Improvement of the predictability of low frequency induced vibration response in timber based floor structures

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Introduction

- Short Term Scientific Mission
  - May – August 2010
  - Part of my master graduation project at TU/e
  - Expecting to graduate 1st quarter 2011

- Edinburgh Napier University

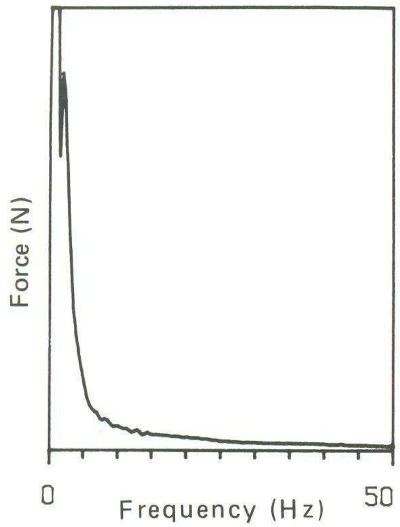
Introduction

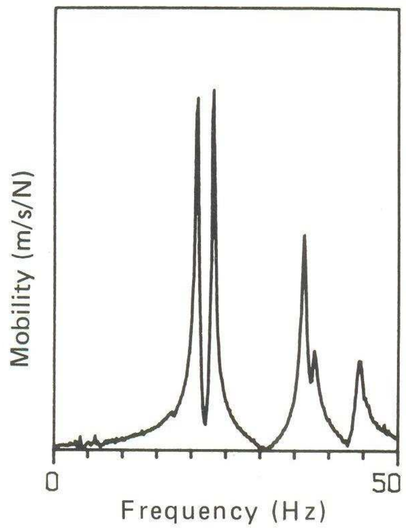
- Timber floors – high frequency floors
  - Low mass
  - High stiffness
- Overall trend: deflection and vibration have greater influence on design
- Eurocode 5 provides little understanding
- Improvement of vibration predictability in design is required

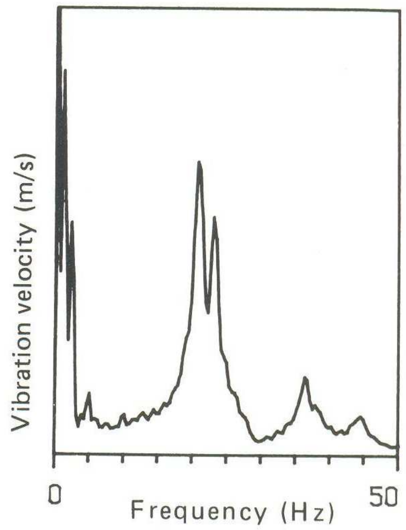
Eurocode 5: Vibration

Eurocode 5: Vibration

Force ✖ **Transferfunction** = **Response**







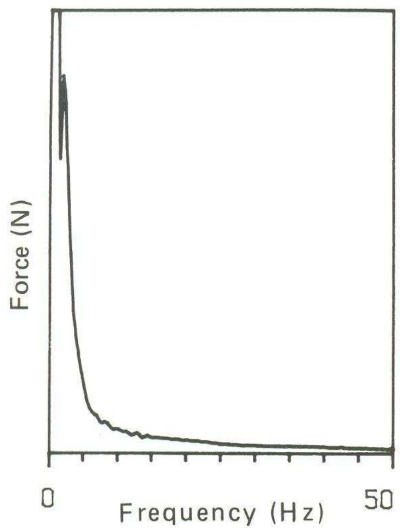
Pedestrian load
>8Hz

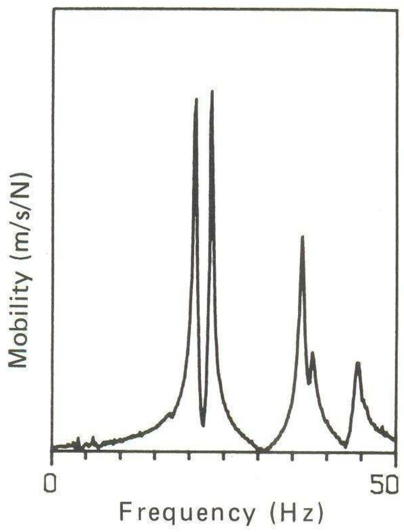
'Mobility' floor structure
Resonance frequencies

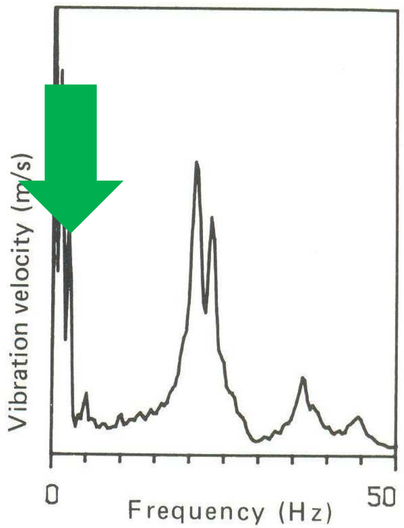
Floor structure
Response to pedestrian load

