Modelling the temperature-dependent dynamic behaviour of a timber bridge with asphalt pavement

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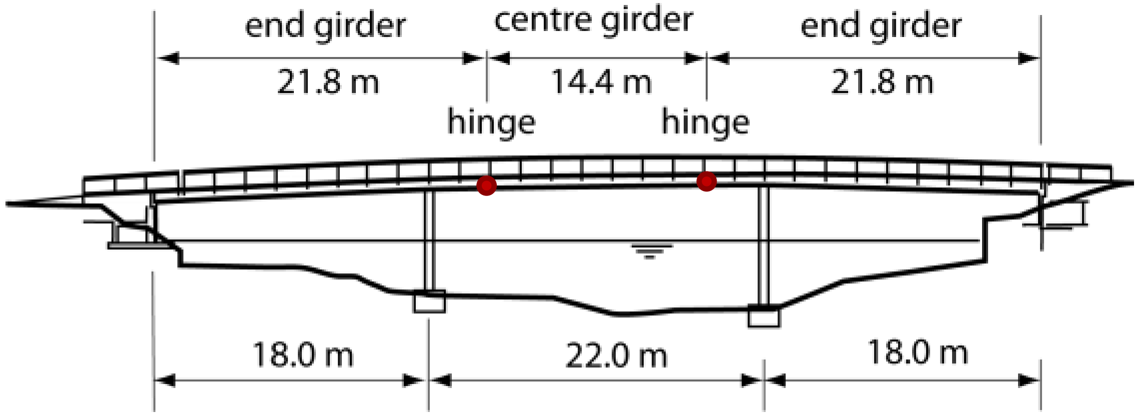
Introduction

- Pedestrian bridges often exhibit excessive vibrations due to walking or jogging
- Avoid fundamental frequencies in ranges 1.6–2.4 Hz and 3.5–4.5 Hz
- Long-term monitoring shows large changes in frequencies with asphalt temperature
- Modelling of this effect provides insight for design

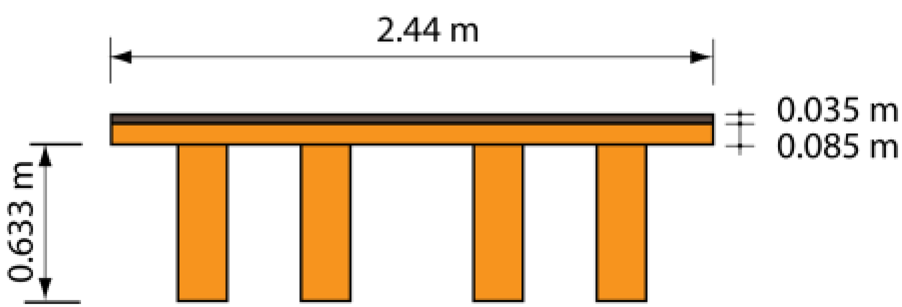
Bridge geometry

Elevation



Gerber hinges

Cross-section



Timber

Cross-laminated timber for deck

Glue-laminated timber for beams

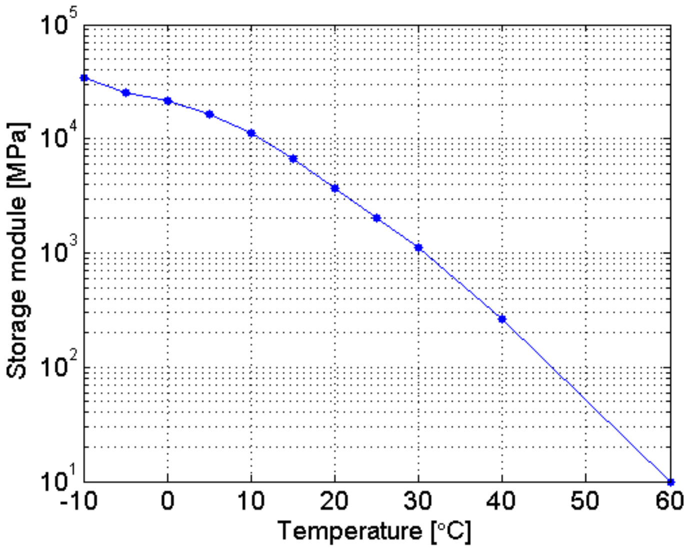
- Orthotropic material: 3 Young's moduli, 3 shear moduli, 3 Poison's ratios
- For beam, only $E_{\parallel}$ and $G_{\parallel\perp}$ important, but other values must be consistent.
- Cannot use isotropic material → negative compressibility

