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EFFECT OF DESIGN PARAMETERS ON MASS TIMBER FLOOR VIBRATION PERFORMANCE

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Mass timber construction is gaining momentum in North America, along with an increase in the construction of tall and large commercial wood buildings. Mass timber is a generic name for a broad range of thick and heavy wood products such as cross-laminated timber (CLT), dowel-laminated timber (DLT), nail-laminated timber (NLT), and glue-laminated timber (GLT), among others. So far, vibration-controlled design methods have been developed mostly for CLT floors. However, it is unclear whether those methods applicable to CLT are valid for other mass timber assemblies.

Effect of concrete topping

It is a common North American practice to add a concrete topping over mass timber floors to improve its acoustic performance; however, its effects on mass timber floor vibration performance remain unknown. In an attempt to better understand these effects, FPInnovations conducted studies to examine the effects of concrete topping on mass timber floor vibration performance. The ultimate goal is to develop a design method to control floor vibrations of a broader range of mass timber floors with various construction details, including with concrete topping.

Laboratory trials were conducted on a DLT floor made of eight 175-mm thick by 610-mm wide panels positioned and fastened together side-by-side. Each DLT panel was made of sawn lumber boards that were set on edge and mechanically laminated with hardwood dowels. A 12.5-mm plywood was nailed on top of the DLT floor to form a DLT-plywood base floor. The floor specimens were built using various construction details, including all four edges simply supported (SSSS or "Supported-Supported-Supported-Supported") and only two ends supported (simple span, SFSF or "Supported-Free-Supported-Free") (Figure 1).

a) SFSF floor panel with edges not supported

b) SSSS floor panel with edges supported

Figure 1. Bare supported-free-supported-free (SFSF) and supported-supported-supported-supported (SSSS) floor panels under vibration modal testing

Two concrete thicknesses (38 mm and 100 mm) and floor spans varying from 6.50 m to 7.58 m were studied. The concrete slab was poured on the base floor through a 12.5-mm wood fibreboard that was placed on top of the base floor without using any mechanical fasteners, and covered with a plastic vapor barrier film. The floor fundamental natural frequencies and maximum centre deflections under a 1-kN point load were measured. The floor vibration performances were also subjectively rated by 20 evaluators. Table 1 provides some of the main results.

It was found that adding 38-mm and 100-mm thick concrete toppings over the 187.5-mm thick base floor improved the floor vibration performances. The improvement was indicated by increased frequencies, reduced deflections, and increased rating scales. For both topping thicknesses, the ratios of the concrete area density to the base floor area density were approximately 1.0 and 2.5, respectively. Adding a 100-mm thick concrete topping did not affect the frequency of the 6.50-m span, indicating that if more concrete topping were added to the floor, it would be expected to have a reduced frequency, which may reduce the vibration performance. The results also suggest that the 100-mm thick concrete topping for the 187.5-mm thick base floor with a ratio of area density of concrete to the base floor of 2.5 would represent a turning point from the positive effect to negative effect of concrete topping on the base floor vibration performance. FPInnovations plans to conduct further studies to verify the observations towards the development of the vibration-controlled design method for a broader range of mass timber floors with various construction details, including with concrete topping. More details can be found in the FPInnovations (2020) report entitled *Expanding Wood Use Towards 2025: Floor Vibration Performance*.

Minimum bending stiffness requirement for supporting beams

Post-and-beam construction is common for mass timber buildings. In this type of construction, the mass timber floors are supported on beams (Figure 2). However, there is no vibration-controlled design method for the supporting beams. It is acknowledged that if the supporting beams do not have adequate stiffness, the overall floor system will be bouncy, no matter how stiff the floors are. In an attempt to understand the effect of supporting beams on floor vibration performance, FPInnovations developed a minimum bending stiffness requirement for supporting beams as a first-line design strategy to reduce floor vibration.

Table 1. Vibration performance attributes of the dowel-laminated timber (DLT)-plywood base floor with various construction details

Floor construction and ID	Span (m)	Support	Ratio of concrete/base(1) floor area density	Frequency (Hz)	1 kN deflection (mm)	Subjective rating scale(2)
F1: Base floor(1)	7.58	SSSS	0.00	6.57	1.01	1.4
F2: F1 with 38-mm concrete topping	7.58	SSSS	0.97	7.69	0.48	2.4
F3: = F2	6.50	SSSS	0.97	9.85	0.38	3.6
F4: = F3 with 100-mm concrete topping	6.50	SFSF	2.50	8.00	0.11(3)	4.0
F5: = F4	6.50	SSSS	2.50	9.85	0.12(3)	> 4.0

Notes:

(1) The base floor was made of a 175-mm DLT structure with 12.5-mm plywood nailed on top

(2) Rating scale: 1 is for Definitely not acceptable floor and 5 for Definitely acceptable floor; 3 to 4 are for Marginal floor.