Based on Ohlsson's Swedish design guide (1988)

Eurocode 5: Vibration

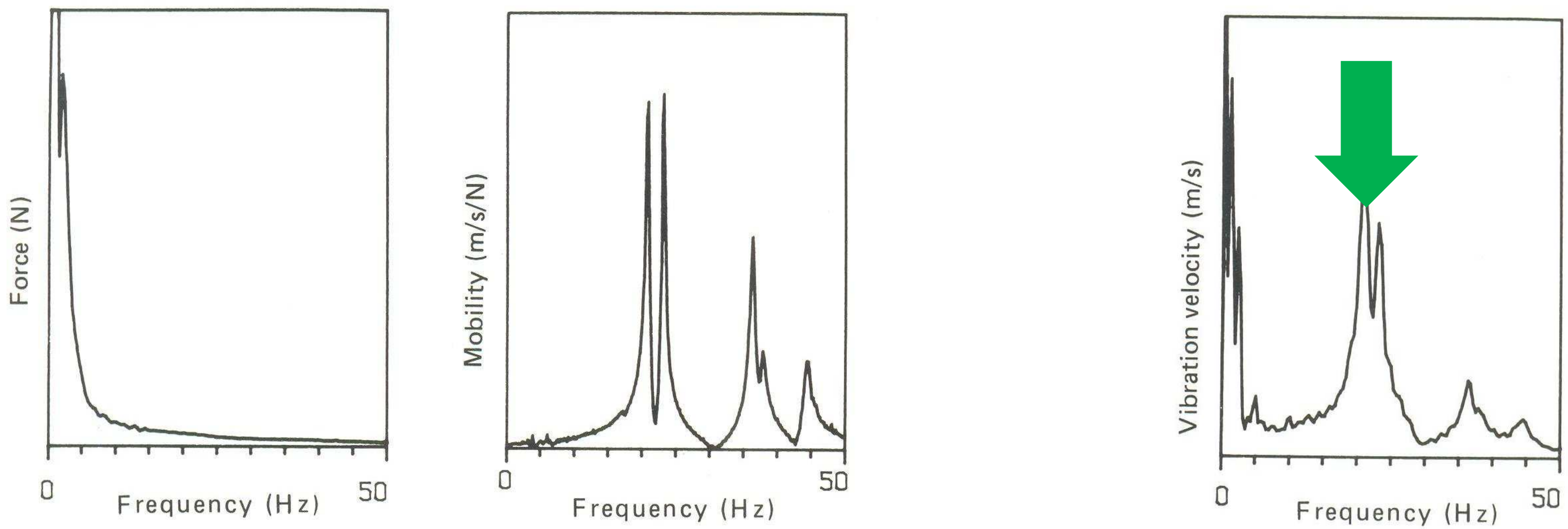






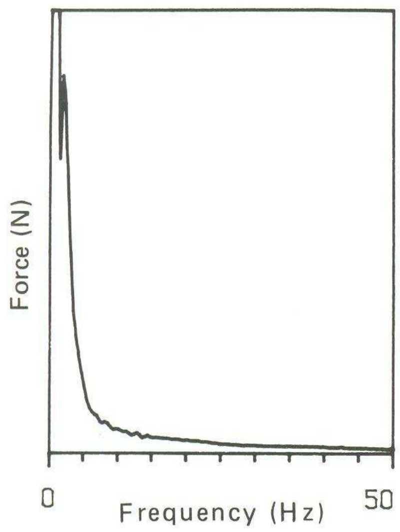
Limit static component
"point load deflection"

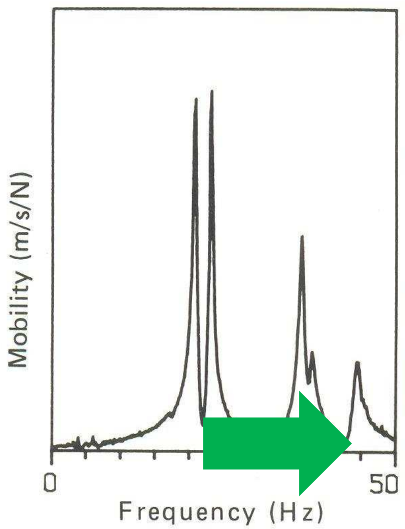
Eurocode 5: Vibration

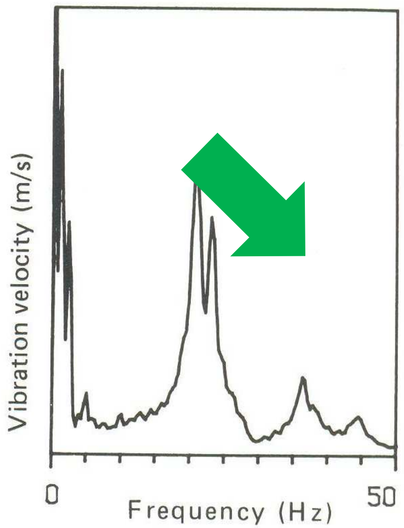


Limit resonance component
"impulse velocity response"