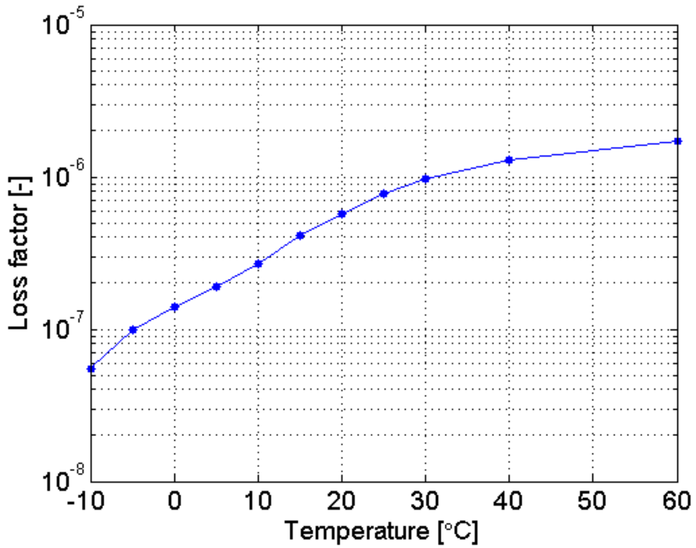
Asphalt

- Asphalt is viscoelastic (temperature and frequency dependent)
- Complex modulus: storage modulus G', loss modulus G'', loss factor η

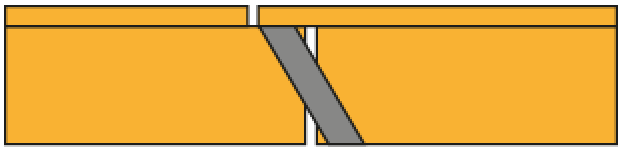
$$G^* = G' + \mathrm{i}G'' = G'(1+\mathrm{i}\eta)$$

- Consider only temperature dependence (constant frequency 4 Hz)
- Use constant bulk modulus → variable Poisson's ratio

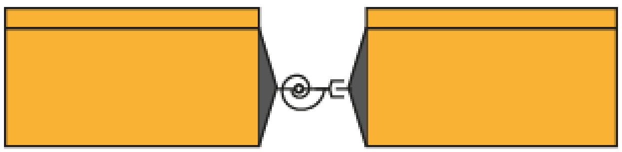




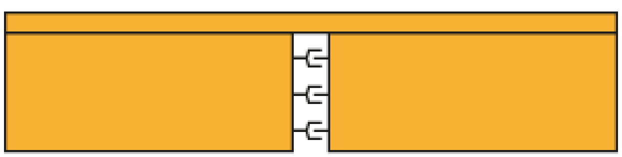
Interior hinges



- Actual construction with steel plate



- Rigid connector
  - Spring on relative rotation not implemented in V4.2a
  - Possible with weak constraint, tricky in 3D with Euler parameters

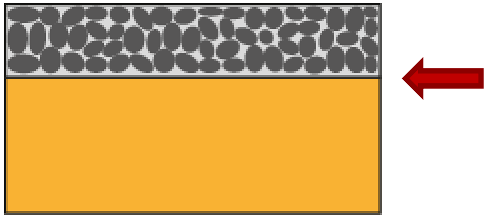


- Constrain vertical displacement
  - Simple
  - Provides right rotational stiffness

