Common Challenges in Light Wood-Frame Gravity Structural Design

Floor Framing Considerations

Mike Romanowski, SE
WoodWorks
Structural Floor Design – Vibration vs. Acoustics

Structural Vibrations
- 1 Hz – 100 Hz
- Transmitted through structure or through ground
- Physical effects

Acoustic Vibrations
- 20 Hz – 15,000 Hz
- Transmitted through air, walls, floors, windows
- Audible effects
US Building Code Requirements for Vibration

None

Barely discussed in IBC, NDS, etc.
ASCE 7 Commentary Appendix C has some discussion, no metrics
US Building Code Requirements for Deflection

Deflection performance does not necessarily equal vibration performance

<table>
<thead>
<tr>
<th>CONSTRUCTION</th>
<th>L</th>
<th>S or W^f</th>
<th>D + L^d,g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof members:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supporting plaster or stucco ceiling</td>
<td>1/360</td>
<td>1/360</td>
<td>1/240</td>
</tr>
<tr>
<td>Supporting nonplaster ceiling</td>
<td>1/240</td>
<td>1/240</td>
<td>1/180</td>
</tr>
<tr>
<td>Not supporting ceiling</td>
<td>1/180</td>
<td>1/180</td>
<td>1/120</td>
</tr>
<tr>
<td>Floor members</td>
<td>1/360</td>
<td>—</td>
<td>1/240</td>
</tr>
<tr>
<td>Exterior walls and interior partitions:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With plaster or stucco finishes</td>
<td>—</td>
<td>1/360</td>
<td>—</td>
</tr>
<tr>
<td>With other brittle finishes</td>
<td>—</td>
<td>1/240</td>
<td>—</td>
</tr>
<tr>
<td>With flexible finishes</td>
<td>—</td>
<td>1/120</td>
<td>—</td>
</tr>
<tr>
<td>Farm buildings</td>
<td>—</td>
<td>—</td>
<td>1/180</td>
</tr>
<tr>
<td>Greenhouses</td>
<td>—</td>
<td>—</td>
<td>1/120</td>
</tr>
</tbody>
</table>
Systems View of Vibration

Excitation Force(s)  Structure  Vibration Response
## Framing Materials Properties for Vibration

<table>
<thead>
<tr>
<th>Material</th>
<th>Floor Weight (psf)</th>
<th>Damping</th>
<th>Material Stiffness ($10^6$ psi)</th>
<th>Material Mass (pcf)</th>
<th>Example Floor System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>100-150</td>
<td>1-5%</td>
<td>3.2-5.8</td>
<td>120-150</td>
<td>2-way slab on columns</td>
</tr>
<tr>
<td>Steel</td>
<td>50-100</td>
<td>0.5-5%</td>
<td>30</td>
<td>490</td>
<td>Concrete on metal deck on purlins and girders</td>
</tr>
<tr>
<td>Mass Timber</td>
<td>15-65</td>
<td>1-5%</td>
<td>1.2-1.8</td>
<td>30-40</td>
<td>Beam or wall supported panels</td>
</tr>
<tr>
<td>Wood Frame</td>
<td>10-40</td>
<td>2-12%</td>
<td>1.2-2.0</td>
<td>30-40</td>
<td>Wall supported joists or trusses</td>
</tr>
</tbody>
</table>
Vibration Design Methods

\[ \Delta \leq \frac{L}{360} \text{ for floor live load} \]

IBC code limit on floor deflection

**Wood Frame**

Joists:
\[ \Delta \leq \frac{L}{360} \text{ for } L < 15 \text{ ft} \]
\[ \Delta < 0.5'' \text{ for } L \geq 15 \text{ ft} \]

Trusses:
\[ \Delta \leq \frac{L}{480} \text{ with strong-backs} \]

Woeste and Dolan
*Beyond Code: Preventing Floor Vibration.*
1998, Journal of Light Construction
Vibration Design Methods

Wood Frame

\[ f_n \geq 14 \text{ Hz for occupied (e.g. furnished) floors} \]
\[ f_n \geq 15 \text{ Hz for unoccupied floors} \]


Proprietary rating systems from Joist Manufacturers
Where can I find criteria for vibration control for wood members?