Eurocode 5: Vibration







Minimum fundamental frequency

Eurocode 5: Vibration

- Limit **point load deflection**
- Limit **impulse velocity response**
- Minimum **fundamental frequency**

Impulse velocity response

Impulse velocity response

$$v = \frac{4\left(0.4 + 0.6N_{40}\right)}{m_0 LB + 200}$$

$$N_{40} = \left\{\left(\left(\frac{40}{f_1}\right)^2 - 1\right) \cdot \left(\frac{B}{L}\right)^4 \cdot \left(\frac{EI_L}{EI_B}\right)\right\}^{1/4}$$

- Represents the maximum **velocity** of the **vibrating** floor generated by an idealized **impulse** force.

- Tool does not help **understanding** vibration design.

Impulse velocity response

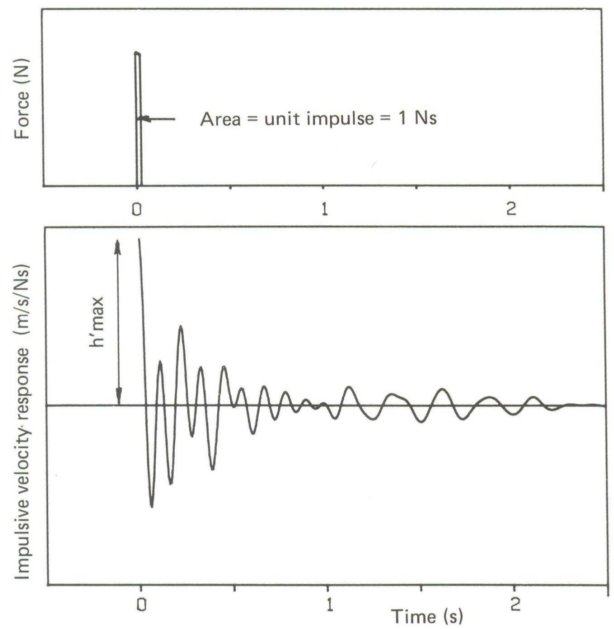
$$v_{\max} = \left(\frac{du}{dt}\right)_{\max} = \frac{F \cdot t}{m} \cdot \sum \psi_n{}^2$$

Impulse velocity response = $\dfrac{\text{Unit impulse}}{\text{Vibrating mass}}$ × Shape of deformation

Impulse velocity response

Impulse velocity response = **Unit impulse** / Vibrating mass × Shape of deformation

- Unit impulse = 1



Impulse velocity response

Impulse velocity response = I / **Vibrating mass** × Shape of deformation

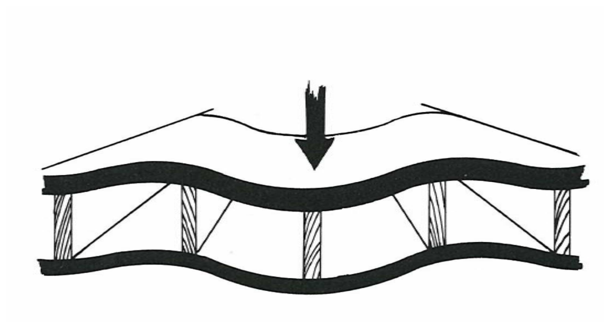
- Vibrating mass is based on
  - 4 side supported plate
  - 50kg bodymasss

$$m = \frac{m_0 LB + 200}{4} [kg]$$

Impulse velocity response

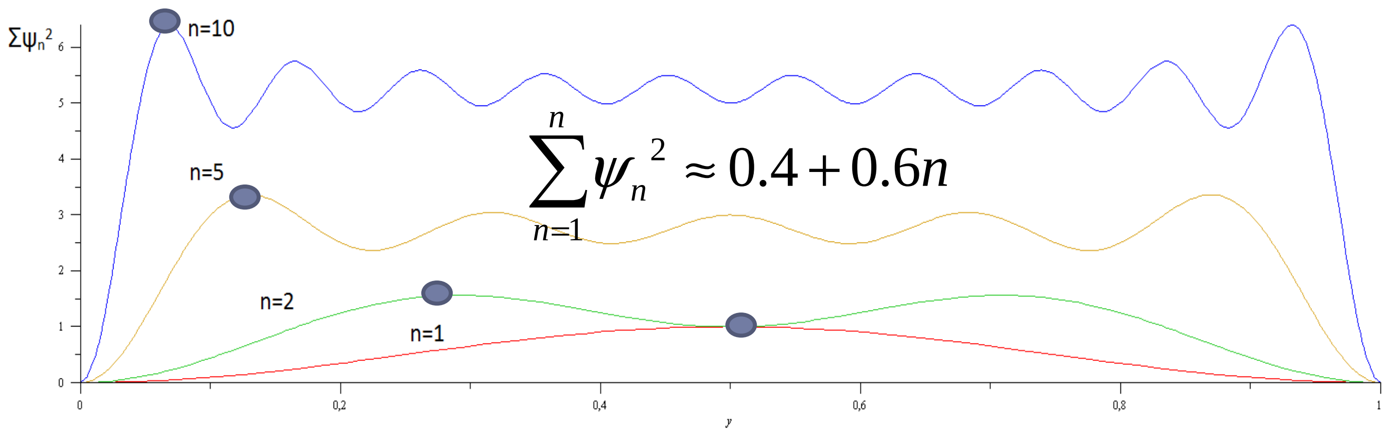
Impulse velocity response = I / Vibrating mass × **Shape of deformation**

