A Comparison of Design, Construction and Dynamic Performance of Timber Floors in the UK and Finland

- STSM of COST Action E55 -

Host: Dr. Tomi Toratti

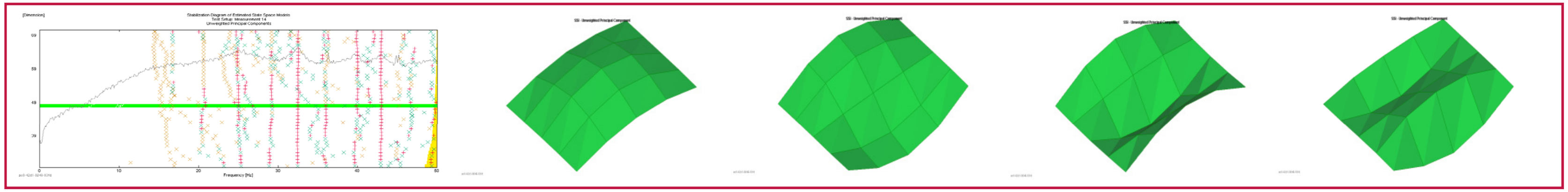
Host Institution: VTT - Technical Research Centre of Finland

Visiting Scientist: Jan Weckendorf

Home Institution: CTE THE CENTRE FOR TIMBER ENGINEERING - Edinburgh Napier University

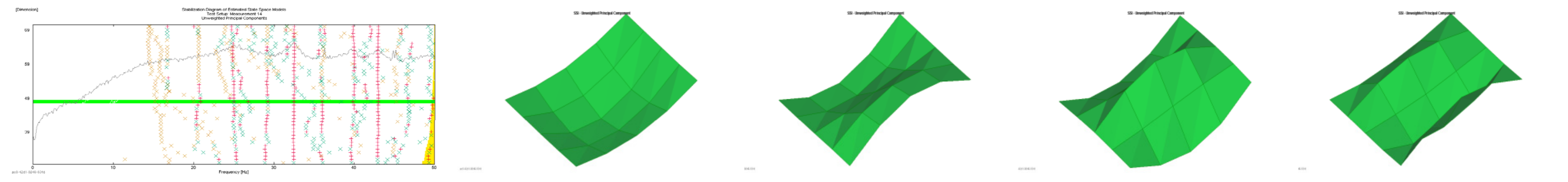
Proposer: Dr. Binsheng Zhang

Duration: 05 - 29 October 2007



Contents of presentation

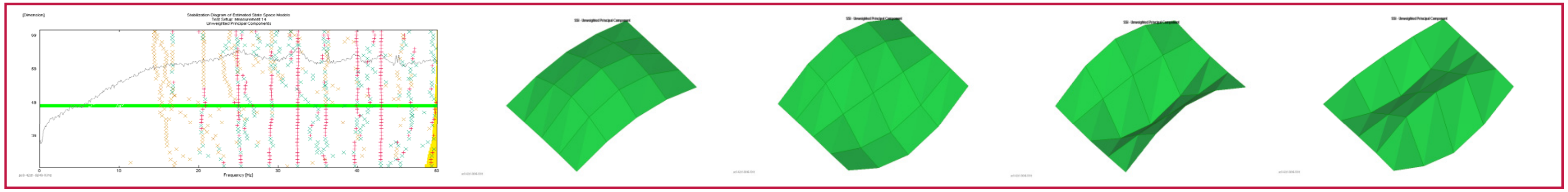
- Background
- Objectives of STSM
- Undertaken research
- Conclusions



Background of research on floor vibration

Lightweight flooring structures easily get excited and start to vibrate:

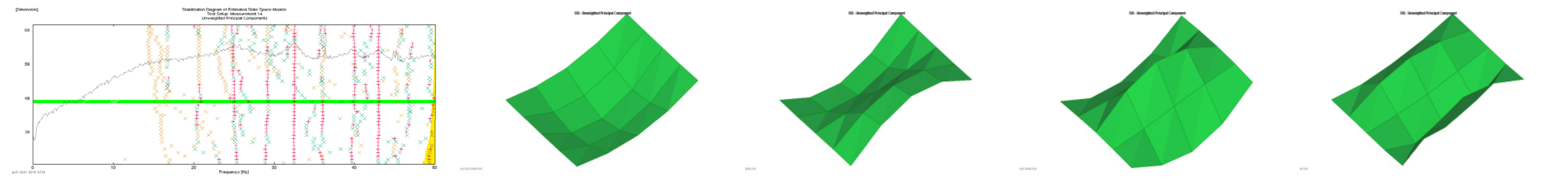
- Occupants may get annoyed by excessive floor vibrations;
- Current design rules do not satisfactorily control floor vibrations;
- Design rules are not fully harmonised within EU.



Main research background as basis for STSM

- VTT:
  - rating of vibration performance
  - classification of flooring structures
  - modification of design criteria

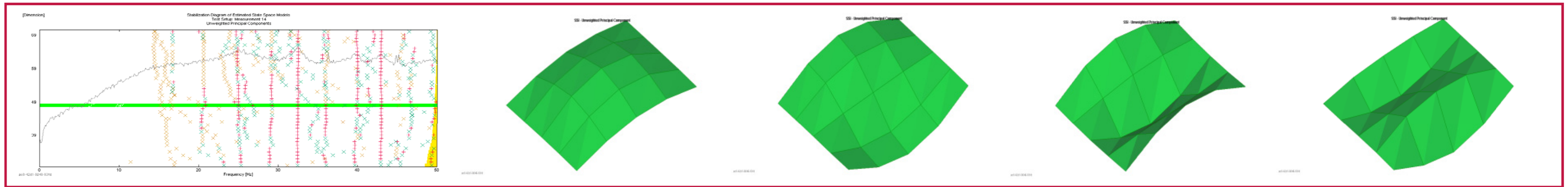
- Napier University:
  - parametric studies on timber floor design
  - determination of the effects of (non-)structural modifications
  - prediction of floor performance by FE-method



Objectives of STSM in line with those of COST Action E55

Improving the understanding with respect to:

- Serviceability
- Design criteria
- Construction details

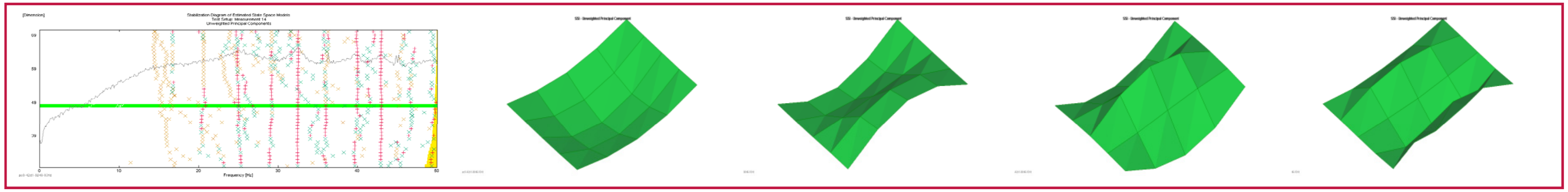


Design criteria

Serviceability Limit States (SLS) in Eurocode 5

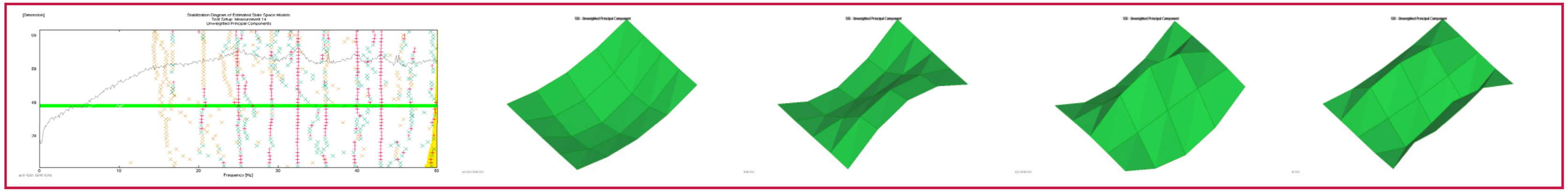
Country	**Low-frequency floor**		**High-frequency floor**	
	Condition	Guidance	Condition	Guidance
UK (based on EC5)	$f_1 \leq 8$ Hz	N/A	$f_1 > 8$ Hz	1) Limiting unit point load deflection w * 2) Limiting unit impulse velocity response v
FI (NA)	$f_1 < 9$ Hz	N/A	$f_1 \geq 9$ Hz	Limiting unit point load deflection δ

