Modelling the Temperature-Dependent Dynamic Behaviour of a Timber Bridge with Asphalt Pavement

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Abstract

The fundamental frequency and the corresponding damping value are the main design parameters for footbridges against excessive vibrations induced by pedestrians. Since pedestrians typically walk at a pace of 1.6-2.4 Hz, this frequency range as well as the range of the second harmonic, namely 3.5-4.5 Hz, should be avoided. However it has been observed that the fundamental frequency of a bridge with asphalt pavement is not a constant but can vary considerably with temperature. This effect is mainly due to the temperature-dependent material behavior of asphalt. As shown in Figure 1, the storage module varies by two orders of magnitude in the temperature range between -10 °C and + 40 °C. To better understand the influence of the temperature on the dynamic behavior, a timber bridge was monitored over a long period, and frequencies and damping values were measured for a broad temperature range. These values have been compared with a numerical model. The bridge geometry is shown in Figure 2. The timber structure is modeled as an orthotropic material, while the asphalt pavement is represented by a viscoelastic material. Since the viscoelastic material leads to a complex modulus, the complex eigenvalue problem was solved and the frequencies and the damping ratios were extracted from the complex eigenvalues. At high temperatures, the asphalt merely acts as an added mass without stiffness. This fact was used to calibrate the model without the effect of asphalt. In the present structure, the eigenfrequency of each mode is influenced by a different parameter. The first mode depends mainly on the bending stiffness of the timber beams, the second mode is controlled by the elastic rotational stiffness of the interior joints, and the third mode is modified by the shear stiffness of the timber beams. Three mode shapes for the calibrated model at 40 °C are presented in Figure 3. Using the calibrated model and engaging the effect of asphalt at different temperatures, the calculated frequencies were considerably too high at low temperatures. The effect of the asphalt stiffness had thus to be reduced. This was achieved by introducing an elastic interface between the timber deck and the asphalt layer. Calibrating the elastic stiffness of this interface improved at the same time the frequencies and the damping values of all three modes over the whole temperature range. A comparison with measured frequencies is shown in Figure 4. Although the model is pure mechanical, a number of advanced modeling techniques have been used: orthotropic elastic material, viscoelastic material, complex eigenvalues, elastic interface, and parameter sweep over temperatures.

Figures used in the abstract

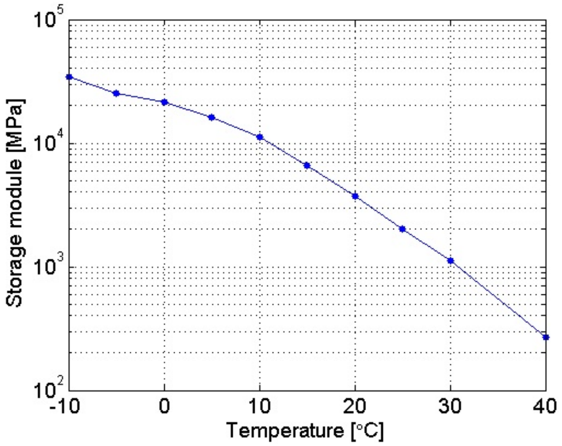

Figure 1: Storage modulus of asphalt vs. temperature.

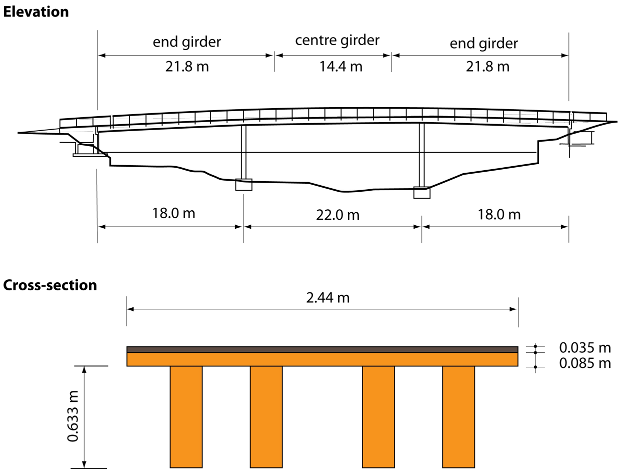

Figure 2: Bridge geometry.

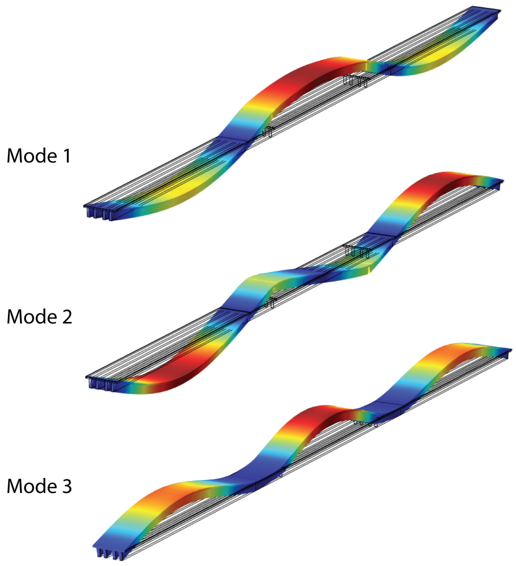

Figure 3: Mode shapes.

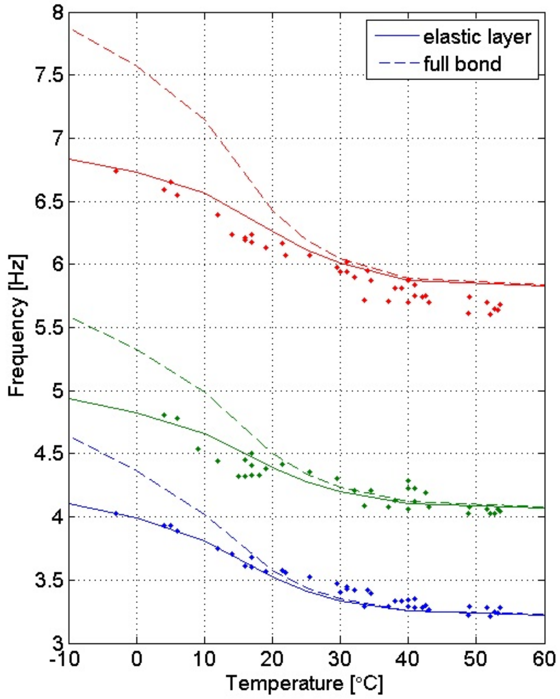

Figure 4: Comparison with measured frequencies.