engineering.

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