** Formula not provided in EC5*



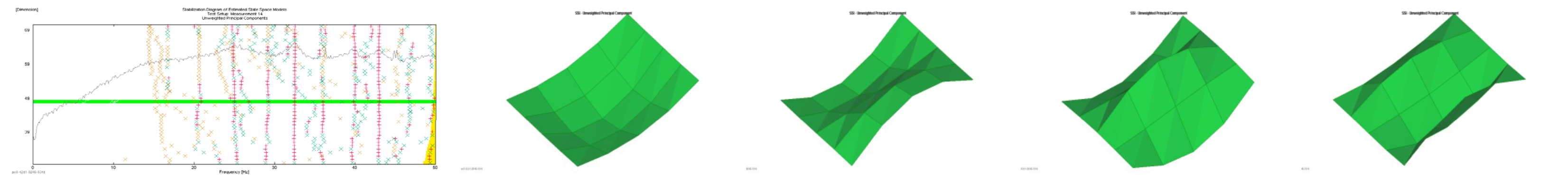
Design criteria

Country	Fundamental frequency	Point load deflection	Velocity response
UK	*"For a rectangular floor [...], simply supported along all four edges [...]"* (EC5-1-1): $$f_1 = \frac{\pi}{2\ell^2}\sqrt{\frac{(EI)_\ell}{m}}$$ ***EC5***		
FI (NA)			



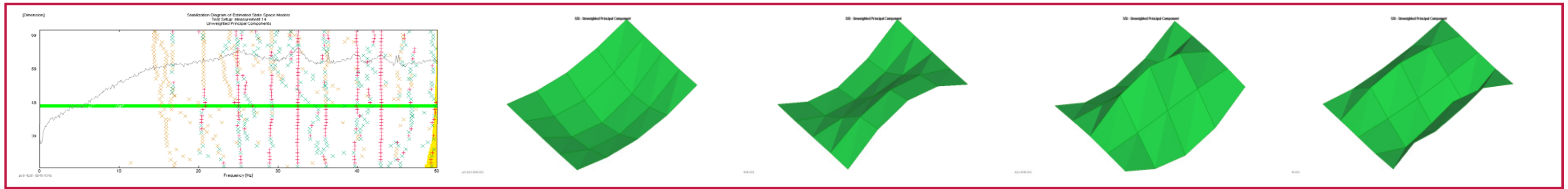
Design criteria

Country	Fundamental frequency	Point load deflection	Velocity response
UK	*"For a rectangular floor [...], simply supported along all four edges [...]"* (EC5-1-1): $$f_1 = \frac{\pi}{2\ell^2}\sqrt{\frac{(EI)_\ell}{m}}$$ ***EC5***		
FI (NA)	for 2-side supported floors: $$f_1 = \frac{\pi}{2\ell^2}\sqrt{\frac{(EI)_\ell}{m}}$$		



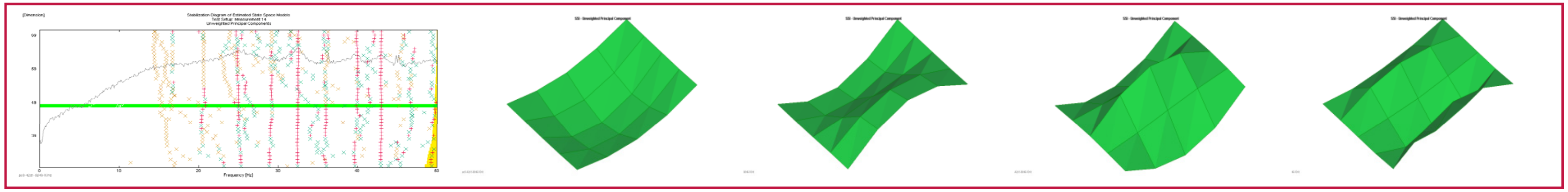
Design criteria

Country	Fundamental frequency	Point load deflection	Velocity response
UK	*"For a rectangular floor [...], simply supported along all four edges [...]"* (EC5-1-1): $$f_1 = \frac{\pi}{2\ell^2}\sqrt{\frac{(EI)_\ell}{m}}$$ ***EC5***		
FI (NA)	for 2-side supported floors: $$f_1 = \frac{\pi}{2\ell^2}\sqrt{\frac{(EI)_\ell}{m}}$$ for 4-side supported floors: $$f_1 = \frac{\pi}{2\ell^2}\sqrt{\frac{(EI)_\ell}{m}} \cdot \sqrt{1 + \left[2 \cdot \left(\frac{\ell}{b}\right)^2 + \left(\frac{\ell}{b}\right)^4\right] \cdot \frac{(EI)_b}{(EI)_\ell}}$$		



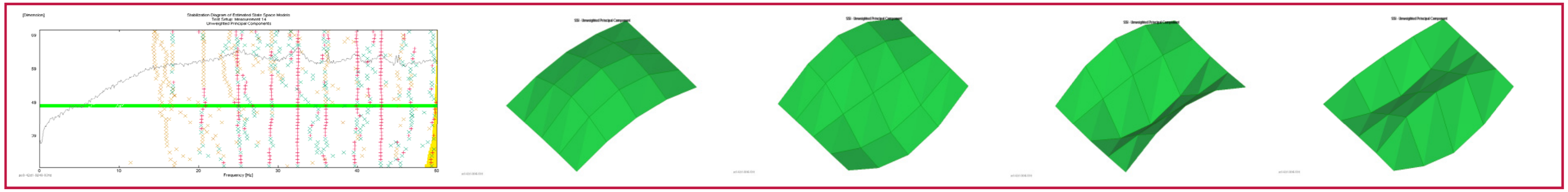
Design criteria

Country	Fundamental frequency	Point load deflection	Velocity response
UK	*"For a rectangular floor [...], simply supported along all four edges [...]"* (EC5-1-1): $$f_1 = \frac{\pi}{2\ell^2}\sqrt{\frac{(EI)_\ell}{m}}$$ ***EC5***	$$w = \frac{k_{dist} 1000 L_{eq}{}^3 k_{amp}}{48(EI)_{joist}}$$ ***UK NA***	
FI (NA)	for 2-side supported floors: $$f_1 = \frac{\pi}{2\ell^2}\sqrt{\frac{(EI)_\ell}{m}}$$ for 4-side supported floors: $$f_1 = \frac{\pi}{2\ell^2}\sqrt{\frac{(EI)_\ell}{m}} \cdot \sqrt{1 + \left[2 \cdot \left(\frac{\ell}{b}\right)^2 + \left(\frac{\ell}{b}\right)^4\right] \cdot \frac{(EI)_b}{(EI)_\ell}}$$	$$\delta = \min \begin{cases} \dfrac{F\ell^2}{42 \cdot k_\delta \cdot (EI)_\ell} \\ \dfrac{F\ell^3}{48 \cdot s \cdot (EI)_\ell} \end{cases}$$	



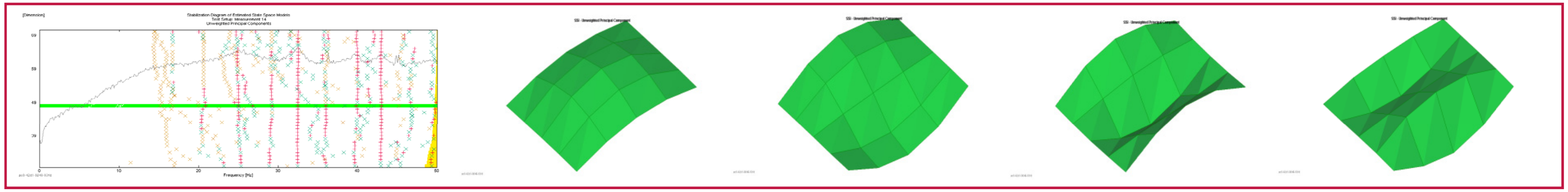
Design criteria

Country	Fundamental frequency	Point load deflection	Velocity response
UK	*"For a rectangular floor [...], simply supported along all four edges [...]"* (EC5-1-1): $$f_1 = \frac{\pi}{2\ell^2}\sqrt{\frac{(EI)_\ell}{m}}$$ ***EC5***	$$w = \frac{k_{dist} 1000 L_{eq}^{3} k_{amp}}{48(EI)_{joist}}$$ ***UK NA***	$$v = \frac{4(0.4 + 0.6\, n_{40})}{m L B + 200}$$ ***EC5***
FI (NA)	for 2-side supported floors: $$f_1 = \frac{\pi}{2\ell^2}\sqrt{\frac{(EI)_\ell}{m}}$$ for 4-side supported floors: $$f_1 = \frac{\pi}{2\ell^2}\sqrt{\frac{(EI)_\ell}{m}} \cdot \sqrt{1 + \left[2\cdot\left(\frac{\ell}{b}\right)^2 + \left(\frac{\ell}{b}\right)^4\right] \cdot \frac{(EI)_b}{(EI)_\ell}}$$	$$\delta = \min\begin{cases} \dfrac{F\ell^2}{42 \cdot k_\delta \cdot (EI)_\ell} \\ \dfrac{F\ell^3}{48 \cdot s \cdot (EI)_\ell} \end{cases}$$	N/A