- Shape of deformation
  - Multiple vibration modes activated in transverse direction
  - Sum of vibration modes $$\sum_{n=1}^{\infty} \psi_n^{\ 2}$$



Impulse velocity response

$$\text{Impulse velocity response} = \frac{I}{\text{Vibrating mass}} \times \textbf{Shape of deformation}$$



$$\sum_{n=1}^{n} \psi_n{}^2 \approx 0.4 + 0.6n$$

- Contribution of every mode is considered equal

Impulse velocity response

Impulse velocity response = I / Vibrating mass × **Shape of deformation**

- Maximum for summation → "N_{40}"
- Consider vibration modes up to 40 Hertz
- Based on frequency prediction of a 4 side supported orthotropic plate

$$N_{40} = \left\{ \sqrt{\left(\left(\frac{40}{f_1}\right)^2 \underbrace{+\frac{D_y}{D_x}}_{neglected} - 1 \right) \cdot \left(\frac{B}{L}\right)^4 \cdot \left(\frac{D_x}{D_y}\right)} \underbrace{- \left(\frac{B}{L}\right)^2}_{neglected} \right\}^{1/2}$$

Impulse velocity response

Impulse velocity response = $\dfrac{\text{I}}{\text{Vibrating mass}}$ × Shape of deformation

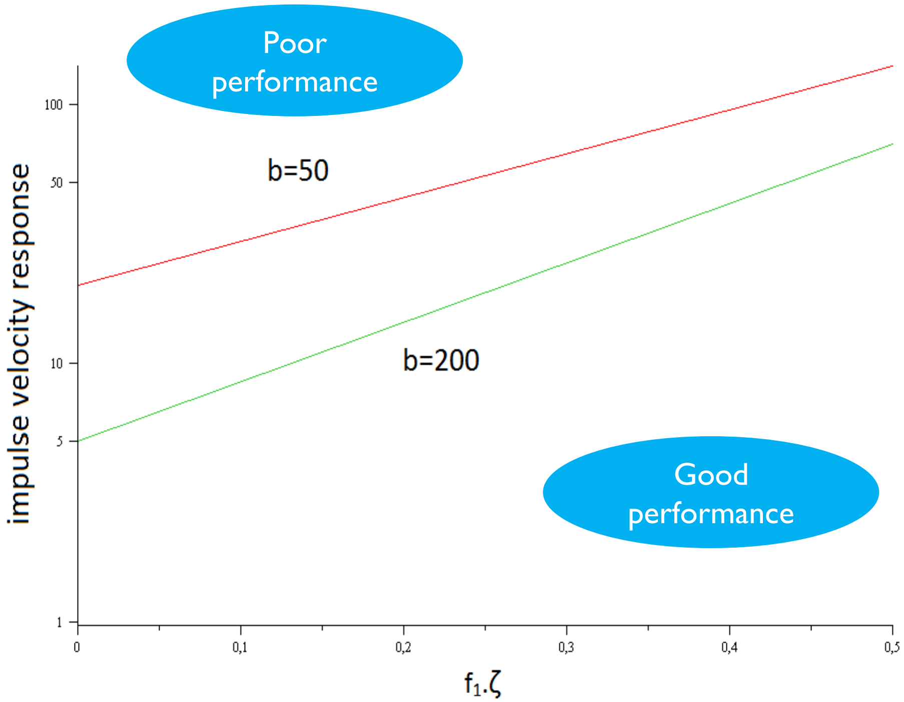
$$v = \frac{4}{m_0 LB + 200}\left(0.4 + 0.6 N_{40}\right)$$

$$N_{40} = \left\{ \left(\left(\frac{40}{f_1} \right)^2 - 1 \right) \cdot \left(\frac{B}{L} \right)^4 \cdot \left(\frac{EI_L}{EI_B} \right) \right\}^{1/4}$$

Impulse velocity response

Introduction – Eurocode 5 – **Impulse velocity response** – Frequency - Discussion

- Limit for ‘impulse velocity response: $v \leq b^{(f_1 \cdot \zeta - 1)}$
- Parameter ‘b’ in National Annex



Impulse velocity response

- The appearance of the **squared shape function** cannot be explained.
- The participating **mass** is based on a 4 sided simply supported plate.
- All vibration modes up to N_{40} are considered **equally activated.**
- The determination of the N_{40} is based on a 4 side simply supported **orthotropic plate** and **neglects two terms**.

