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# Modal strain-based SHM of steel railway bridges

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**Abstract:** Natural frequencies are the most widely used modal characteristics in vibration-based monitoring. However, they can be highly influenced by temperature and this influence can completely mask the effect of damage. Displacement mode shapes are less sensitive to temperature, but obtaining them in a dense grid, a requirement for damage localization, is cumbersome due to the large number of sensors needed. Strain mode shapes on the other hand can be nearly insensitive to temperature, while obtaining them in a dense grid is possible when fiber-Bragg gratings (FBG) are used. This work presents an overview of the continuous modal strain-based monitoring of three steel railway bridges of different structural typologies. All bridges were instrumented with FBGs and their strain mode shapes were automatically obtained on an hourly basis from ambient and operational dynamic strains. The influence of temperature on the strain mode shapes is investigated and their low sensitivity to temperature is confirmed for all bridges. The damage detection and localization capabilities of the strain mode shapes are also demonstrated numerically and experimentally.

**Keywords:** modal strains, vibration-based monitoring, environmental influence, damage localization

## 1 Introduction

Strain mode shapes [1] are an advantageous alternative to displacement mode shapes for vibration-based monitoring (VBM) [2]. Strain mode shapes consist of modal strains, similarly to the conventional displacement mode shapes, which consist of modal displacements. Modal strains are obtained from dynamic strain measurements. Dense strain sensor grids can be easily achieved when fiber-Bragg gratings (FBG) are employed, due to their multiplexing possibility. Modal strains are generally much more sensitive to local damage than modal displacements and less sensitive to temperature than natural frequencies [2, 1]. Laboratory experiments on concrete beams have illustrated these advantages [1].

The assessment of the strain mode shapes' performance in situ has remained an open problem until recently. This work presents the results, conclusions and lessons learned from the continuous dynamic strain monitoring with FBGs of three steel railway bridges of different structural typology. The natural frequencies and the strain mode shapes of these bridges were automatically identified on an hourly basis through the method that was developed and described in [3], in order to evaluate their condition. The influence of temperature on the monitored quantities is assessed, as well as the influence of real-life and simulated damage.

## 2 Modal strain-based monitoring of railway bridges

A steel Vierendeel arch bridge, a steel tied-arch bridge and a steel riveted beam bridge have been monitored in the course of the past four years. The bridges are shown in Figure 1.

**Figure 1**: Left: The Vierendeel arch bridge (Mechelen, Belgium). Center: The KW51 tied-arch bridge (Leuven, Belgium). Right: The Nieuwebrugstraat riveted beam bridge (Ronse, Belgium).

The same observations were made for all bridges, regardless of their type. First, the strain mode shapes of all identified modes were found to be insensitive to temperature changes higher than 0°C. Exception are the strain mode shapes of the higher order modes of the KW51 bridge, which were found to be sensitive to frost, due to the freezing of the ballast layer. However, this influence was significantly smaller than the influence that was observed on natural frequencies due to frost and most importantly, to the influence of small-scale, simulated damage on the strain mode shapes. Second, the natural frequencies of all modes were found to be influenced by temperature. The change in natural frequency due to the change in temperature was higher than the change imposed by small-scale damage in both simulated and real-life damage cases. This underlines the necessity of damage normalization, before using the natural frequencies for monitoring purposes. Third, contrary to natural frequencies, strain modes shapes were highly sensitive to small-scale damage that occurred in the vicinity of the monitored locations, an outcome that combined with their temperature insensitivity renders them ideal for direct damage assessment.

## 3 Conclusions

The observations from these three case-studies demonstrate the high potential of strain mode shapes for damage detection and localization and consequently, for the practical VBM.

## References


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