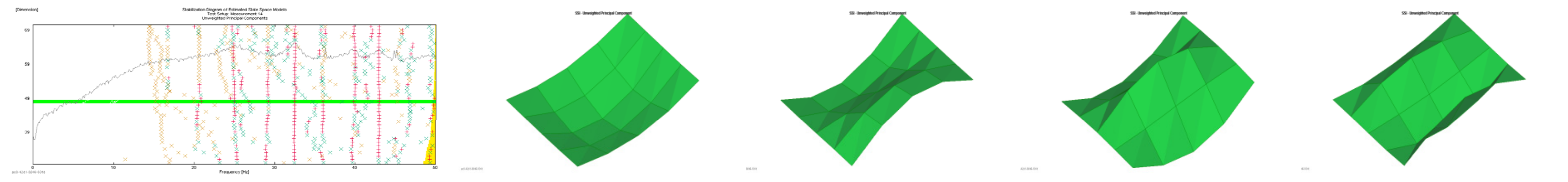
Design limits and thresholds

Country	Fundamental frequency	Point load deflection	Velocity response
UK	$f_1 > 8$ Hz	1.8 mm/kN for $\ell \leq 4000$ mm $16500/\ell^{1.1}$ mm/kN for $\ell > 4000$ mm	
FI	$f_1 \geq 9$ Hz	$0.5 \times \min\left\{\dfrac{\sqrt[4]{(EI)_b}}{(EI)_\ell}, \dfrac{b}{\ell}\right\}$ mm/kN for $\ell \leq 6000$ mm 0.5 mm/kN for $\ell > 6000$ mm An additional 0.5 mm deflection can be allowed in case of floating and raised floors	



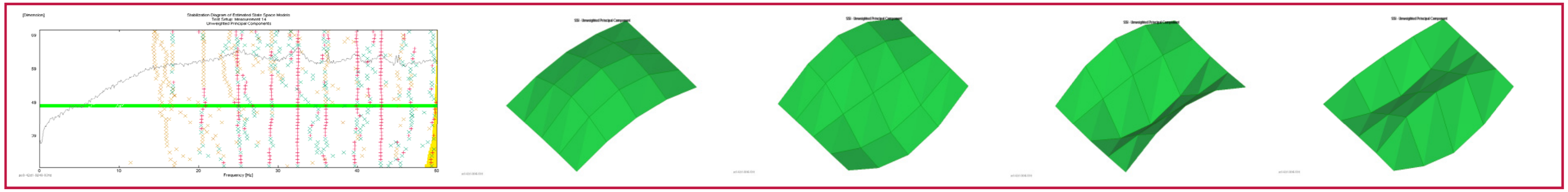
Design limits and thresholds

Country	Fundamental frequency	Point load deflection	Velocity response
UK	$f_1 > 8$ Hz	1.8 mm/kN for $\ell \leq 4000$ mm $16500/\ell^{1.1}$ mm/kN for $\ell > 4000$ mm	$v \leq b^{(f_1 \zeta - 1)}$ where $\zeta = 0.02$ (EC5: $\zeta = 0.01$)
FI	$f_1 \geq 9$ Hz	$0.5 \times \min\left\{ \frac{\sqrt[4]{(EI)_b}}{(EI)_\ell}, \frac{b}{\ell} \right.$ mm/kN for $\ell \leq 6000$ mm 0.5 mm/kN for $\ell > 6000$ mm An additional 0.5 mm deflection can be allowed in case of floating and raised floors	N/A



Summary of design criteria

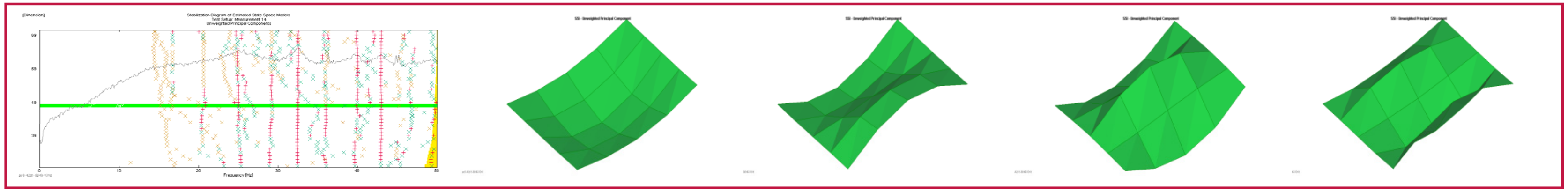
- British design criteria
  - based on EC5
  - deflection criterion defined in UK NA
  - damping ratio doubled in UK NA
- Finnish design criteria
  - EC5 criteria revised by adopting own NDPs
  - assessment based on deflection and frequency only
  - frequency threshold 12% above the EC5 threshold



Test floors

The Finnish test floor (6.0 m x 4.3 m)

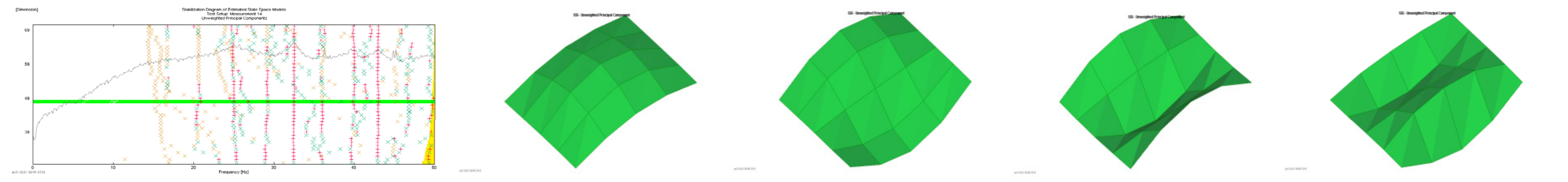
- Laminated Veneer Lumber (LVL) joists (600 mm spacing)
- LVL blocking
- Tension bar
- Glue and screws
- Concrete screed on top of mineral wool isolation layer
- Four-side supported



Test floors

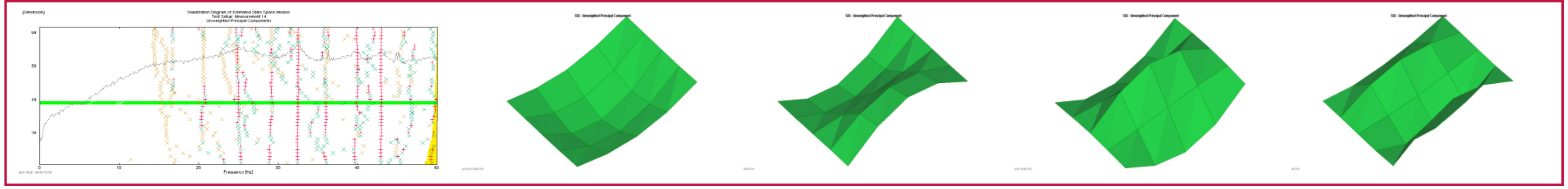
The British test floor (3.5 m x 2.44 m)

- I-joists (400 mm spacing)
- Screws
- Particleboard deck
- Two-side supported



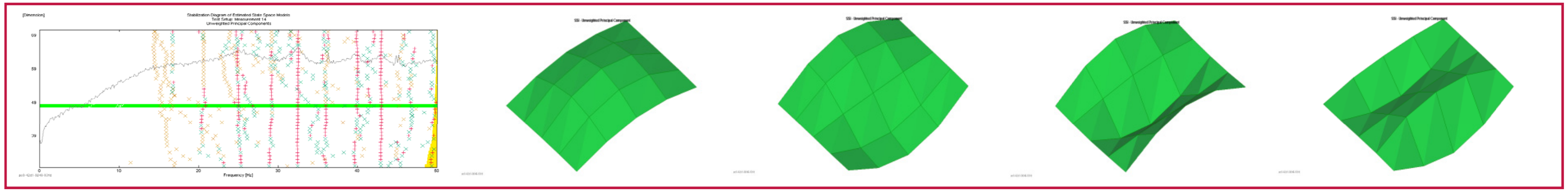
Summary of differences in common construction practices