Impulse velocity response

Unable to verify design method

Reconsideration advised

Impulse velocity response

Fundamental frequency

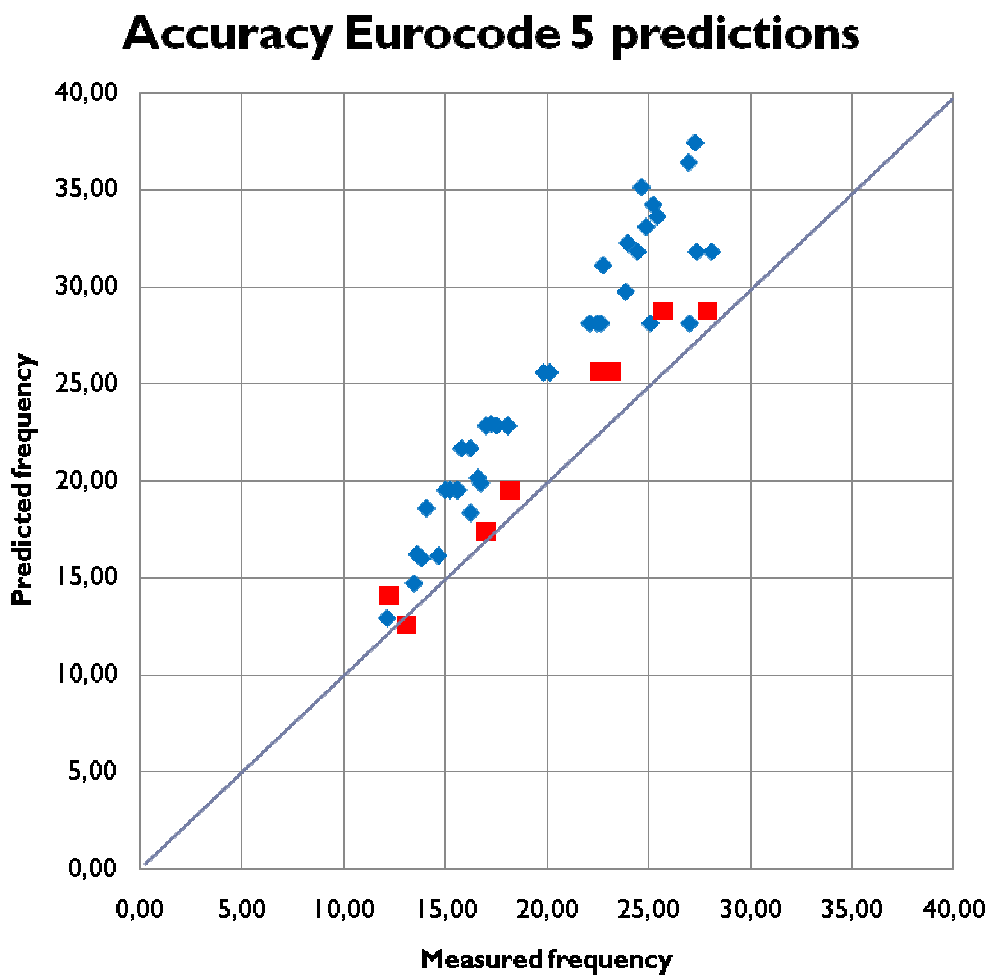
Fundamental frequency

$$f_1 = \frac{\pi}{2}\sqrt{\frac{EI}{mL^4}}$$

- Based on a 2 side supported beam
- Based on Euler-Bernoulli theory
  - Bending moments
  - Deflection

Fundamental frequency

- Predictions compared with tests
  - 39 I-joist floors (Weckendorf)
  - 8 solid joist floors (Ohlsson)
- Accuracy of predictions:
  - Solid joist floors
  - I-joist floors



Fundamental frequency

- Unknown what parameters are most affecting the frequency prediction.