Interface between asphalt and timber

- Elastic shear connection reduces bending stiffness

- Available in COMSOL on internal boundary



- Possible explanation: weak interface in plane without aggregate interlock

Complex eigenvalues

- Asphalt: temperature-dependent complex shear modulus

$$G^* = G'(1 + \mathrm{i}\eta_A)$$

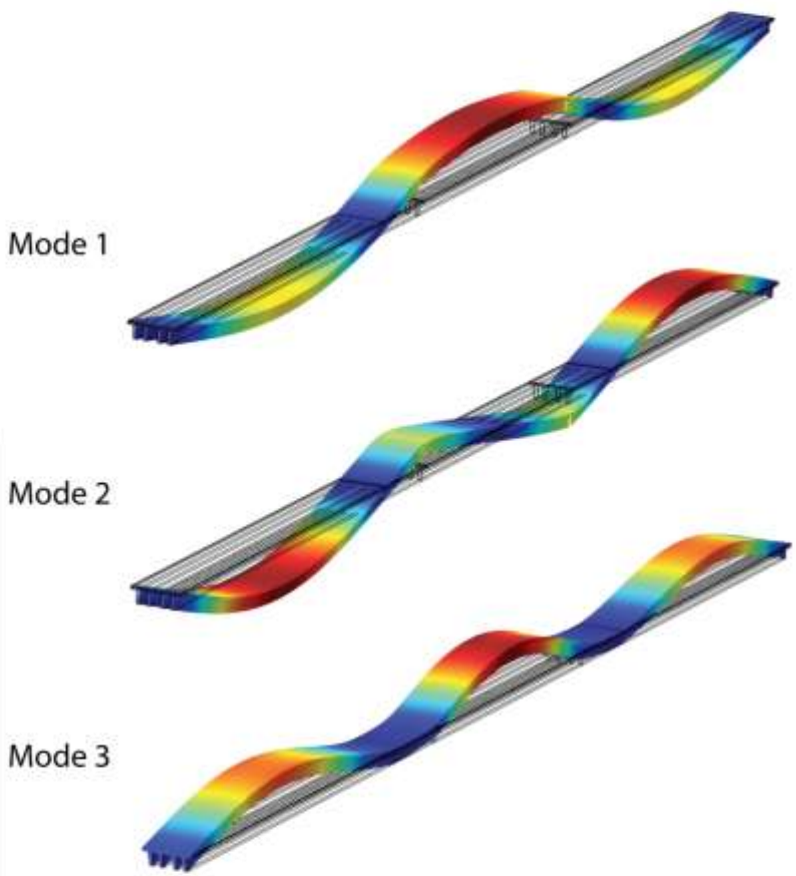
- Timber: isotropic loss factor

$$E^* = E(1 + \mathrm{i}\eta_T) \qquad \eta_T = 0.04 \Leftrightarrow \zeta = 0.02$$

- Complex eigenvalue → frequency and damping of total structure

$$\lambda = \zeta\omega_n - \mathrm{i}\,\omega_n\sqrt{1-\zeta^2}$$

Mode shapes and calibration



- For T= 50°C no influence of asphalt (except mass)
- Three parameters with weak coupling:
  - Mode 1: Young’s modulus of timber
  - Mode 2: Rotational stiffness in hinges
  - Mode 3: Shear modulus of timber
- For T= 0°C large influence of asphalt
- Calibration of timber-asphalt interface stiffness