Material	**Finnish floors**	**British floors**
Joist types	LVL/Solid timber joists	I-joists
Fasteners	Glue and screws	Screws mainly
Deck	Plywood + (sometimes) concrete screed	Wood based panels mainly



Investigation of design criteria

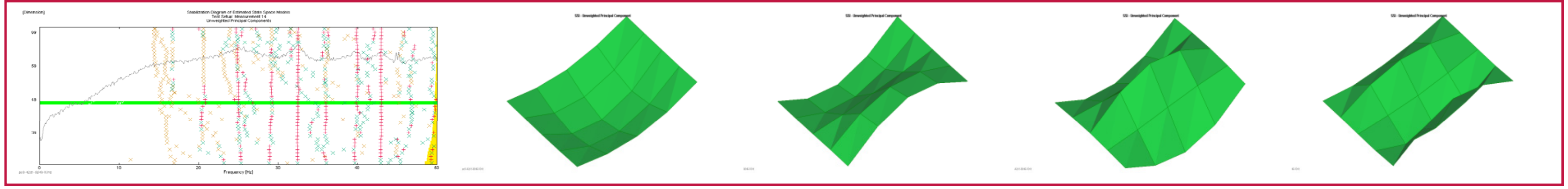
- Finnish flooring structure at two design stages
  - without concrete screed and isolation layer
  - completed (with concrete screed)
- British flooring structure (completed)



Investigation of design criteria

Assessing floor performance using Finnish and British rules

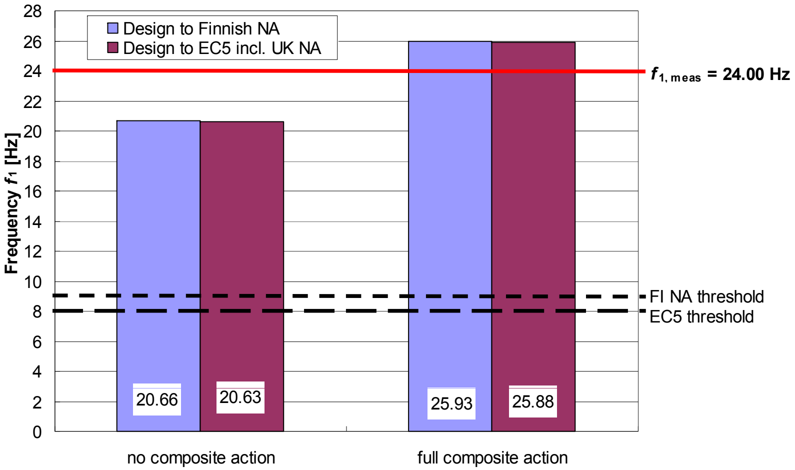
- Fundamental frequency calculated twice, without and with partial/full composite action
- Other parameters calculated under consideration of composite action
- Results (columns) presented in blue regarding the Finnish criteria and in violet regarding the British criteria



