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CLT Floor Vibration Control

Lin J. Hu

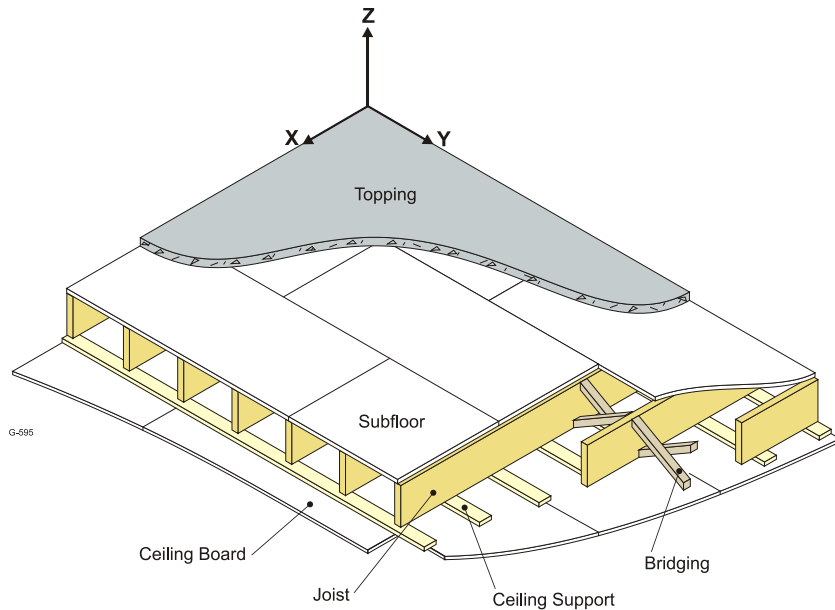
Building Systems, Quebec

CLT Slab...

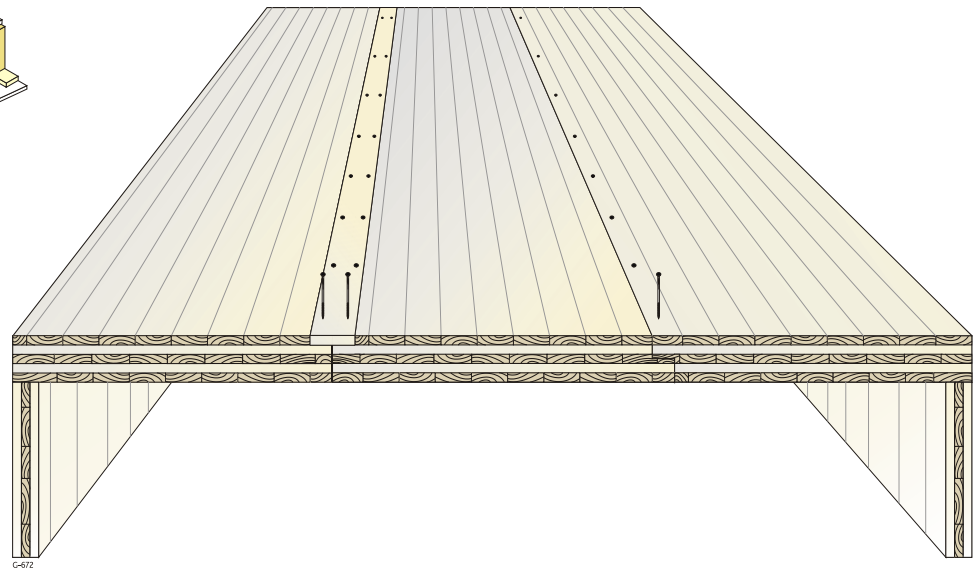
- A green and light-weight alternative to concrete slab

Revolutionary CLT Floor

Conventional wood floor



Cross-section of a CLT floor



Revolutionary CLT Floor

- Solid
- Massive
- No joists

Revolutionary CLT Floor

- Shallow wood floor

Example:

6.5 m span floor

- 0.25 m thick CLT
- 0.3 m deep lumber, wood I-joist or truss

Revolutionary CLT Floor – Dynamic Behaviour

	Bare Light-weight joisted floor	Bare CLT floor	Bare Steel-concrete, concrete slab floor
Mass/Area (kg/m ²)	15-30	30-150	>150
Fundamental Natural Frequency (Hz)	>15	>9	<9
Damping Ratio (%)	3	1	1

What Does 9 Hz or 15 Hz Floor Frequency Mean to You?

