Temperature dependence of eigenfrequencies on a railway bridge

Ignacio GONZALEZ
PhD Student
KTH Royal Institute of Technology
Stockholm, Sweden
ignacio.gonzalez@byv.kth.se

Ignacio Gonzalez, born 1985, received his civil engineering degree from KTH Royal Institute of Technology, Sweden. He has since then occupied a position as PhD student at the aforementioned Institute. His fields of research are health and traffic monitoring.

Summary

In this study it is demonstrated that ballasted bridges can exhibit a step-like variation on the eigenfrequencies as the temperature varies. This change manifests as an important increase in the eigenfrequencies as temperature drop below 0 °C. The reason for this phenomenon is unknown but it is theorized that it is due to frozen water acting as a bonding agent between the ballast particles, increasing the stiffness of the ballast layer and thus the eigenfrequencies of the bridge. The step-like nature of the change and the fact that it occurs at around 0 °C seem to point in this direction. A Finite Element model of the bridge was developed to explore what elasticity modulus for the ballast would lead to an increment of the eigenfrequencies that matches the observed one.

Keywords: High speed railway bridge, Monitoring, Temperature effects.

1. Introduction

Typically when railway bridges are designed for low speeds, only static analyses are performed. A number of simplifying assumptions are usually made for these calculations. For example, when the modulus of elasticity or other stiffness properties of a material or component is unknown, it is safe for a static analysis to assume a very low value. However, these assumptions need not to be safe in dynamic analyses. Results from these linear dynamic analyses are only accurate if the eigenmodes and eigenfrequencies of the structure are accurately represented by the FE model. Both these features can be unrepresentative of the real structure if too low a stiffness is assumed for a material, as it is sometimes done for static analyses. Furthermore, some of these parameters can be expected to change with time. Therefore, to ensure the safety and comfort levels in bridges, simulations should be made taking into account the natural variability of certain parameters. It follows that, for high-speed bridges, it is important to have a precise estimation of the values that these parameters might assume during the lifetime of the structure. In this particular study we look at the variability of ballast stiffness in extreme low temperatures (-10 °C to -30 °C) that are common in colder climates such as the one in northern Sweden. It was observed, though, that the eigenfrequencies of a bridge could vary considerable from winter to summer (18% for the first eigenfrequency). This change is far more than what could be expected by thermal expansion in a simply supported beam and the change was step-shaped, rather than linear. It was therefore attributed to an increased stiffness in the ballast due to water freezing and acting as bonding between the ballast particles. The goal of this study is to infer some stiffness properties of the stiff ballast layer from measurements.

https://doi.org/10.2749/222137813806501687

2. Bridge and Instrumentation

The Skidträsk Bridge is a one span, simply supported, composite railway bridge situated along a part of the Bothnia Line. The bridge is composed of two identical, I-beams with variable cross section, a concrete slab and a ballast layer with sleepers and tracks. The bridge is skewed, so the beams run parallel but with a longitudinal offset. The two beams are connected by four transversal stiffeners. The reinforced concrete slab is U-shaped and of 330 mm of thickness. The ballast layer is 600 mm thick. The Skidträsk Bridge was instrumented with four accelerometers, a thermocouple and four strain gauges. The accelerometers where located one at each quarter point (on the east beam), and two at the mid-span point (in both the east and west beams). All the accelerometers measured vertical acceleration. Two longitudinal strain gauges were located at the upper and lower flanges of the east beam at mid-span. Two transversal strain gauges were placed at the upper flange at the mid-span and quarter point of the east beam. The setup was used to gather data from train passages from all seasons and spanning temperatures of -30 C to 30 C. From these measurements the first bending and torsional eigenfrequencies were extracted. These analyses revealed that the eigenfrequencies of the bridge varied with temperature. For example the first eigenfrequency was clustered around a value of 3,8 Hz for temperatures above 10 C and around a completely different value of 4,5 Hz for temperatures below -10 C. Given the binary nature of this change, it was assumed that it was caused by the freezing of water between the ballast particles working as a bonding agent. A three-dimensional Finite Element model was constructed that capture the bending and torsional behavior. The numerical values in the stiffness of the ballast could then be tuned to match the experimental results.

3. Results and conclusions

For ballast elasticity modulus of 0 GPa the model's first two eigenfrequencies lay at 3.8 and 4.7 Hz, which coincides with the values observed in hot conditions. To obtain good agreement for in the cold condition the elasticity modulus of the ballast needed to be set at around 3 GPa. There is a large spread of the observed eigenfrequencies in the cold conditions, so a range of different values gave plausible results. Between 2 and 4 Gpa where found to lay within the measured values of eigenfrequencies. In this study it was shown in this study that ballasted bridges can show a step-like variation of the eigenfrequencies with temperature. This change cannot be attributed to thermal variations of the elasticity modulus of steel and concrete, since it was observed to be non-linear and its magnitude is far larger than what is expected from this phenomenon. Water freezing and acting as a bond between ballast particles was the alternative explanation offered. This would explain at least the step-like shape of the frequency vs. temperature curve. The eigenfrequencies of the bridge showed important variance for any given temperature, but especially so for the cold conditions. This is compatible with the idea of water freezing being the cause of the frequency shift, since the bonding properties of ice can be expected to vary wildly with parameters other than air temperature. The changes observed in the eigenfrequencies are large enough to render numeric simulations inaccurate if not taken into consideration.

4. Acknowledgments

Long Life Bridges is a European Commission, Marie Curie 7th Framework Programme Project, funded under the Industry and Academia Partnerships and Pathways call, Grant Agreement No. 286276.