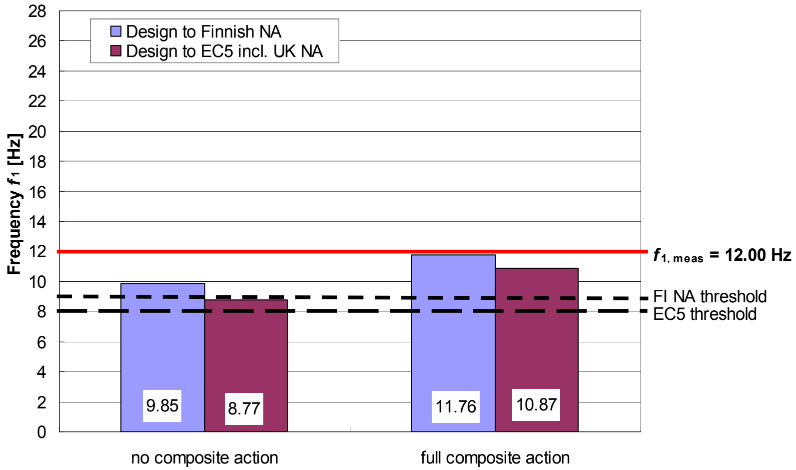
Investigation of design criteria

Finnish flooring structure at the two design stages

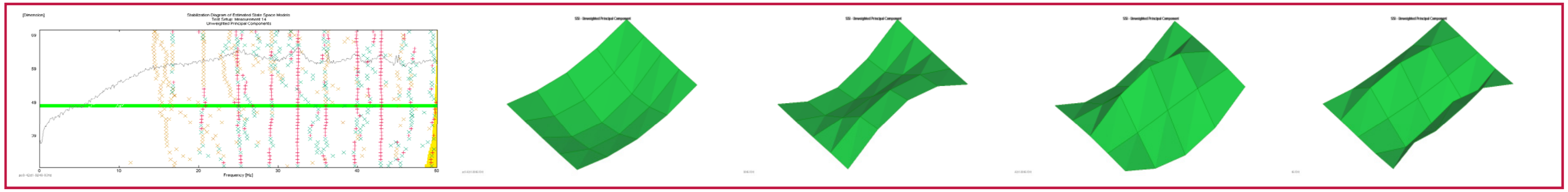
Fundamental frequency



Without concrete screed



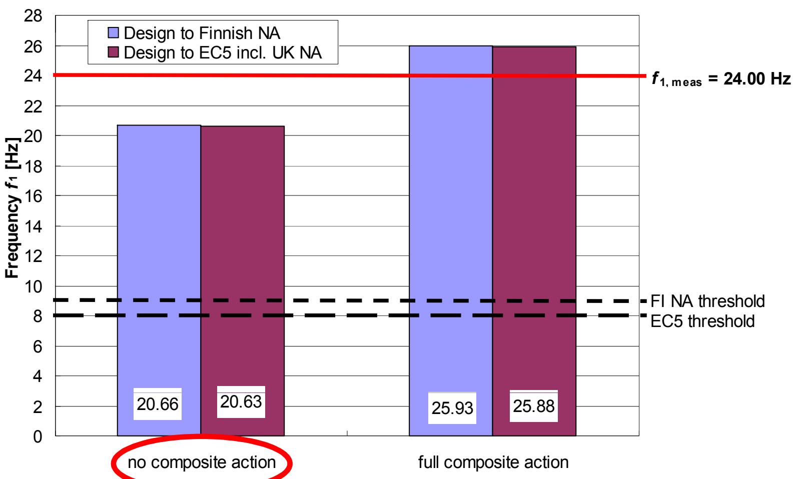
With concrete screed



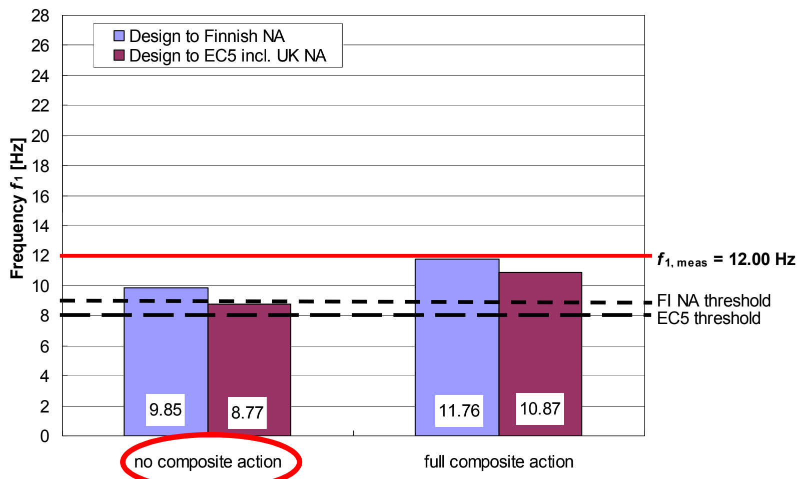
Investigation of design criteria

Finnish flooring structure at the two design stages

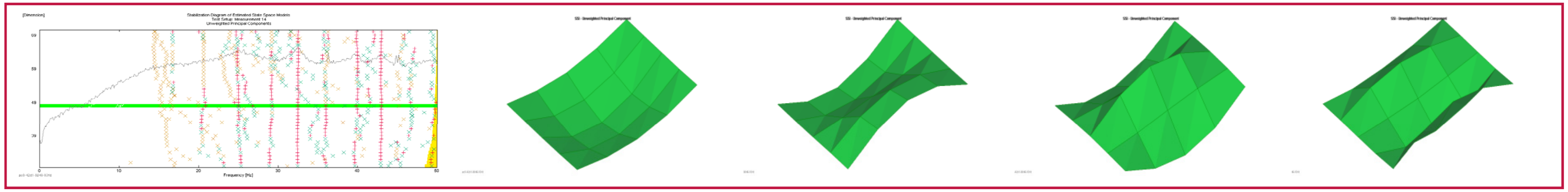
Fundamental frequency



Without concrete screed



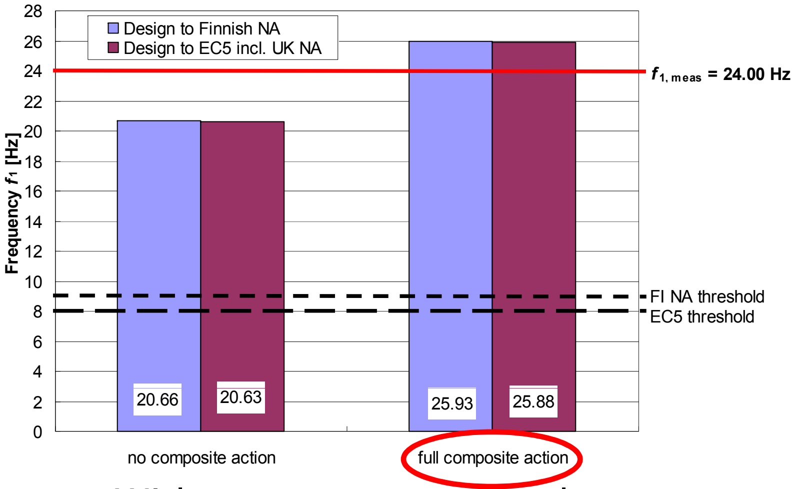
With concrete screed



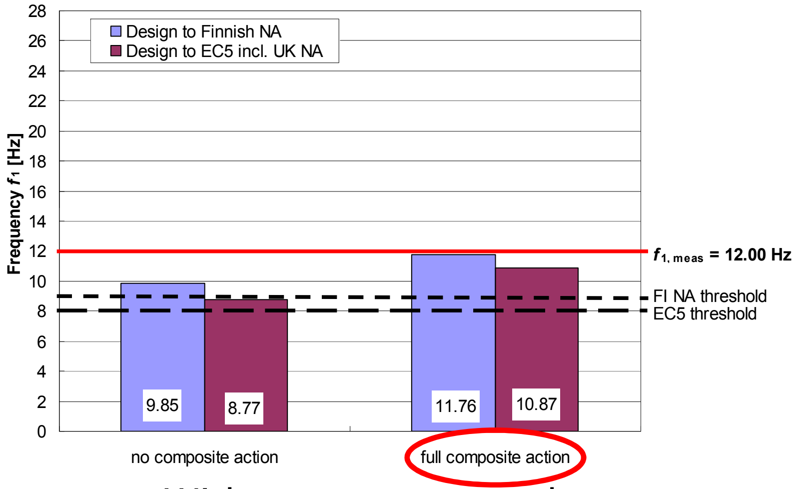
Investigation of design criteria

Finnish flooring structure at the two design stages

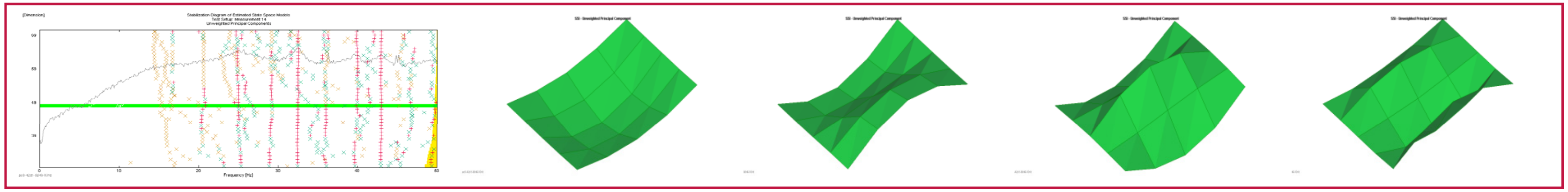
Fundamental frequency



Without concrete screed



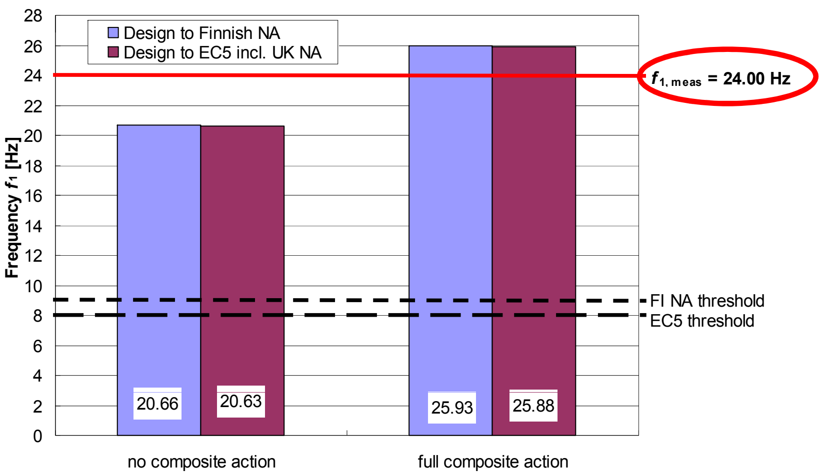
With concrete screed



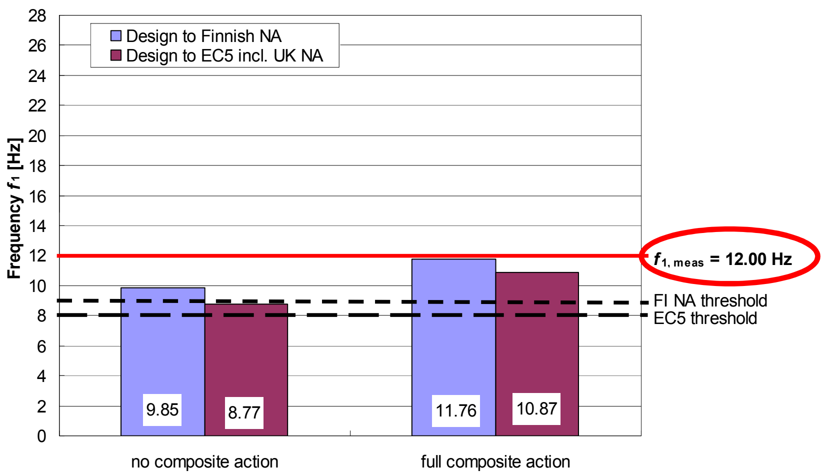
Investigation of design criteria

Finnish flooring structure at the two design stages

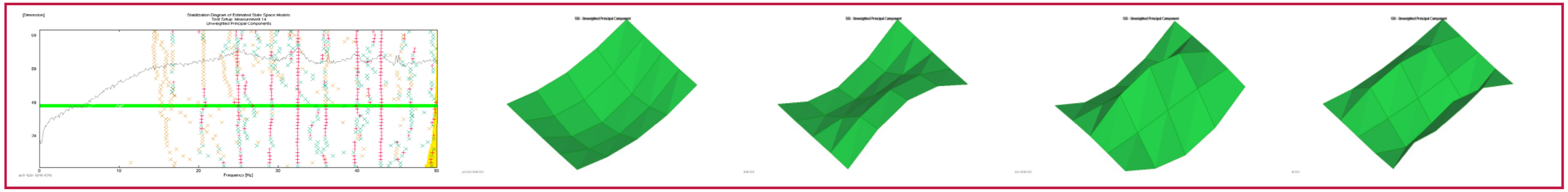
Fundamental frequency



Without concrete screed



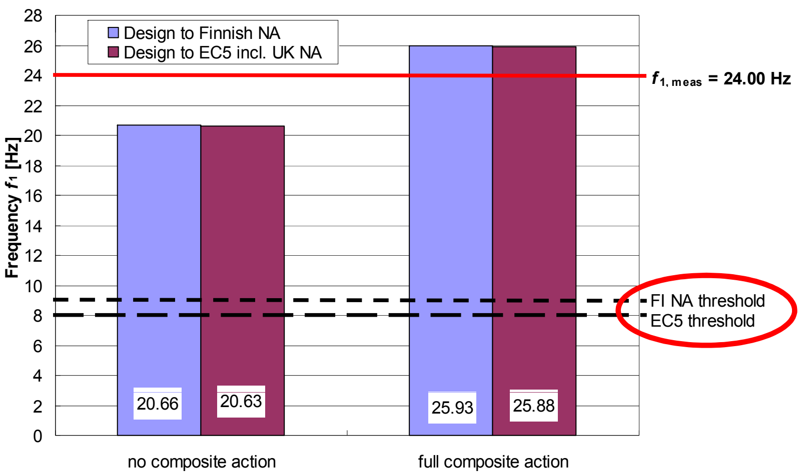
With concrete screed



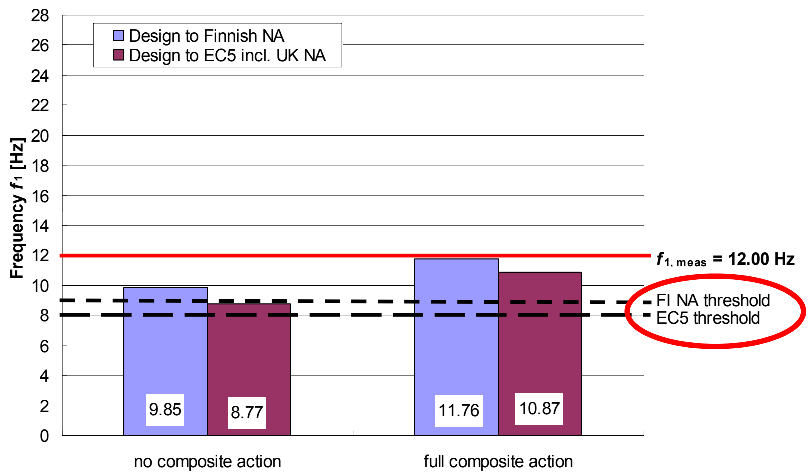
Investigation of design criteria