- Improving the frequency prediction
  - **Rotary inertia**
  - **Shear**
  - Combined **rotary inertia** and **shear**
  - Combining the **support stiffness** with the floor stiffness
  - Altered **boundary conditions**

Fundamental frequency

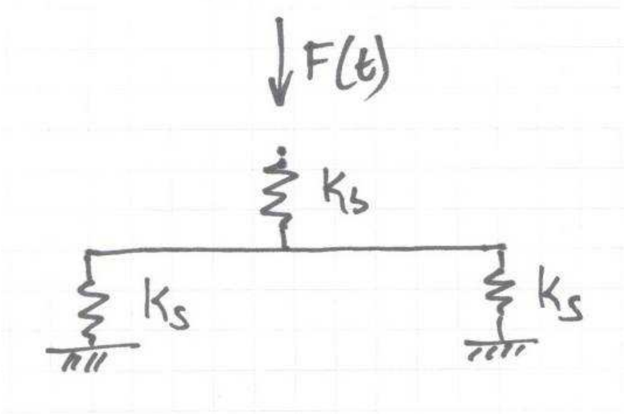
$$f_{Euler-Bernoulli} = \frac{\pi}{2L^2}\sqrt{\frac{EI}{m}}$$

$$f_{Rotary\ inertia} = f_{Euler-Bernoulli} \cdot \sqrt{\frac{1}{\left(\left(\frac{\pi}{L}\right)^2 \frac{I}{A_{total}} + 1\right)}}$$

$$f_{Shear} = f_{Euler-Bernoulli} \cdot \sqrt{\frac{1}{\left(\left(\frac{\pi}{L}\right)^2 \frac{EI}{k'GA_{shear}} + 1\right)}}$$

$$f_{Shear\&RotInertia} = f_{Euler-Bernoulli} \cdot \sqrt{\frac{1}{\left(\frac{\pi}{L}\right)^2 \left(\frac{EI}{k'GA_{shear}} + \frac{I}{A_{total}}\right) + 1}}$$

Fundamental frequency



$$k_b = EI$$

$$k_s = \frac{E_{90} A_s}{h_s}$$

$$f = \frac{\pi}{2L^2}\sqrt{\frac{k_{tot}}{m}}$$

$$k_{tot} = \frac{1}{\frac{1}{k_b} + \frac{1}{2k_s}}$$

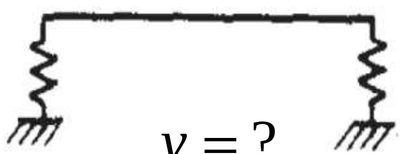
- Combining stiffness
  - Support
  - Floor

