# Fire, Acoustics, and Structural Detailing of Light-Frame Horizontal Assemblies

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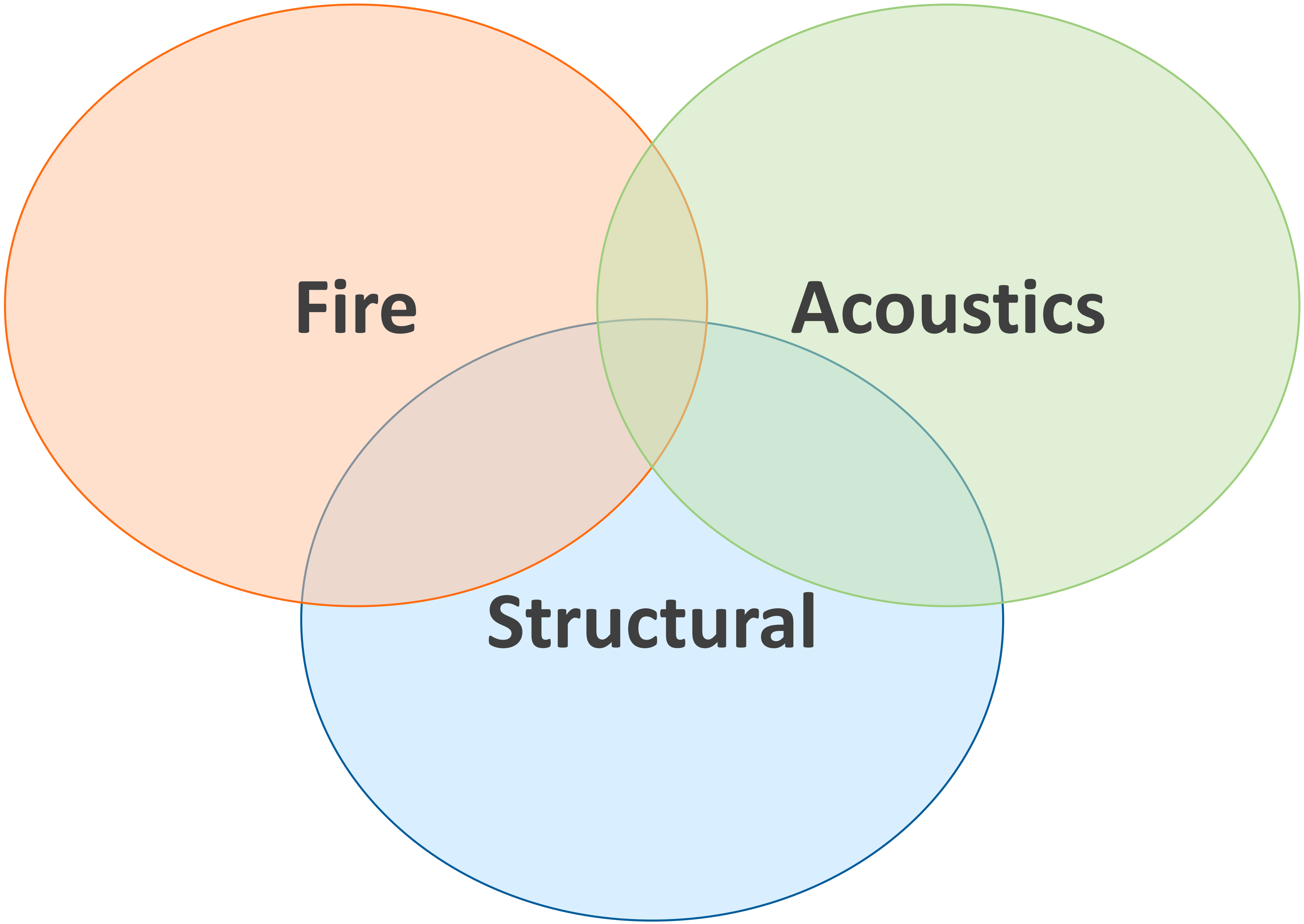
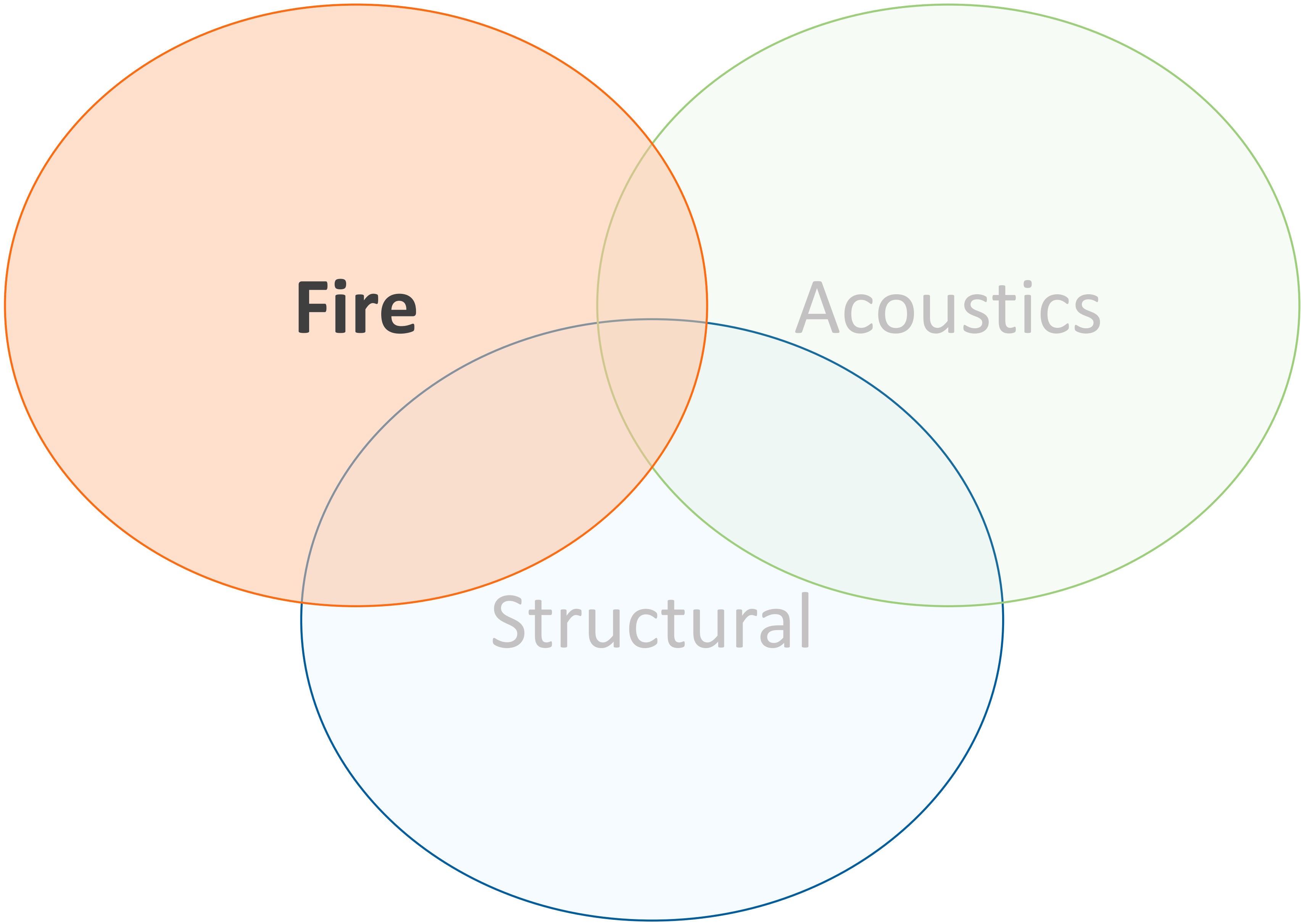
# 3-Part Series on Light-Frame Interior Detailing