Finnish flooring structure at the two design stages

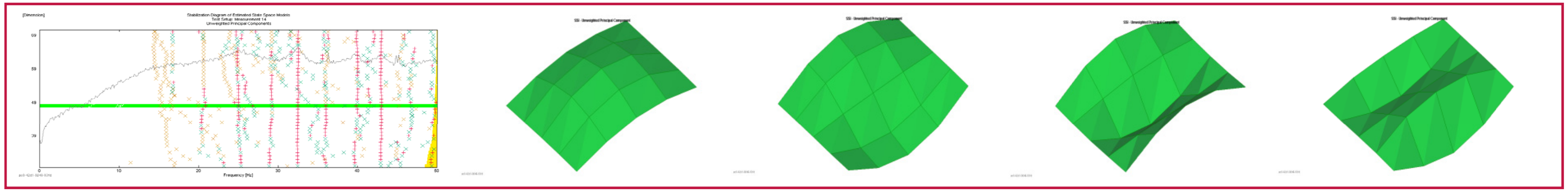
Fundamental frequency



Without concrete screed



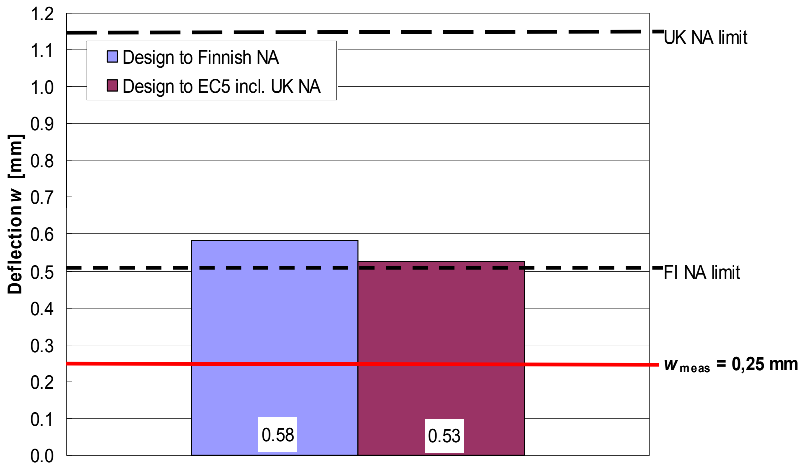
With concrete screed



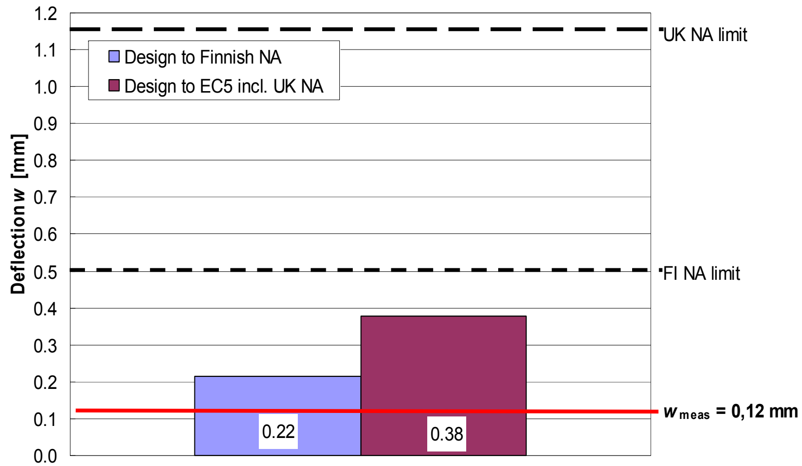
Investigation of design criteria

Finnish flooring structure at the two design stages

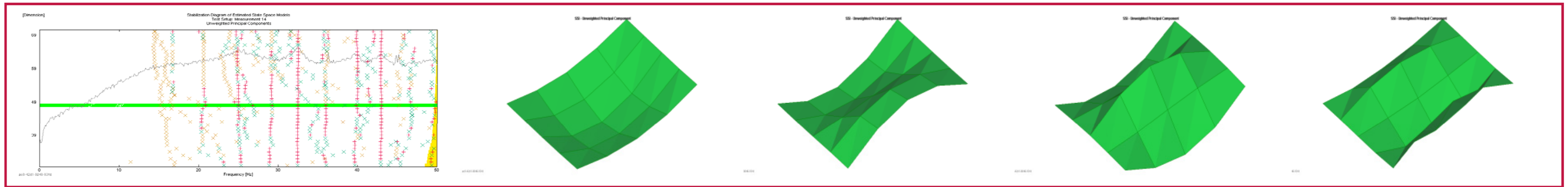
Unit point load deflection



Without concrete screed



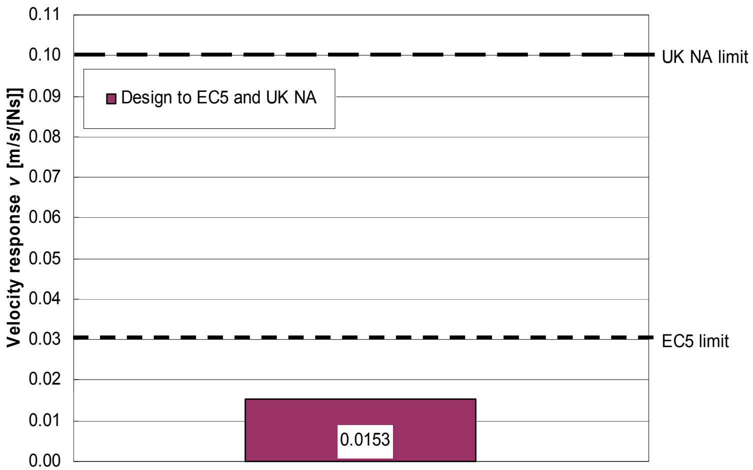
With concrete screed



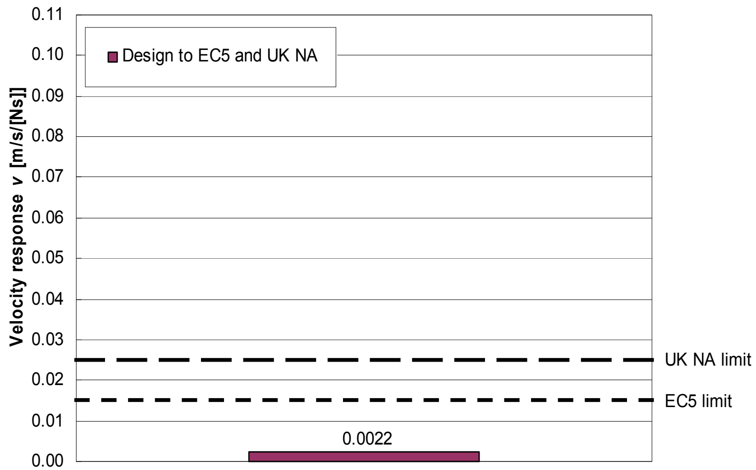
Investigation of design criteria

Finnish flooring structure at the two design stages

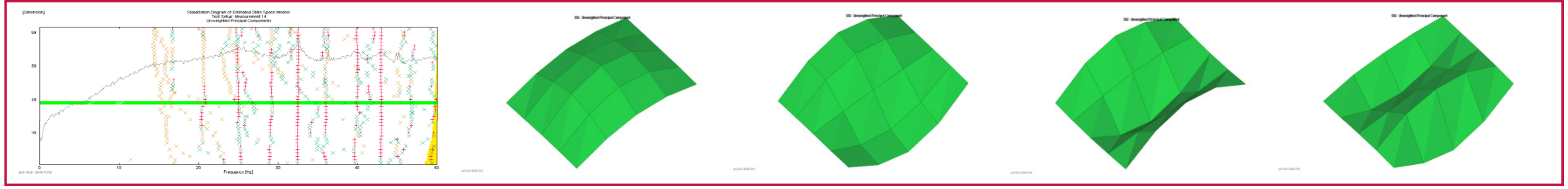
Unit impulse velocity response



Without concrete screed



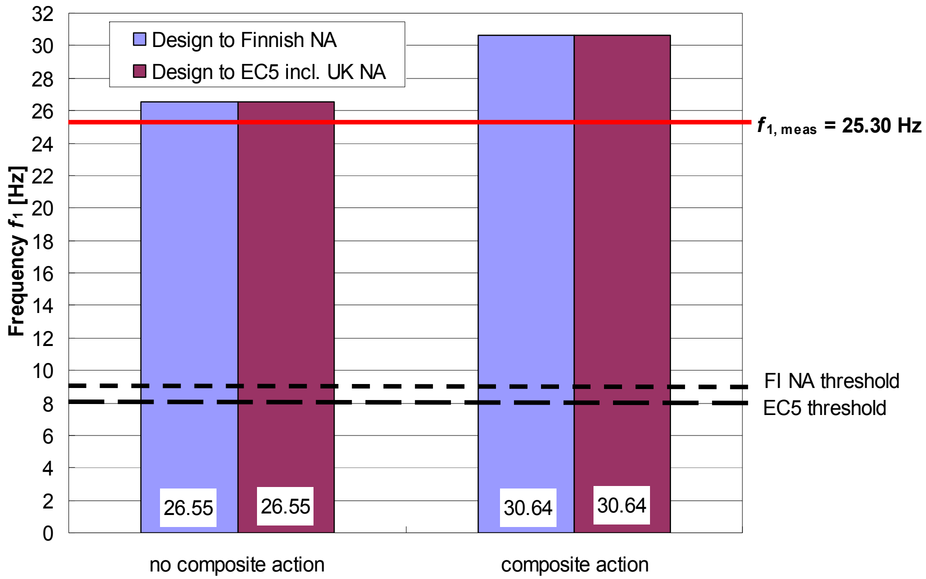
With concrete screed

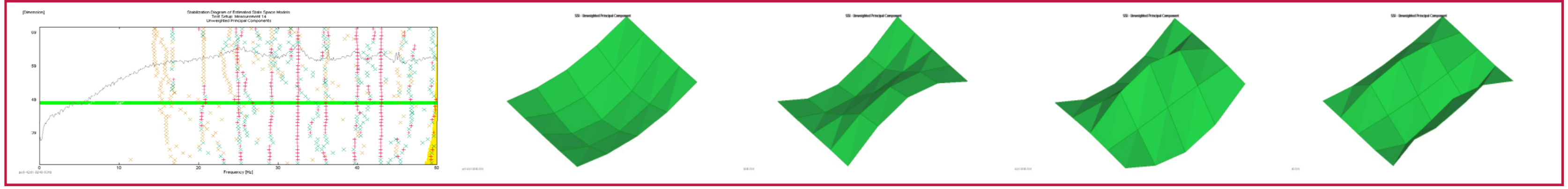


Investigation of design criteria

British flooring structure

Fundamental frequency

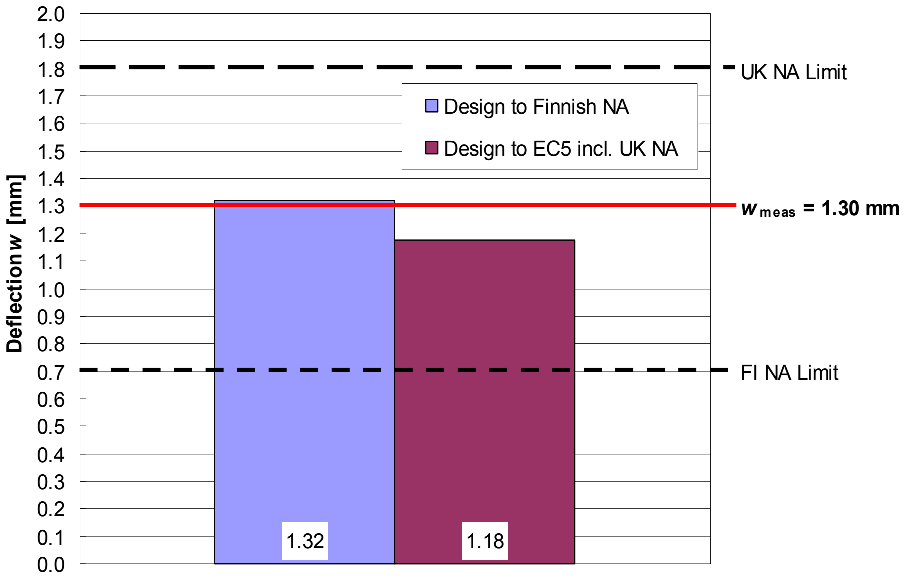


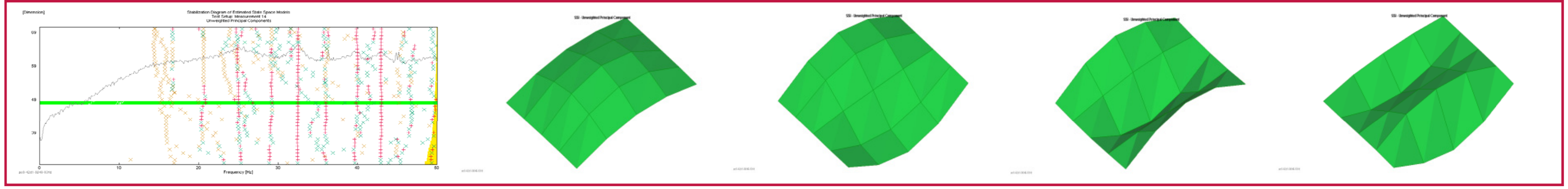


Investigation of design criteria

British flooring structure

Unit point load deflection

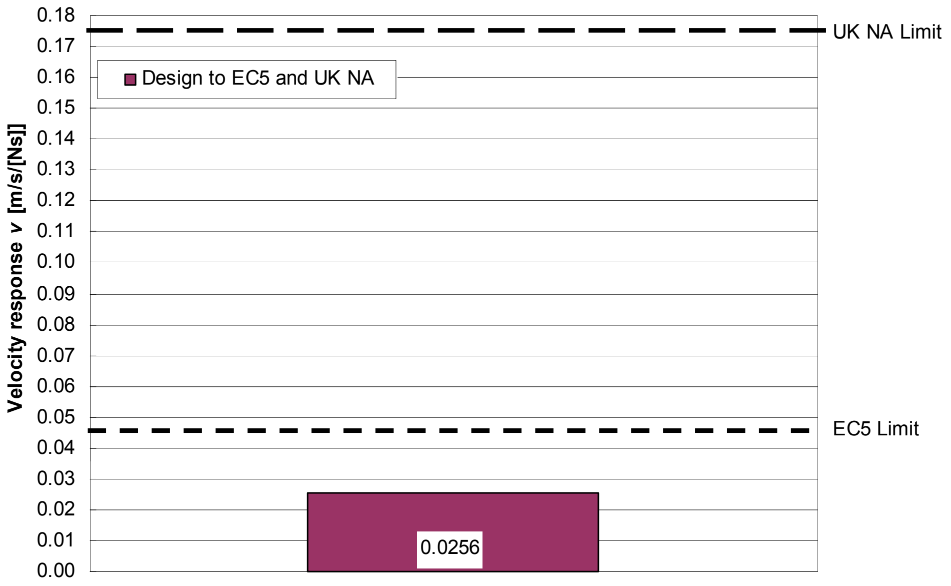


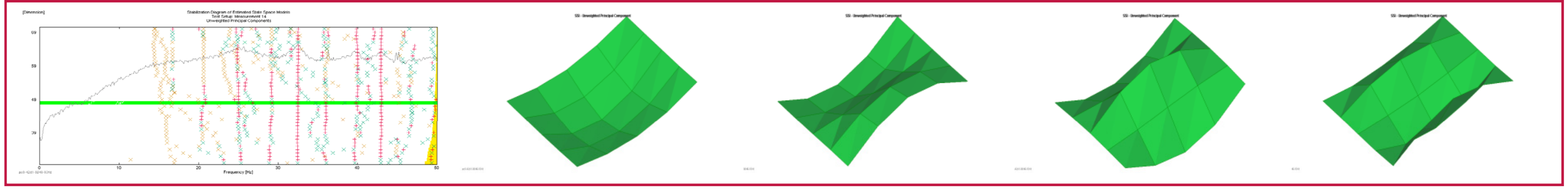


Investigation of design criteria

British flooring structure

