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Feasibility study of vibration monitoring by using fibre Bragg grating sensors

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ABSTRACT: In this paper, the feasibility study by using the FBG sensors are divided into two cases and its results are shown. Firstly, the FBG strain sensors were installed on the surface of girders of the steel bridge and it has been shown that the measured strains give stable and high-accuracy vibrational information for over 8 years. Secondly, the FBG accelerometers were applied to the existing building and it has been shown that the various seismic performance of the building can be analysed through the real-time vibration monitoring by using the FBG accelerometers for over 3 years. It is suggested that the FBG sensors can be easily applied to the existing buildings or civil structures for reasonable structural health monitoring.

1 INTRODUCTION

By the great east japan earthquake, a lot of buildings and civil structures were seriously damaged. And in recent years, it is pointed that the natural period of the buildings or civil structures varies by the earthquake damages or aging degradation. Hence, the structural health monitoring (SHM) is developed in order to detect the degradation of the structural mechanical performance. We have been performing the vibration monitoring by using the fibre Bragg grating (FBG) sensors. Based on these, this paper shows the two cases of results of feasibility study on the vibration monitoring by using the FBG sensors. Firstly, the FBG strain sensors were installed on the surface of girders of the steel bridge and it has been shown that the measured strains give stable and high-accuracy vibrational information for over 8 years even if it setup in the outdoors. Secondly, the FBG accelerometers were applied to the existing building and it has been shown that and the various seismic performances of the building can be analysed through the real-time vibration monitoring by using the FBG accelerometers for over 3 years. Furthermore, it is made clear that the analytical procedure to investigate the vibration characteristics by using the FBG accelerometer in this paper.

2 FBG SENSOR AND FBG ACCELEROMETERS

The FBG sensor consists of the clad and the core in which the simple elements called Bragg diffraction grating are photo-imprinted as shown in Fig.1. The sensor length is 10 millimetres and the grating pitch is around 500 nanometres. When a broadband spectrum light comes in through the grating, the specific narrowband spectrum light in dependence on the grating pitch, so-called Bragg wavelength reflects. The Bragg wavelength varies due to the elongation of the sensor that corresponds to fractional change in grating pitch. Then the measured shift of the

Bragg wavelength introduces its corresponding strain value through the preliminary calibrated formula having the variables for the adopted sensor. And it is possible that many FBG sensors put in one fibre optic network as shown in Fig. 2 because the wavelength of the narrowband spectrum light can vary.

The FBG accelerometer consists of the FBG sensor and the pendulum as shown in Fig 3. It converts strain to acceleration by using the pendulum. The acceleration, *Acc*, can be expressed using the following equation,

$$Acc = (\lambda - \lambda_0)/SF \quad (1)$$

where λ_0 is the Bragg wavelength in strain less condition, λ the measured Bragg wavelength and SF [nm/(cm/s^2)] the specific coefficient of the FBG sensor to convert wavelength into acceleration. Fig. 4 shows the frequency response characteristics of FBG accelerometers. It has stable characters between 0.1Hz to 30Hz.

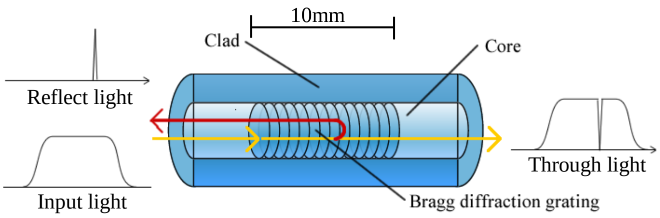


Figure 1. FBG sensor.

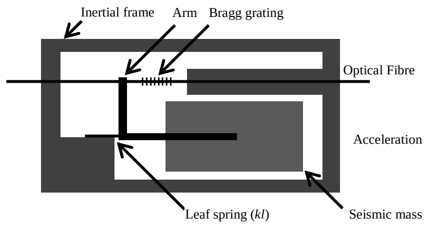


Figure 3. FBG accelerometer.

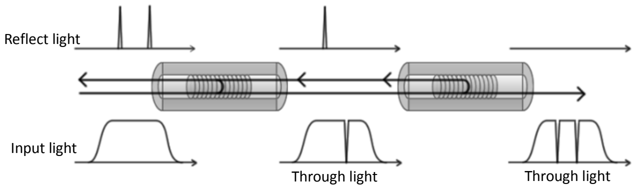


Figure 2. Diagram of the multi-FBG mesurement.

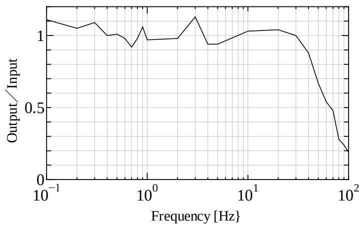


Figure 4. Frequency character of FBG accelerometer.