Results

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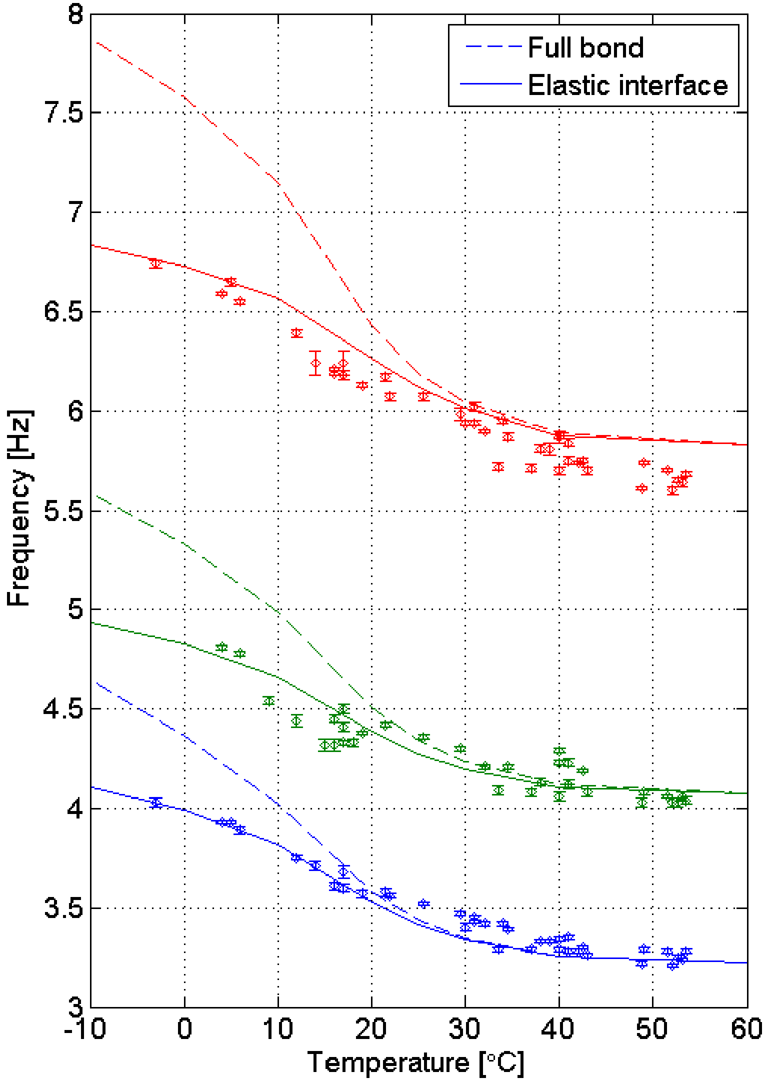

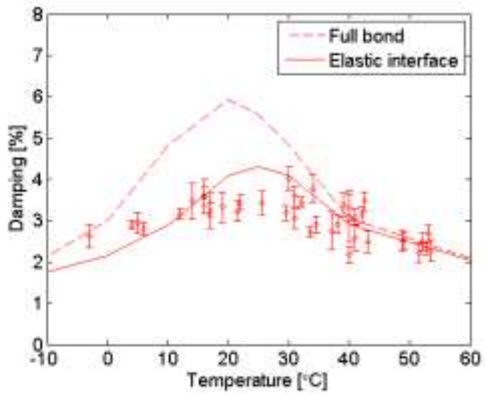

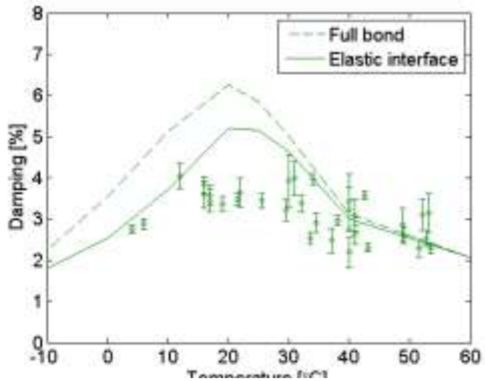

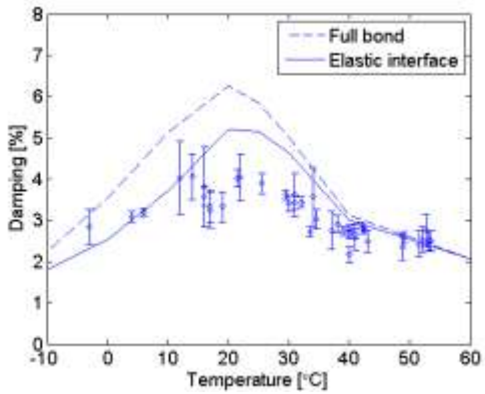

Conclusions

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- Mechanical model with
  - Orthotropic elastic material (timber)
  - Viscoelastic material (asphalt)
  - Elastic interface between asphalt and timber deck
  - Complex eigenvalue problem
  - Temperature sweep
- Good agreement with measurement (4 tuning parameters)
  - Elastic interface: single parameter improves all frequencies and damping values
- Large influence of asphalt temperature
  - Fundamental frequency 3.2–4 Hz
  - Damping largest at 20°C, no influence at high and low temperatures

Thank you!