Vibration-based structural health monitoring from operational long-gauge fiber optic strain data

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Abstract

Vibration monitoring from strain data is a promising alternative to acceleration-based monitoring because a dense measurement grid can be achieved at a relatively low cost and because strain mode shapes are more sensitive to local stiffness changes than displacement mode shapes. However, the feasibility of monitoring strain mode shapes of full-scale civil structures, where the operational dynamic strain levels are of very low amplitude and temperature changes can influence the modal characteristics, has remained an open question. The present work provides a proof of concept in which the deck of a steel bowstring railway bridge is instrumented with 80 Fiber-optic Bragg Grating strain sensors, multiplexed in four fibers, that are interrogated with a technique that achieves high accuracy and precision. For more than a year, the natural frequencies and strain mode shapes of 10 modes have been automatically identified from operational strain time histories, with typical root-mean-square values of 0.01 microstrain, on an hourly basis. Furthermore, using these modal data, the influence of temperature fluctuations and that of a retrofitting of the hangers connecting the bridge deck and the bow, which took place during the monitoring period, are extensively investigated. Both have an influence on the overall stiffness of the bridge and therefore they result in clear changes in the natural frequencies. They do not have an influence on the local stiffness and therefore they do not influence the strain mode shapes, except when the retrofitting induces an interaction between previously well-separated modes.

Keywords: Structural health monitoring, fiber optic sensors, bridge engineering, vibration testing.

1 Introduction

Vibration-Based structural health monitoring (SHM) relies the fact that the modal characteristics of a structure (eigenfrequencies, damping ratios and mode shapes) depend entirely on its stiffness, mass and energy dissipation. Structural damage results in a stiffness change, so it can therefore be detected, in principle, by monitoring modal characteristics. Eigenfrequencies can be obtained from only one or a few sensors, e.g. accelerometers, placed at proper locations. As a result, they are very often used for SHM. Eigenfrequencies are mainly sensitive to global stiffness modifications. Local damage of small severity therefore has a small influence on eigenfrequencies, while the global stiffness is often significantly influenced by variations in environmental factors such as temperature, necessitating data normalization [1]. Displacement mode shapes can also be used for SHM. They are attractive in the sense that they are more sensitive to local stiffness changes than eigenfrequencies, and less sensitive to temperature variations. The main disadvantage is that a dense sensor grid is required for good damage localization capabilities,

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