3 DYNAMIC STRAIN MONITORING FOR BRIDGE

The adopted bridge for vibration monitoring is a Hatakeda-bridge in Toyohashi as shown in Fig. 5. The targeted bridge has 28.1m span direction and with steel girders. The FBG strain sensors were installed in bottom flanges as shown in Fig. 6. The dynamic strain monitoring by using FBG sensor has been continuing from December, 2004. In this study, the temperature calibration was not applied because the analytical time was not long enough to vary the temperature.

Fig. 7 shows the time history strain response and Fig. 8 as the Fourier spectrum in 2005. The high-accuracy dynamic strains are measured by the FBG sensor and the strain amount is corresponding to the weight of the cars running over the bridge as shown in Fig. 7. The predominant frequency of the adopted bridge is assumed 4.33Hz as shown in Fig. 8. Also, Fig. 9 shows the time history strain response and Fig. 10 as the Fourier spectrum in 2012. It is determined that the FBG strain sensor can measure the dynamic strains for over 8 years. Also the predominant frequency did not vary significantly. However, the clutter of the measured strains slightly increased as shown in Fig. 9.

Figure 5. The adopted bridge.

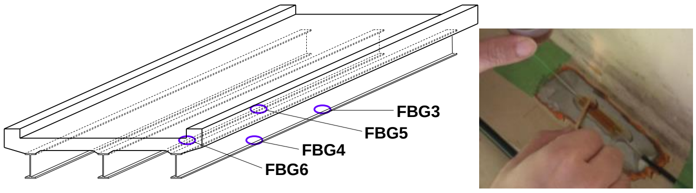


Figure 6. Setup condition of FBG sensor.

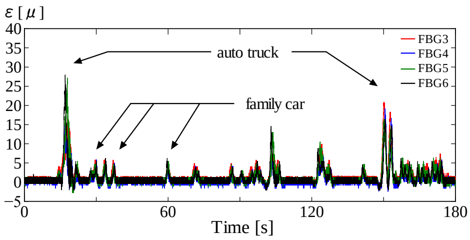


Figure 7. Time history response strain in 2005.

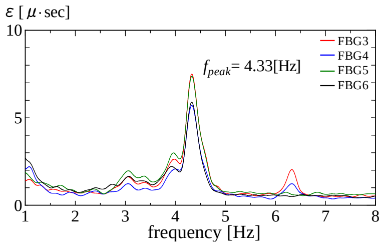


Figure 8. Fourier spectrum in 2005.

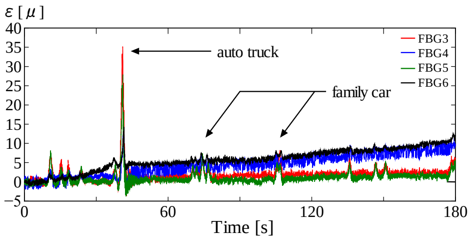


Figure 9. Time history response stain in 2012.

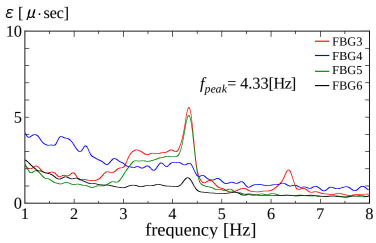


Figure 10. Fourier spectrum in 2012.

4 VIBRATION MONITORING FOR BUILDING

The adopted building for vibration monitoring is a building in Toyohashi University of Technology as shown in Fig. 11. The targeted building has 9-storey steel-framed reinforced concrete structure. The height is 38.8m (including penthouse), the length of longer direction (east and west direction) is 28.8m and the length of shorter direction (north and south direction) is 16.8m. The FBG accelerometers were installed in 1st and 9th floor and the monitoring system was put in 1st floor as shown in Fig. 12. The acceleration response monitoring by using FBG accelerometer has been continuing from October, 2009. Then, 20 acceleration responses have been obtained by the earthquake. Table 1 shows instrumental seismic intensity and the measured numbers. Fig. 13 shows the analytical methods for the obtained acceleration responses. Firstly, the relative waveform is made by subtracting 1st floors waveform from the 9th floor waveform. Secondly, the waveform is transformed to Fourier spectrum by FFT (Fast Fourier transform) and the predominant frequency of the adopted building is obtained by Fourier spectrum. The velocity waveform and the displacement waveform are calculated from acceleration waveform by the linear acceleration method. At this time, the band-pass filter and the baseline correction are applied to the waveform because of the long-period noise and the offset of the baseline. Fig. 14 shows character of the band-pass filter. Finally, 1st floor acceleration waveform is regarded as ground acceleration waveform and the time history response analysis of SDOF model (a single degree of freedom system) is analysed. Then, the maximum responses value is obtained. Fig. 15 shows an example of analysis result. In this study, the length of time history acceleration response is determined to 5 minutes.