- Dolan and Woeste developed some information on controlling vibration published in *Structural Engineer* magazine.
- APA Technical Note called *Minimizing Floor Vibration by Design and Retrofit*
- *Wood Design Focus* paper by Dolan and Kalkert called "Overview of Proposed Wood Floor Vibration Design Criteria" (Vol. 5, #3).
  [http://www.forestprod.org/buy_publications/wood_design_focus_past_articles.php#volume5](http://www.forestprod.org/buy_publications/wood_design_focus_past_articles.php#volume5)
Vibration Design Methods

IS A "SPRING IN YOUR STEP" CAUSING PROBLEMS?

June 2007 » Feature Article

Annoying vibration is probably the most common performance complaint for light-frame wood floors.

Frank Wueste, Ph.D., P.E., and Daniel Dolan, Ph.D., P.E.

Recommendations to minimize annoying wood-floor vibrations

Annoying vibration is probably the most common performance complaint for light-frame wood floors. The International Code Council’s 2006 International Residential Code (IRC) and its 2006 International Building Code (IBC) do not address this issue, yet the engineer-of-record for a project may face the issue of determining whether the vibration is expected under the prescriptive provisions of the IRC. While wood floor vibration deserves attention by the design professional at the design stage, it is impossible to fix.

\[
f = 1.57 \sqrt{\frac{386E}{W}} \frac{L}{3}
\]  
(Equation 1)

![Graph showing vibration criteria for different loads and spans.](image)
Vibration Design Methods

Multi-family floor spans in the 24’-30’ range work well from a layout perspective. Floor design of wood members in this span range are often governed by vibration and/or deflection control, not structural capacity.

Live Load Deflection Chart, Courtesy: Redbuilt
Vibration Design Methods

**Tools available to designers**

Vibration Analysis: FP Innovations  
(Spreadsheet available upon request)

Joist Manufacturer’s  
Rating Systems

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**NOISE AND VIBRATION CONTROL OF LIGHT FRAME WOOD JOIST FLOORS TOPPED WITH CONCRETE**

Lin Hu¹, Mohammad Mohammad² and Sylvain Gagnon³

**ABSTRACT:** Light frame wood joint floors have reduced sound insulation because of their lightweight nature. The popular solution to the noise transmission problem is to float a 20mm or thicker cementitious topping over the floor. Although this solution efficiently improves sound insulation of light frame floors, it makes normal walk-induced vibrations more perceivable than with the floors without the topping. Currently, more than half of the housing market in Canada is multi-family construction. As more multi-family light frame wood buildings are being built, more and more complaints about excessive footable vibrations through concrete topped wood joint floors are being received. This paper explains the myths behind this phenomenon, and more importantly, sheds some lights on available solutions.

**KEYWORDS:** Light frame, multi-family building, wood joint floor, concrete topping, noise control, vibration control

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**Floor Performance Expectations**

- Less demanding  
- Typical  
- More demanding

- Storage  
- Warehouse  
- Mezzanine  
- Affordable housing  
- Manufacturing  
- Hotels and multifamily: private room  
- Hotels and multifamily: public room  
- Lobby  
- Laboratory  
- Operating room  
- High-end residential  
- Dance hall  
- Gymnasium

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[Diagram showing floor performance expectations with different categories and performance levels]
## Vibration Design Methods

**Determine vibration controlled span using the simple design method, i.e. Vibration controlled span = (EI)\^{0.25}/(8.22(m)^{0.5})**

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</tbody>
</table>

### Results:

**Vibration controlled span = (EI)^{0.25}/(8.22(m)^{0.5})**

<table>
<thead>
<tr>
<th>Input</th>
<th>Test Design 15.33-24</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.49</td>
</tr>
</tbody>
</table>

**Effective composite bending stiffness:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>E (GPa)</td>
<td>193.0</td>
</tr>
</tbody>
</table>

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### Notes:

- **EI** represents the bending stiffness of the floor beam.
- The equation is used to calculate the vibration-controlled span, which is a critical parameter in the design of structures to minimize vibration-induced issues.
What methods exist for checking floor vibration of light-frame wood structures?