(3) The 0.11 and 0.12 values can be interpreted as no significant difference.

Figure 2. CLT floors on supporting beams in a post-and-beam construction

A database of various wood supporting beams and their vibration performance in occupied buildings has been built over the years from results from field vibration tests and subjective evaluations of various wood floors, namely mass timber floors in current mid- to high-rise mass timber buildings, as well as from laboratory studies. Heel drop tests were performed on these simply-supported beams. Moreover, subjective evaluation was conducted on these supporting beams of varying spans until the evaluators felt they were "solid" when they were dropping their heels on the beams. The database includes the field and laboratory

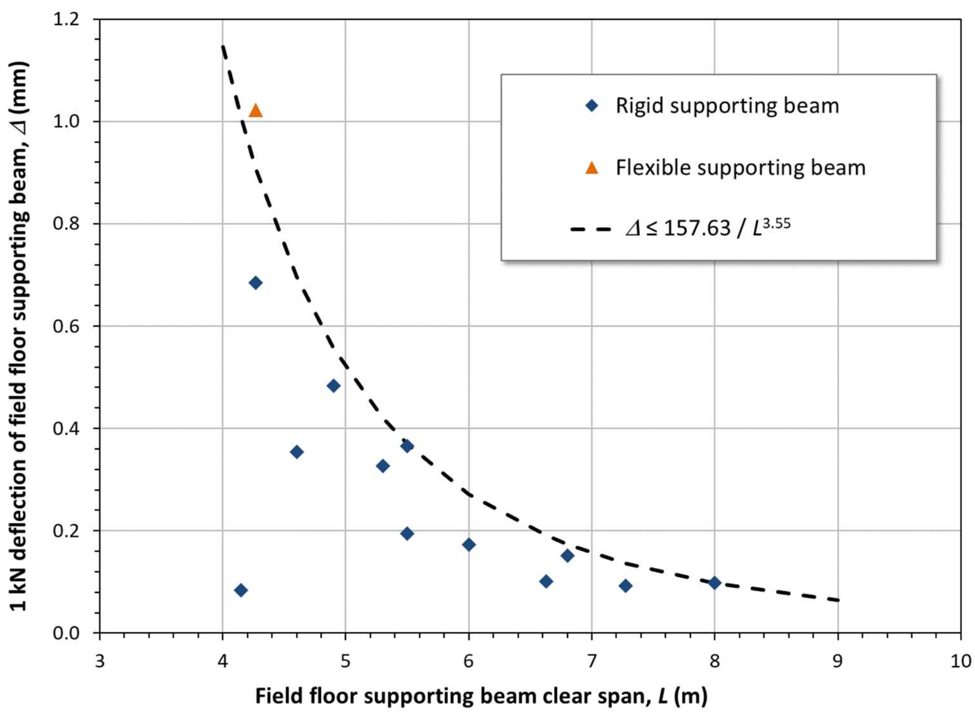

Figure 3. Verification of the proposed minimum requirement for wood supporting beam bending stiffness for floor vibration control

tests on supporting beam vibration performance and the beams' bending stiffness *(EI)*$_{beam}$. The database was used to derive the minimum beam stiffness *(EI)*$_{beam}$ requirement described below so that the rigid supports design assumption remains valid:

$$(EI)_{beam} \geq F_{span} 132.17\, L_{beam}{}^{6.55}$$

where:

L_{beam} = clear span of the supporting beam (m)

F_{span} = 1.0 for a simple span beam, and

≈ 0.7 for multi-span continuous beam.

Figure 3 shows the verification of the requirement using the database. More detailed information can be found in the FPInnovations (2018) report entitled *Advanced Wood-based Solutions for Mid-rise and High-rise Construction: Proposed Vibration-controlled Design Criterion for Supporting Beams*. Feedback is needed to further verify the proposed requirement. It must be pointed out that besides meeting the proposed minimum requirement for vibration-controlled floor supporting beams, the supporting beams should also meet the other code requirements, including strength, deflection, and creep, among others.

Further to these findings, FPInnovations' working plan for the development of change proposals was approved by the CSA O86 Technical Committee to address these design parameters during its 2024 revision cycle.

References

Hu, L. & Omeranovic, A. (2020). *Expanding Wood Use Towards 2025: Floor Vibration Performance*, FPInnovations

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