Figure 11. The adopted building.

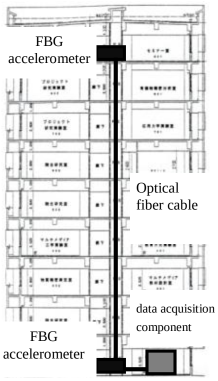


Figure 12. Setup condition of vibration monitoring system.

Table 1. The number of times of the vibration

Level	0	1	2	3	Sum
Number	1	11	5	3	20

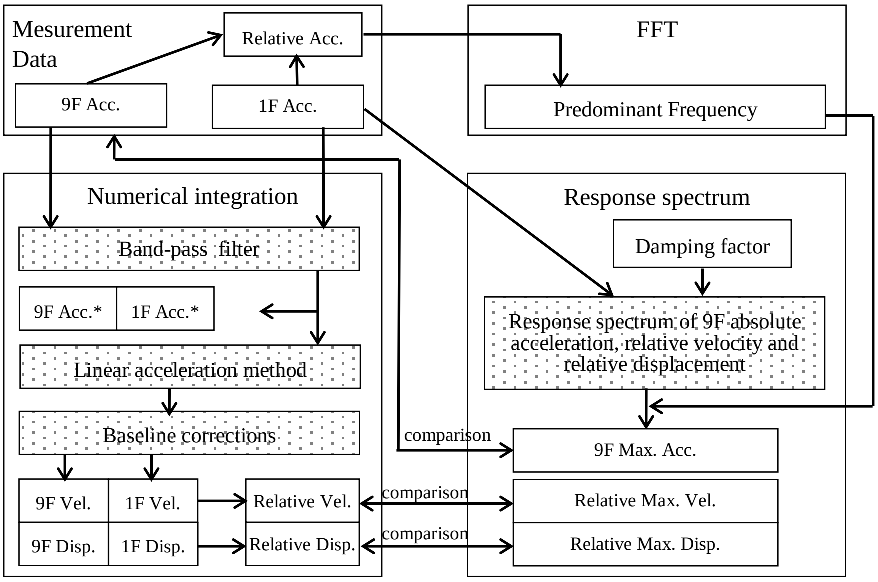


Figure 13. Analytical methods for the present FBG accelerometer.

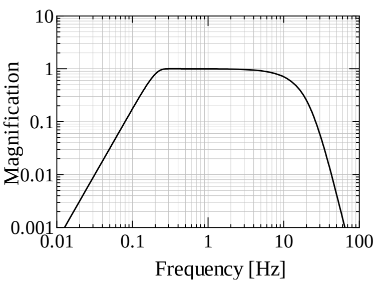
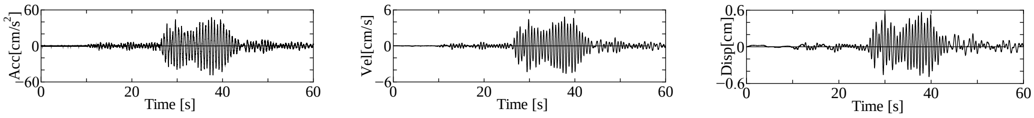
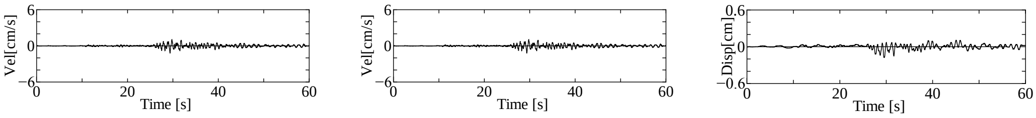


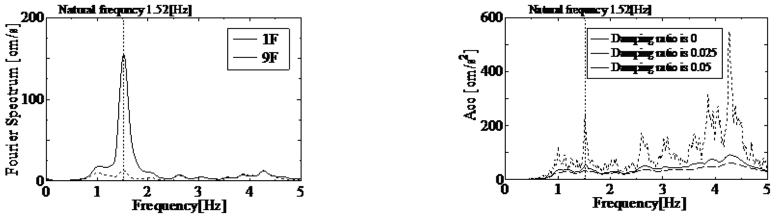
Figure 14. Band-pass filter.



Time history response at 9th floor



Time history response at 1st floor



Fourier spectrum Absolute acceleration response spectrum

Figure 15. Response behaviour by the earthquake in 15th March 2011.

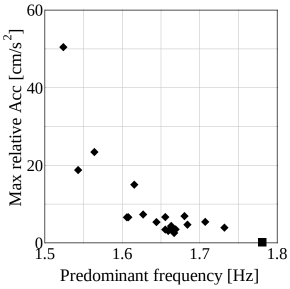


Figure 16. Maximum response acceleration - predominant frequency relationship.