Vibration of light-frame wood floor construction can be a significant occupant comfort issue. However, achieving acceptable levels of floor vibration is not a code requirement. As such, it is possible to design a code-compliant wood floor structure that produces annoying or unacceptable levels of vibration due to standard foot traffic.

A variety of factors can affect a floor's vibration performance, including:
- Presence of concrete topping or other massing materials
- Thickness/stiffness of floor sheathing
- Stiffness, spacing and span of floor joists/strusses
- Presence, size and spacing of blocking/bridging/strong backs
- Presence of direct-applied ceiling
- Stiffness of joist supporting elements (i.e., beams, bearing walls)
- Presence of partition walls

Several vibration analysis methods have been published, each of which takes into account some or all of these variables.

What constitutes an “acceptable vibration level” is subjective, but level of performance is generally measured by floor frequency. According to an article by Frank Woeste and Dan Dolan, "Occupants are very sensitive to vibrations in the range of 7-10 Hz. In theory, joist designs (or floor system designs) that vibrate well above 7-10 Hz should be judged by the occupants as acceptable simply because they can’t feel the higher frequencies. As a general rule, wider joist spacing (24 inches on center versus 12 inches on center) will produce a higher frequency because deeper members, having a greater bending stiffness (EI), will be required to meet building code deflection requirements." However, studies by FPInnovations have shown that this approach may be “too simple to differentiate the vibration behavior of the floors with and without concrete topping, and to control vibration in a broad range of light-frame wood joist floors. For example, a long-span light-frame wood joist floor with a concrete topping can have frequency below 14Hz, but..."
Structural Floor Design

Common Wood Floor Assembly:

- LW Concrete Topping
- Acoustical Mat
- Wood Floor Sheathing
- Wood Trusses/I-joists
- Batt Insulation
- Resilient Channel
- Gypsum Ceiling
Topping on Floor Sheathing

Can topping be poured directly on wood floor sheathing?

APA Engineered Wood Construction Guide, E30 states:

APA Rated Sheathing or Sturd-I-Floor (plywood and OSB) panels are an excellent base for lightweight concrete floors. For gypsum concrete recommendations, contact manufacturer of floor topping. Install panels continuous over two or more spans with the strength axis across supports. Use a moisture barrier when recommended by concrete manufacturer.
Topping on Floor Sheathing

Can topping be poured directly on wood floor sheathing?

Can assume that WSP panels will receive more moisture from the curing concrete than without

If WSP can properly dry to a typical equilibrium moisture content of 8 to 12% during construction, moisture exposure from the topping does not appear to be a great concern. *Always check with flooring and topping manufacturer for additional information.*
Corridor Floor Framing Options

Corridor floor framing often shallower than adjacent rooms:
Shorter spans, room for MEP

<table>
<thead>
<tr>
<th></th>
<th>Approximate Max Corridor Width for Solid Sawn Floor Framing Options</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>@ 16”</td>
</tr>
<tr>
<td>2x6</td>
<td>6’-2”</td>
</tr>
<tr>
<td>2x8</td>
<td>7’-10”</td>
</tr>
<tr>
<td>2x10</td>
<td>9’-6”</td>
</tr>
<tr>
<td>2x12</td>
<td>11’-0”</td>
</tr>
</tbody>
</table>

SPF #2, DL = 30, LL = 100
Corridor Floor Framing Options

UL L502
GA FC5104

1 HOUR FIRE

- 1” gypsum underlayment
- 19/32” WSP
- 3 ½” Fiberglass Batt
- 2x10 joists @24 “ oc
- Resilient channel
- 5/8” Type-X Gyp

Common issues with UL approved assemblies:
- Shallow Floor depth
  - Use prescriptive assemblies: IBC 721.1(3) assembly 21-1.1
  - Or use the CAM method in IBC 722
- Use of Structural Composite Lumber
  - Manufacturer’s ESR shows equivalent fire performance to solid sawn
Head of Partition Wall Detailing