The **higher** the floor frequency,
the **easier** the vibration control

What Does 1% and 3% Damping Mean to You?

The **lower** the damping, the **lower** the acceptance of human to the vibrations

Control CLT Floor Vibrations – Three Strategies

- During production – **Quality control**
- During floor design – **Sharpen your pencil**
- During floor construction – **On-site quality control**

Control CLT Floor Vibrations – No. 1: Production Quality Control

- Actual CLT panel properties > design values

HOW?

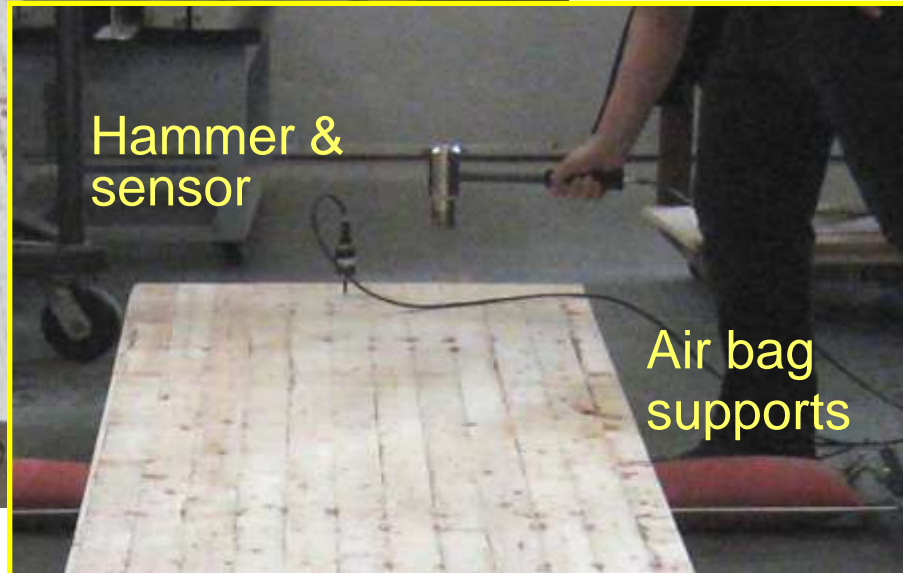
**Adopt a non-destructive evaluation
technique for CLT QC**

- Increase CLT damping

Control CLT Floor Vibrations – No. 1: NDE for QC



- Good correlation between NDE and other standard test methods ($r^2 > 0.99$)
- NDE is inexpensive and simple to carry out



Control CLT Floor Vibrations – No. 2: Sharpen your Pencil

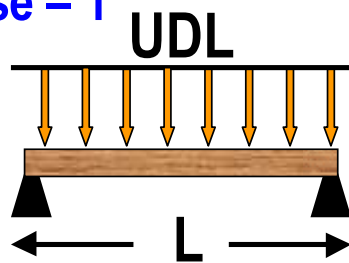
- Use a science-based design method –
the Sharp Pencil
- Experience is not a sharp pencil:
Example . . .

Is the UDL Method of L/480 a Sharp Pencil?

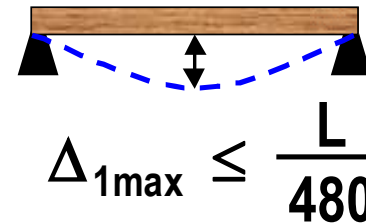
Allowable deflection linearly increases with the increase of the span ????