- July 2021 Workshop on Fire, Acoustics, and Structural Detailing of Light-Frame **Interior Walls**
  - https://www.woodinstitute.org/enrol/index.php?id=207
- November 2021 Symposium session on Fire, Acoustics, and Structural Detailing of Light-Frame **Horizontal Assmblies**
  - Will be posted to The Wood Institute prior to December Webinar
- **December 8 Webinar** wrap up on interior floor and wall assemblies
  - Answering follow-up questions, commonly asked questions
  - https://www.woodworks.org/education-event/2021-dec-webinar/



Fire
Acoustics
Structural


Fire
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# Horizontal Assemblies

- A floor or roof assembly required to have a fire resistance rating such as for occupancy separations and fire area separations
- May be constructed with any materials permitted by the construction type
- Occupancy separation: Fire resistance ratings per IBC Table 508.4
- Required to be continuous without vertical openings except as permitted in IBC 712
- Supporting construction required to have same fire-resistance rating as the fire barrier being supported (with exceptions per 711.4)
- Other requirements for openings, penetrations, joints

# Fire Ratings of Horizontal Assemblies – 711.2.4

Fire resistance rating shall not be less than that required for:

- **Building's construction type – Table 601**
  - 1-hr for III-A, V-A
  - 0-hr for III-B, V-B
- Separating mixed occupancies – Table 508.4
- Separating fire areas – Table 707.3.10
- **Separating dwelling units – 711.2.4**
  - Not less than 1-hr
  - Except: III-B, V-B with NFPA 13 sprinklers is ½-hr
- Separating smoke compartments – 709.3
- Separating incidental uses – Table 509

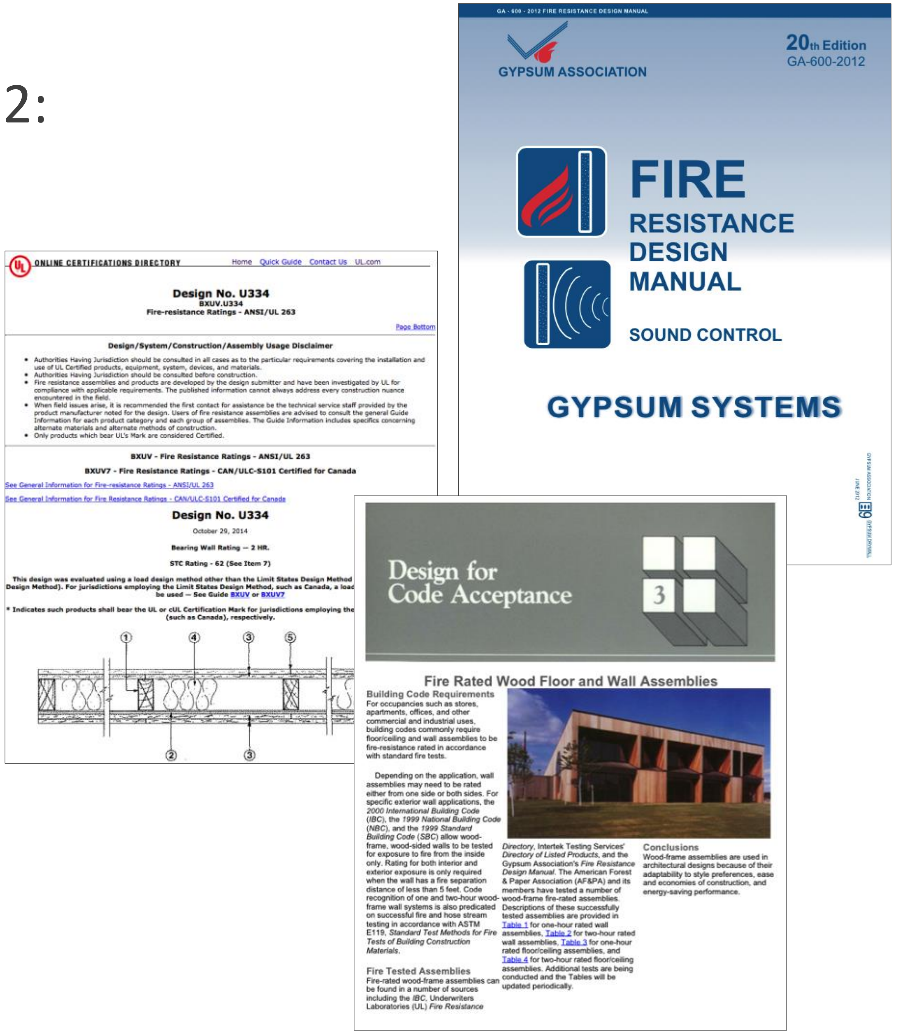
# Choosing Fire Rated Assemblies

Common tested assemblies (ASTM E119) per IBC 703.2:

- UL Listings
- Gypsum Catalog
- Proprietary Manufacturer Tests
- Industry Documents: such as AWC's DCA3