Fundamental frequency

- Adjusting boundary conditions

$$f = y^2 \cdot \frac{1}{2\pi L^2} \cdot \sqrt{\frac{EI}{m}}$$

$$y = \pi$$



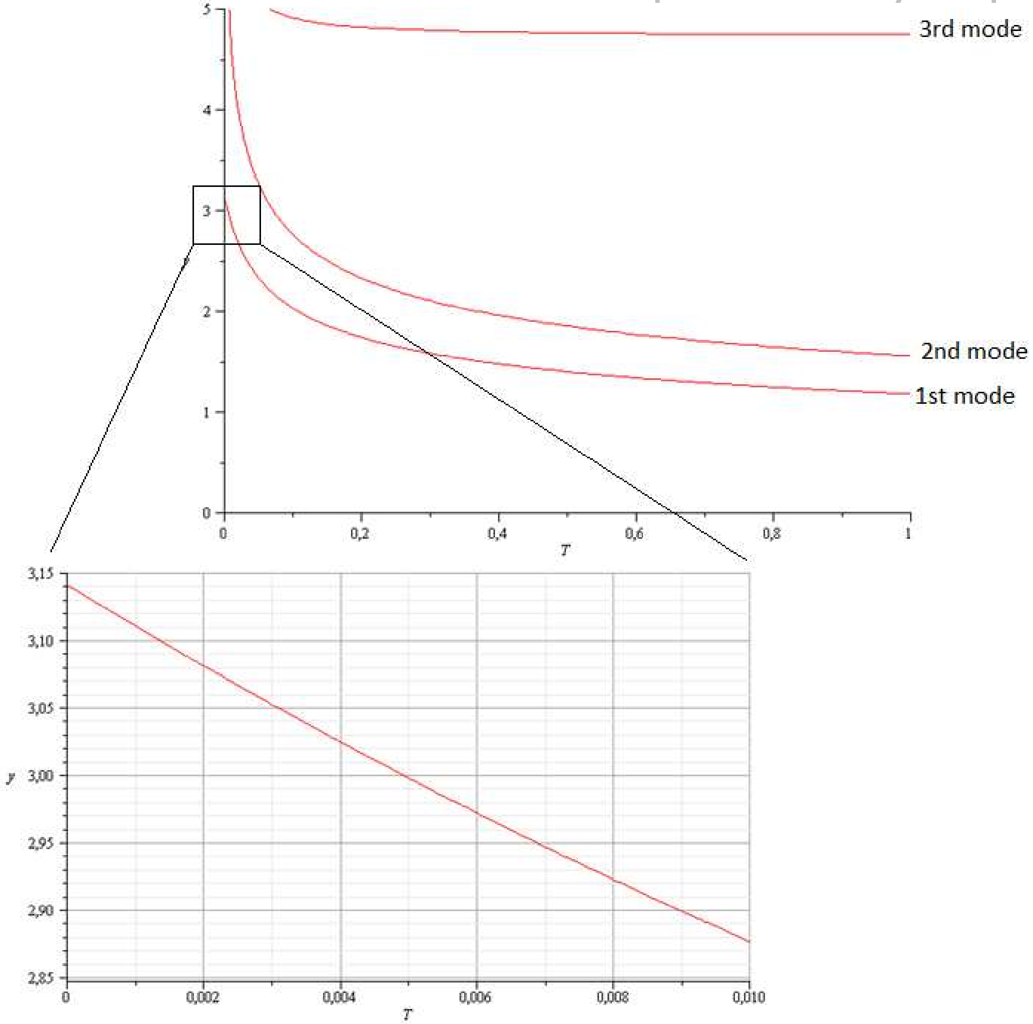
$$y = ?$$

$$T = \frac{EI}{K_T L^3}$$

$$y = ?$$

$$R = \frac{EI}{K_R L}$$

Fundamental frequency

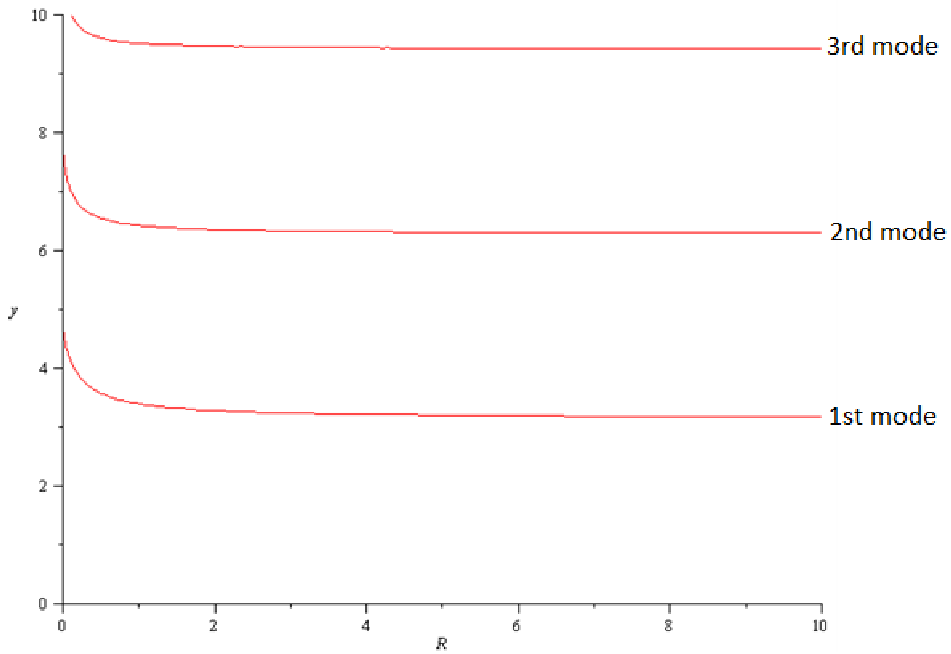


$$T = \frac{EI}{K_T L^3}$$

$$for \;\; T < 10^{-2}$$

$$f_1 \approx \frac{\pi - 26.46T}{2}\sqrt{\frac{EI}{mL^4}}$$

Fundamental frequency

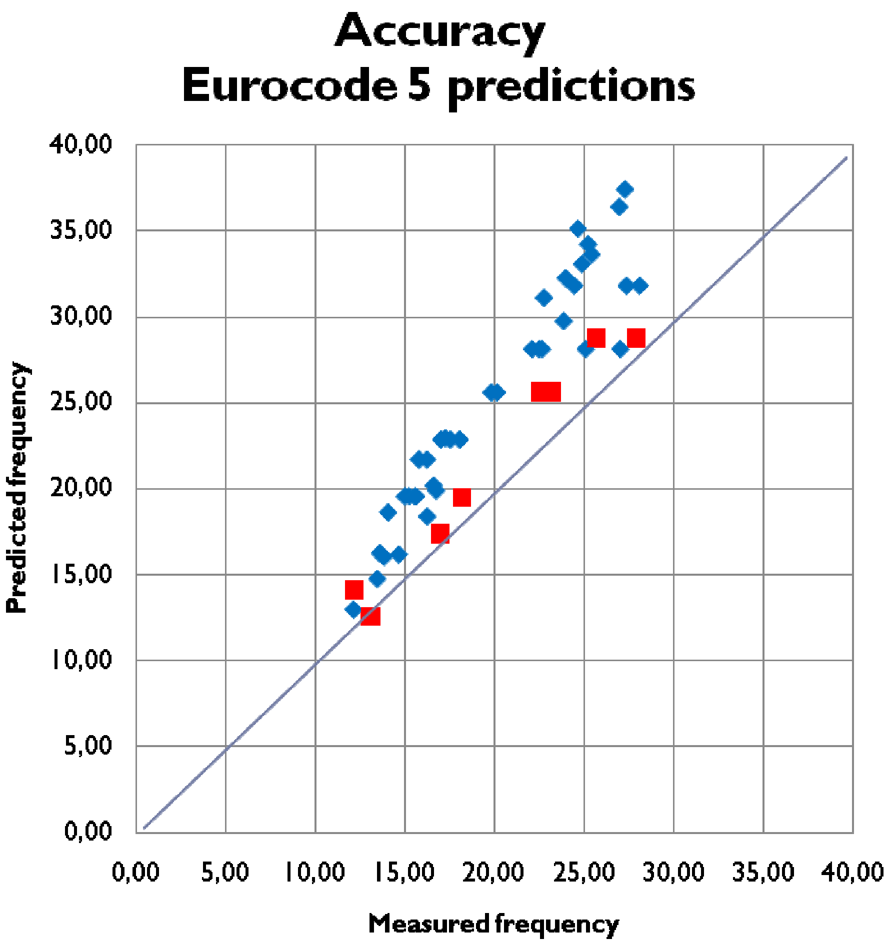


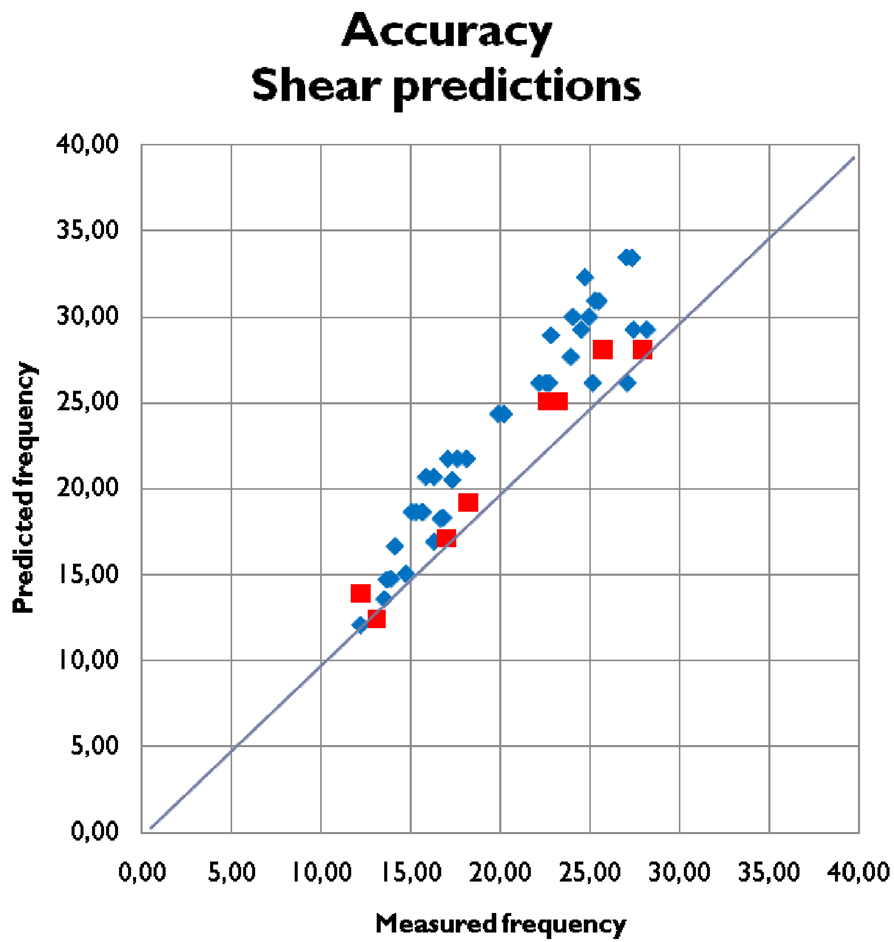
$$R = \frac{EI}{K_R L}$$

$$for \quad R > 10$$

$$f_1 \approx \frac{\pi}{2}\sqrt{\frac{EI}{mL^4}}$$

Fundamental frequency





Fundamental frequency

- Solid joist floors
  - Euler-Bernoulli model is sufficiently accurate

$$f_1 = \frac{\pi}{2}\sqrt{\frac{EI}{mL^4}}$$

- I-joist floors
  - Shear model is a slight improvement
  - Still quite unaccurate, optimization required

$$f_1 = \frac{\pi}{2}\sqrt{\frac{EI}{mL^4}} \cdot \sqrt{\frac{1}{\left(\left(\frac{\pi}{L}\right)^2 \frac{EI}{k'GA_{shear}} + 1\right)}}$$

Fundamental frequency

Valid for solid joist floors

Needs adjustment for I-joist floors

Fundamental frequency

Conclusions

Determining a static deflection

Point load deflection

Unable to verify design method

Reconsideration advised

Impulse velocity response

Valid for solid joist floors

Needs adjustment for I-joist floors

Fundamental frequency

Discussion