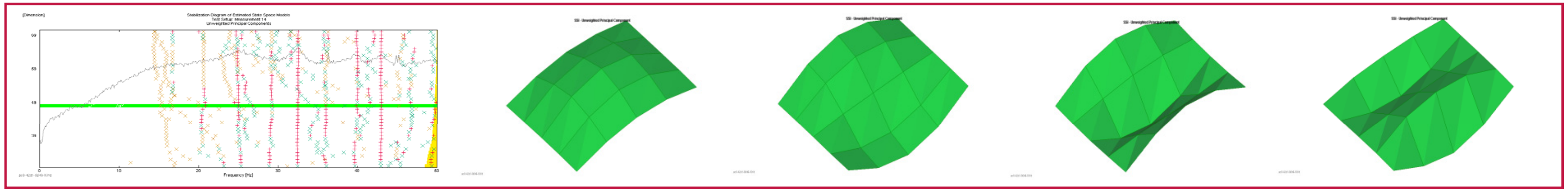
Unit impulse velocity response





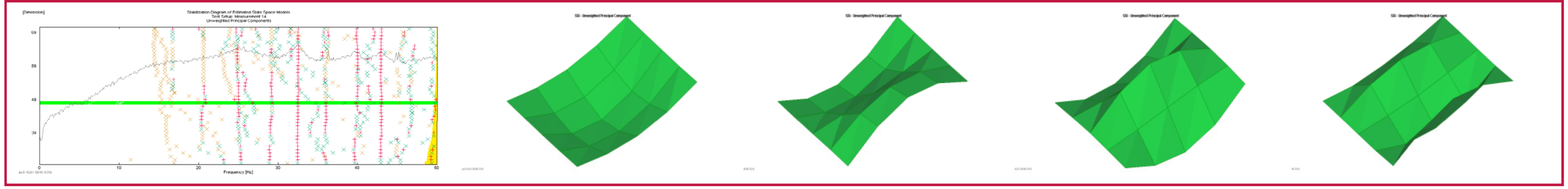
Summary of assessment (General)

- All three structures classified satisfactory regarding UK criteria
- Two structures classified unsatisfactory regarding FI criteria
  - classification as unsatisfactory due to deflection criterion
  - misclassification of one system
- The concrete screed clearly lowered fundamental frequency, point load deflection and velocity response and its limit



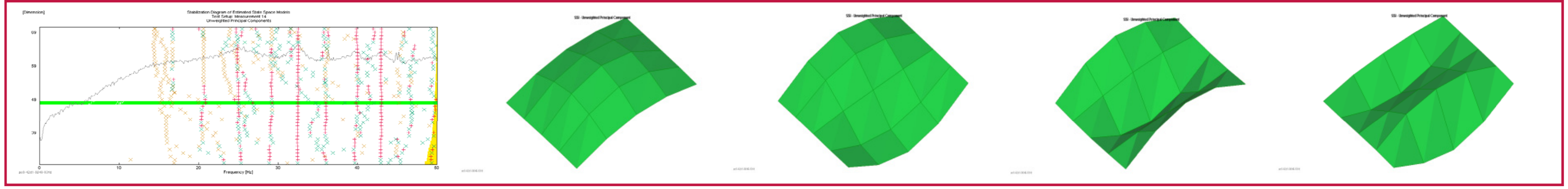
Summary of assessment (Fundamental natural frequency)

- Consideration of composite action overestimated the frequencies of two structures but non-consideration may underestimate frequencies.
- More precise Finnish formula for four-side supported floors yielded more accurate results for lower ratio of longitudinal and transverse stiffness.



Summary of assessment (Unit point load deflection)

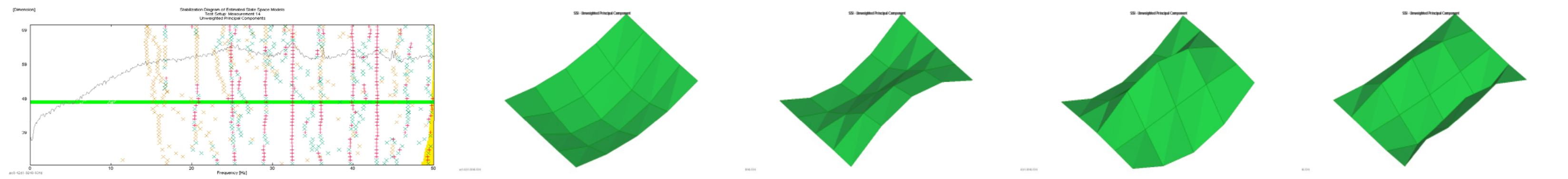
- Overestimated by at least 83% for Finnish floors by both criteria
- Well predicted for the British floor by both criteria
- May differ considerably when calculated using UK and FI criteria



Summary of assessment (Unit impulse velocity response)