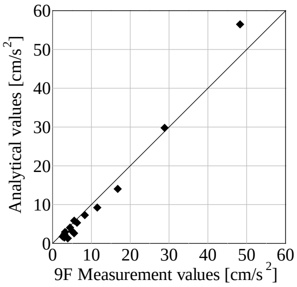


Figure 17. Relationships among maximum acceleration responses.

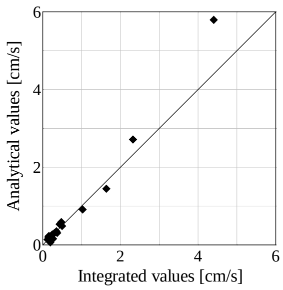


Figure 18. Relatioinships among maximum velocity responses.

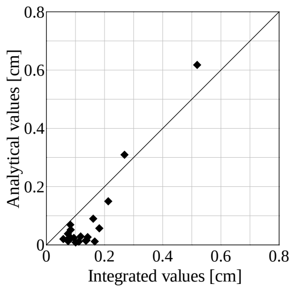


Figure 19. Relatioinships among maximum displacement responses.

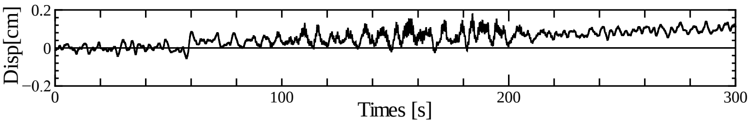


Figure 20. Example of the response displacement calculated by numerical integration.

Fig. 16 shows maximum relative acceleration - predominant frequency relationships. The predominant frequency gets lower with the relative acceleration increase and attains the certain frequency. Also, it is made clear that the amplitude dependency between the natural frequency and the maximum relative acceleration according to this result. On the other hand, the natural frequency of the adopted building is 1.38Hz obtained by eigenvalue analysis. The measurement results are higher than the analytical result because of the effect of non-structural wall. Fig. 17 shows the relationship between the maximum response accelerations calculated by the response spectrum analysis and the maximum response accelerations obtained by the measurement at 9th floor. The damping ratio was assumed to be 2.5% and the analytical values are corresponding to the measured one. Fig. 18 shows relationships between the maximum velocity responses calculated by the time history response analysis and the maximum velocity response obtained by integral calculus of the acceleration waveform. Also, Fig. 19 shows relationships of response displacements. The measurement value or numerically-integrated value corresponds with the analytical value in the maximum velocity, Fig. 18, as with the acceleration, Fig. 17. Therefore it is possible to transform to the velocity from the acceleration as with the traditional accelerometers. On the other hand, in the case of the maximum displacement, the numerically-integrated value is bigger than the analytical value in small displacement area as shown in Fig. 19. This is because the long-period noise and the declination of the baseline affect the numerically-integrated values as shown in Fig. 20. In the case of the small seismic intensity, it is suggested that the reliability of the displacement waveform decreases by using the FBG accelerometer.

5 CONCLUSION

This paper shows the two cases of results of feasibility study on the vibration monitoring by using the FBG sensors. It is determined that the FBG strain sensor can measure the high-accuracy strains under dynamic loading for over 8 years even if it setup in the outdoors. Also it is verified that the FBG accelerometer can measure the acceleration responses and efficiently investigate the vibration characteristics in real time. Furthermore, the analytical procedure, Fig. 13, to investigate the vibration characteristics by using the FBG accelerometer has been made clear. Based on these, it has been suggested that the present FBG sensor can provide the long-term, stable and high-accuracy SHM for any civil or architectural structures. However, it is future subjects that the damage level is assessed by using the present FBG long-term dynamic strain monitoring system. On the other hand, it has been shown that the present proposed FBG acceleration monitoring system would be useful for assessing the damage level after the earthquakes because the relative story displacement corresponds to the damage level.

REFERENCES

Kersey, A.D., et al. 1996. Progress towards the development of practical fiber Bragg grating instrumentation systems. *SPIE*, Vol.2829, 1-24.

Mita, A., Yokoi, I. 2001. Fiber Bragg grating accelerometer for buildings and civil infrastructures, *Proceedings of the international society for optics and photonics*, Vol. 4330: 479-486.

Yamada, S., Nakazawa, H.Y. and Komiya, I. 2003. Hearth monitoring of long-lived structural members reinforced with fiber multi-axial netting polymer layers having fiber optic sensors. *Advancement of Material and Process Engineering*, SAMPE, 183-186.

Yamada, S., Matsumoto, Y., Hiramoto, T., and Yamada S. 2005. Fiber optic sensing for steel bridges. *Proceedings of the First International Conference on Advances in Experimental Structural Engineering*, Volume2: 627-632.