Case Study – 40 psf live load and same joist spacing

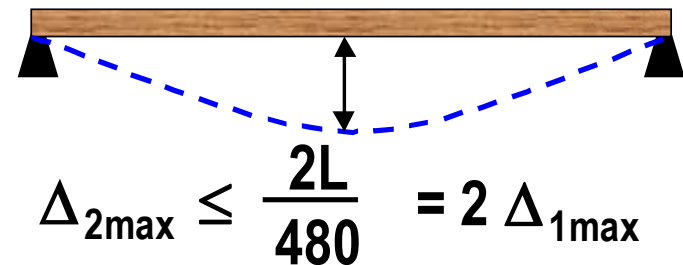
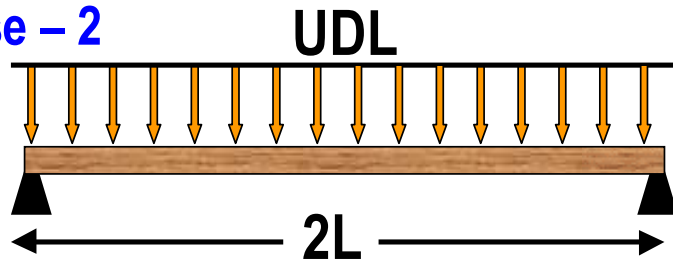
Case – 1



Allowable Deflections



Case – 2



Where is the Sharp Pencil?

Floor construction	Light-weight, joisted, no topping	CLT	- Heavy steel-concrete - Concrete slab
Guidance?	-In NBCC -In Eurocode-5	None	In steel-concrete floor design guide
Floor mass characteristics (kg/m²)	10-30	30-150	>150
Floor frequency characteristics (Hz)	>15	>9	<9

A Sharp Pencil-A Proposed Design Method

$$\frac{f}{d^{0.7}} > 13.0$$

$$f = \frac{3.142}{2l^2} \sqrt{\frac{EI_{eff}^{1m}}{\rho A}} \text{ (Hz)}$$

$$d = \frac{1000 Pl^3}{48EI_{eff}^{1m}} \text{ (mm)}$$

$$P = 1000 \text{ (N)}$$

$$l = \text{span (m)}$$

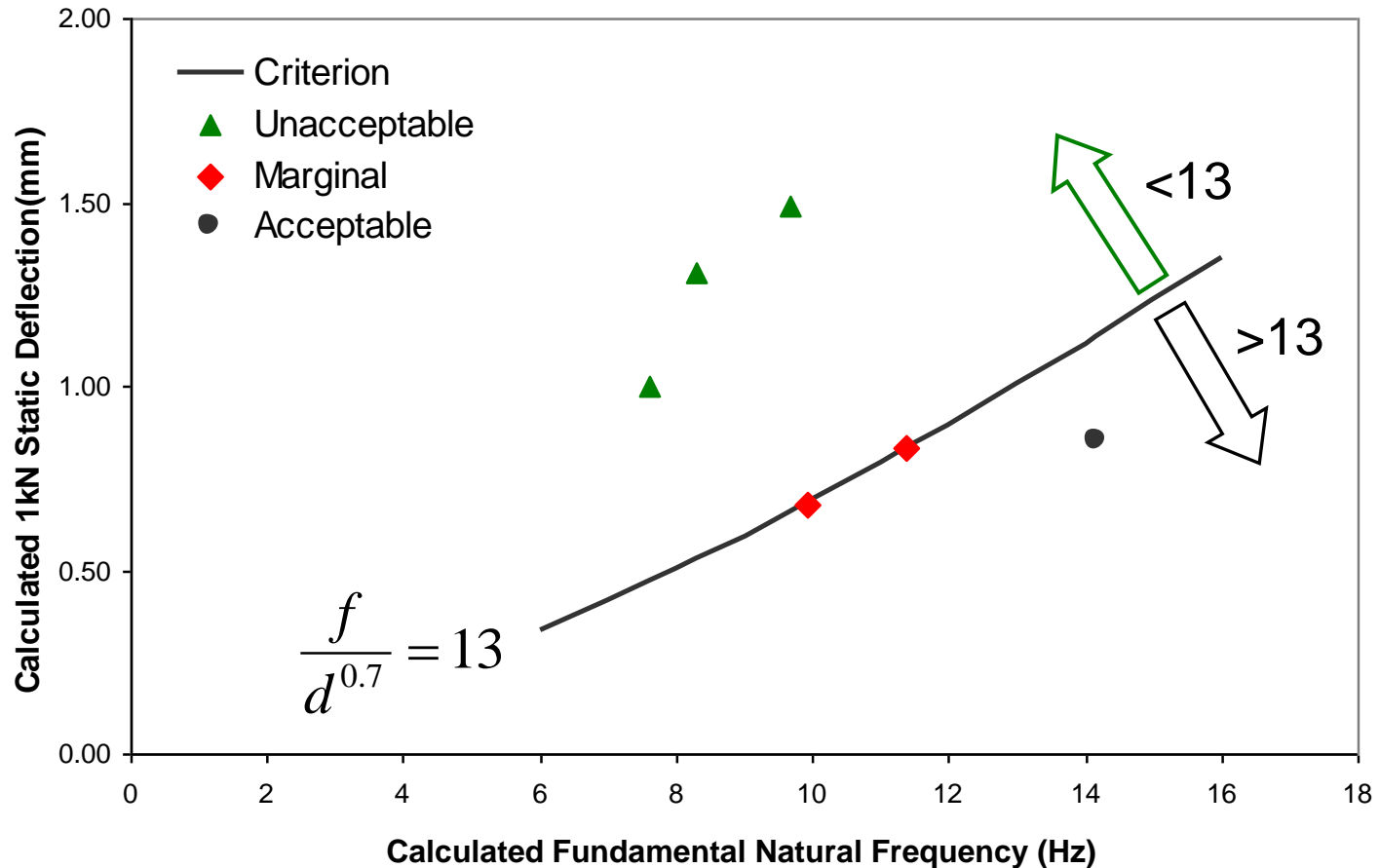
$$\rho = \text{density (kg/m}^3\text{)}$$