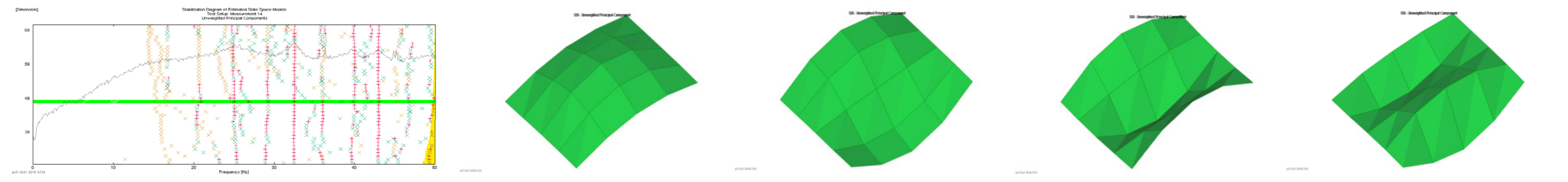
- Velocity limit increases with increase in the damping ratio

➡ Limit of UK NA between 65% - 289% above the EC5 limit



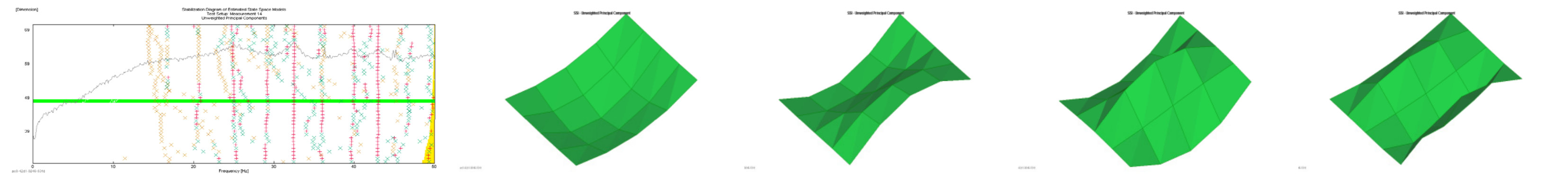
Conclusions

- Finnish design criteria are stricter although only two criteria are used.
- Damping ratio proposed in the UK NA may make velocity response criterion redundant since the requirement is easily fulfilled.
  - ➧ Reconsideration of given set of design criteria is required.
- Recommendations for calculation of transverse stiffness and composite action are required.
- Dynamic properties are not always accurately determinable.
  - ➧ Misclassification of flooring structures is possible.



Conclusions (continued)

- Procedures for more accurately predicting the floor performances and determining the design limits are required and also need to be further harmonised.
- Precise frequency formula for four side supported floors is to be used by considering the transverse stiffness.
- Addition of a concrete screed scales fundamental frequency down due to a higher mass effect than stiffness effect.



Acknowledgements

COST Action E55 committee

James Jones
& SONS LIMITED

Thank you !