How should we detail head of wall conditions where a non-bearing wall intersects the underside of structural floor assembly?
Head of Partition Wall Detailing

Options for connection of non-bearing partition to wood frame floor/roof structure:

- Deflection clips
- Cold formed steel deflection track
Head of Partition Wall Detailing

Options for connection of non-bearing partition to wood frame floor/roof structure:

- Rolled steel angle with vertically slotted holes
- Screws intended for vertical movement
- Blocking on either side of wall, attached to floor/roof framing
Head of Partition Wall Detailing

Can a wall interrupt the ceiling gypsum of a rated horizontal assembly?

**Yes!**

- IBC 2012 714.4.1.2, Except. 7: Permitted if wall is rated to match horizontal assembly
- IBC 2015 714.4.2, Except. 7 or IBC 2018 714.5.2, Except. 7 Permitted if wall is covered with type X gypsum each side
Joint vs. Assembly Intersection

SECTION 202
DEFINITIONS

**Joint.** The opening in or between adjacent assemblies that is created due to building tolerances, or is designed to allow independent movement of the building in any plane caused by thermal, seismic, wind or any other loading.
Exceptions to rated joints:

- Walls that allow unprotected openings
- Control joints not exceeding .625” and tested in E119 assembly

Joint Assemblies available through UL Directory

- Not easily searchable
- HWS or HWD
- Very few wood assemblies
- Joint manufacturer may supply engineering judgement
Joint Systems
Do we need sprinkler protection in floor cavities?

Sprinkler protection (or other means of protection) typically only required in "combustible concealed spaces."

Credit: CADM Architecture
Concealed Spaces: NFPA 13

When does NFPA 13 require for protection of concealed spaces?

- Combustible concealed spaces such as floor/ceiling and roof/ceiling assemblies may require sprinkler protection per NFPA 13
- NFPA 13 section 8.15.1.1 requires combustible concealed spaces to have sprinkler protection unless one of the alternate options are used
Concealed Spaces: NFPA 13

NFPA 13 options for omitting sprinklers in concealed spaces

- When assembly includes bar joists and there is less than 6” from floor/roof deck and ceiling (NFPA 8.15.1.2.4)
- When assembly includes wood joists or similar solid members and ceiling is directly attached to or within 6” of joists (NFPA 8.15.1.2.5)
Concealed Spaces: NFPA 13

NFPA 13 options for omitting sprinklers in concealed spaces

- Composite wood joists with ceiling directly attached or attached to metal channels 1” or less in depth
- Requires that joist cavities are firestopped into volumes not exceeding 160 ft³ with materials equivalent to web construction
- Also requires min. 3.5” batt insulation at bottom of joist cavities when ceiling is attached to metal channels (NFPA 8.15.1.2.6)
Concealed Spaces: NFPA 13

NFPA 13 options for omitting sprinklers in concealed spaces

• Concealed spaces filled with noncombustible insulation (2” air gap at top of space is permitted) (NFPA 8.15.1.2.7)
Concealed Spaces: NFPA 13

NFPA 13 options for omitting sprinklers in concealed spaces

- Concealed spaces with wood joists or composite wood joists, with noncombustible insulation filling the space from ceiling to underside of joists.
- Requires that composite joist cavities are firestopped into volumes not exceeding 160 ft$^3$ with materials equivalent to web construction (NFPA 8.15.1.2.8)

For composite wood joists, firestop into volumes not exceeding 160 ft$^3$

Noncombustible insulation from ceiling to underside of joists
Concealed Spaces: NFPA 13

NFPA 13 options for omitting sprinklers in concealed spaces

• Concealed spaces with noncombustible or limited combustible ceilings suspended from wood joists or composite wood joists with max. nominal chord width of 2”.
• Requires that space from ceiling to underside of joists, and between joists, be filled with noncombustible insulation. Max. 2” air gap allowed at top of insulation (NFPA 8.15.1.2.17)
QUESTIONS?

This concludes The American Institute of Architects Continuing Education Systems Course

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