$$A = \text{area of 1 m wide CLT (m}^2\text{)}$$

$$EI_{eff}^{1m} = \text{effective apparent stiffness in span direction of 1 m wide CLT (N-m}^2\text{)}$$

Why Should I Believe it is a Sharp Pencil?

Predicted CLT floor vibration performance vs. subjective ratings



Proposed Design Method vs. CLT Industry Experience: Which is More Rational?

CLT producer's recommendations:

$$D = 2.4 \text{ kN/m}^2$$

$$L = 1.5 \text{ kN/m}^2$$

$$\text{UDL limit} = L/400$$

Thickness of CLT (mm)	Span of proposed design method (m)	Equivalent UDL limit of proposed design method
140	4.75	L/417
182	5.50	L/497
230	7.00	L/606

Proposed Design Method vs. CLTdesigner

CLT thickness (mm)	FPIinnovations' design method proposed span (m)	CLTdesigner proposed span for 1% damping and no topping floors (m) (Schickhofer, 2010)
100	3.58	3.53
120	3.76	3.75
140	4.50	4.43
160	4.80	4.76
180	5.16	5.14
200	5.68	5.67
220	5.84	5.89
240	6.09	6.17

Simple Form of the Proposed Design Method

$$l \leq \frac{1}{9.15} \frac{(EI_{eff}^{1m})^{0.293}}{(\rho A)^{0.123}}$$

l = vibration controlled span (m)

ρ = density (kg/m³)

A = area of 1 m wide CLT (m²)

EI_{eff}^{1m} = effective apparent stiffness in span direction of 1 m wide CLT (N-m²)

Worked Example 1: Knowing Effective Apparent EI

- Known:

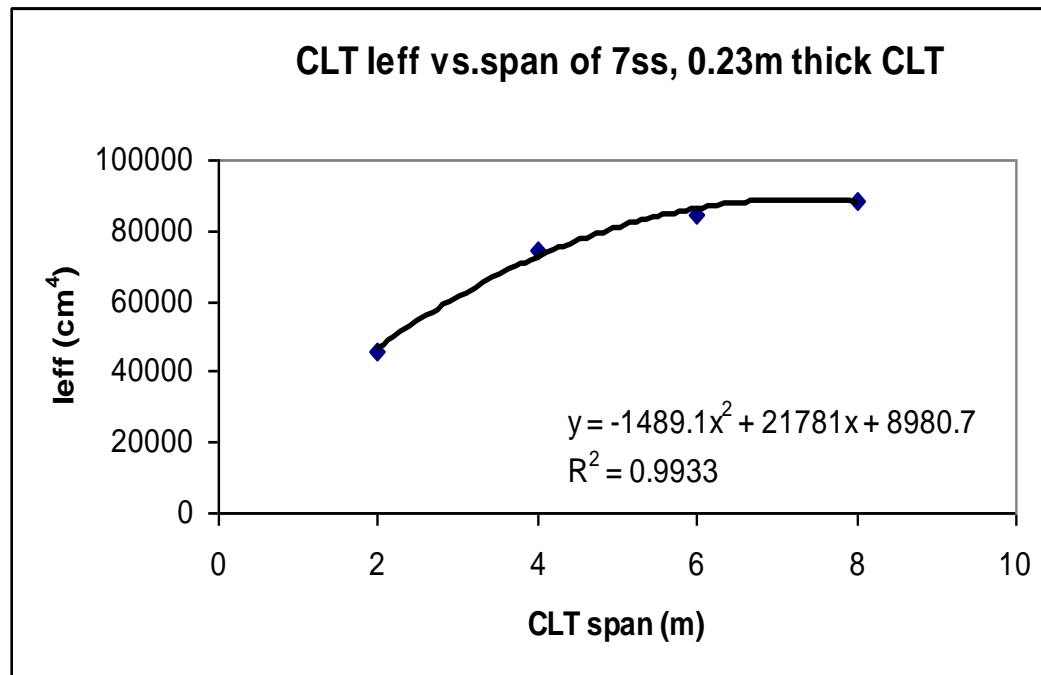
- Thickness = 0.23 m
- Density = 480 kg/m³
- MOE = 12 GPa

Simple span (m)	Effective apparent I_{eff} (cm ⁴)
2	45979
4	74100
6	84238
8	88534

- Unknown: Equation to determine effective apparent EI_{eff} from CLT span

Worked Example 1

Equation to determine effective apparent I_{eff} from span



$$I_{eff} = (-1489.1l^2 + 21781l + 8980.7) / 10^8 \text{ (m}^4\text{)}$$

Worked Example 1

- First trial span = 30* CLT thickness
- Use Excel:

Thickness (m)	Trial span (m)	$I_{\text{eff}} \text{ (m}^4\text{)} =$	MOE (GPa)	Density (kg/m ³)	Span limit (m)
		$(-1489.1l^2 + 21781l + 8980.7)/10^8$			$l \leq \frac{1}{9.15} \frac{(EI_{\text{eff}}^{1m})^{0.293}}{(\rho A)^{0.123}}$
0.23	6.90	0.00088374	12	480	7.01
0.23	7.01	0.00088491	12	480	7.01
0.23	7.30	0.00088628	12	480	7.02

- Iteration criterion: span limit \approx trial span = 7.01 m

Worked Example 2: Knowing True EI and GA

- Design Values:

- Thickness = 0.14 m
- Density = 500 kg/m³
- Width = 1.0 m
- Effective true EI = 2.143x10⁶ N-m²
- Effective GA = 1.082x10⁷ N

- Equation to Determine Effective Apparent EI:

$$EI_{eff}^{1m} = \frac{1}{\frac{1}{TrueEI} + \frac{11.52}{GA * l^2}}$$

Worked Example 2: Knowing True EI and GA

- Trial span = 30* thickness
- Use Excel:

Thickness (m)	Trial Span (m)	True EI (N-m ²) × 10 ⁶	GA (N) × 10 ⁷	EI_{eff}^{1m} (N-m ²) × 10 ⁶	Density (kg/m ³)	Span limit (m)
				$EI_{eff}^{1m} = \frac{1}{\frac{1}{TrueEI} + \frac{11.52}{GA * l^2}}$		$l \leq \frac{1}{9.15} \frac{(EI_{eff}^{1m})^{0.293}}{(\rho A)^{0.123}}$
0.14	4.20	2.143	1.082	1.900	500	4.48
0.14	4.48	2.143	1.082	1.924	500	4.50
0.14	4.50	2.143	1.082	1.926	500	4.50
0.14	4.60	2.143	1.082	1.934	500	4.50

- Iteration criterion: span limit ≈ trial span = 4.5 m

Control CLT Floor Vibrations – No. 3: On-Site QC

- Quality control of CLT floor installation and construction on site
 - Supports
 - Connection details
 - Moisture Content

Final Remark

- Excellent and unique CLT products
- Excellent and cost-effective CLT assemblies and buildings
- Three strategies for CLT floor vibration control:
 - 1) QC for fabrication,
 - 2) proper design,
 - 3) QC for installation

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