Alternate Methods per IBC 703.3

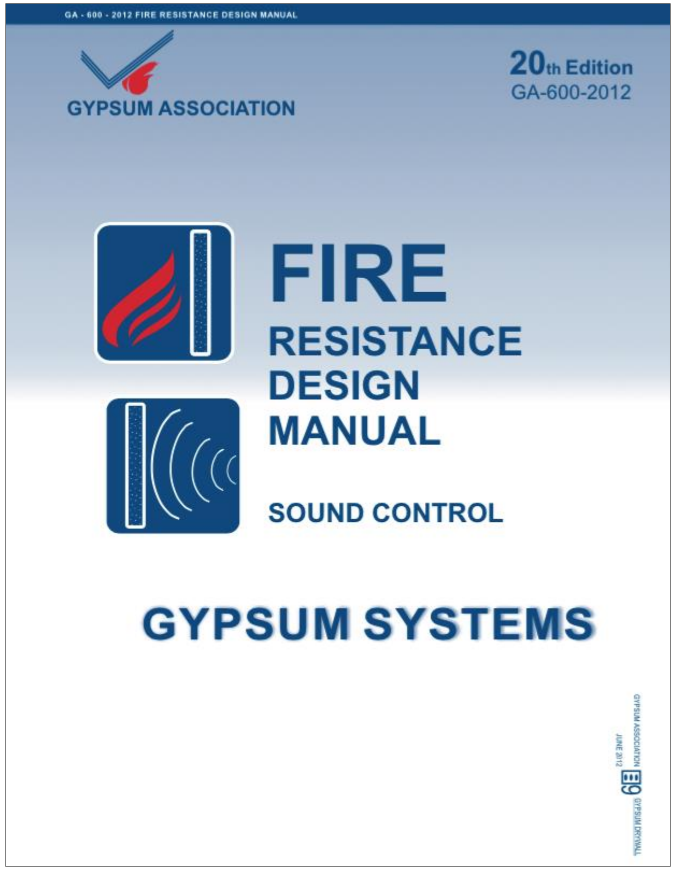
- Prescriptive designs per IBC 721.1
- Calculated Fire Resistance per IBC 722
- Fire-resistance designs documented in sources
- Engineering analysis based on a comparison
- Fire-resistance designs certified by an approved agency



# Fire Resistance – Insulation Effects

*"The addition of up to 16-3/4 inches of 0.5 pcf glass fiber insulation (R-40), either batt or loose-fill, to any 1- or 2-hour fire resistance rated floor-ceiling or roof-ceiling system having a cavity deep enough to accept the insulation is permitted provided that one additional layer of either 1/2 inch or 5/8 inch type X gypsum board is applied to the ceiling. The additional layer of gypsum board shall be applied as described for the face layer of the tested system except that the fastener length shall be increased by not less than the thickness of the additional layer of gypsum board."*

Section 1.12 Gypsum Association's
Fire Resistance Design Manual



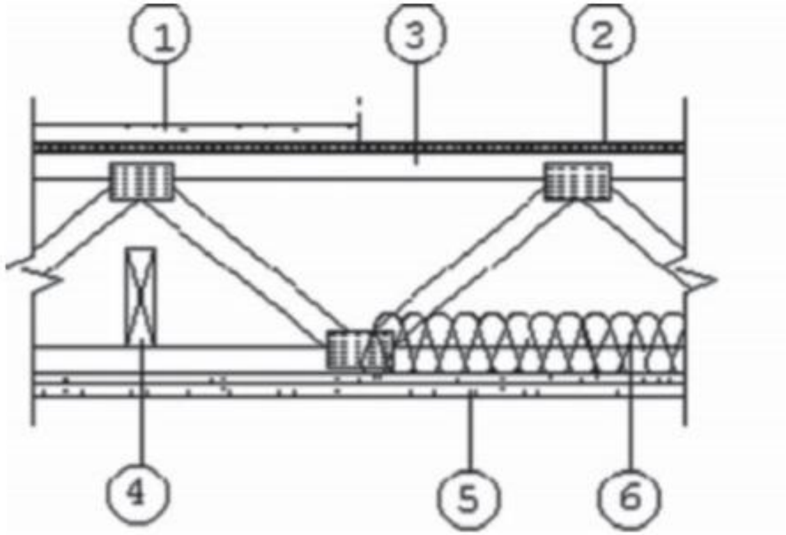
# Trusses

*"Specified floor-ceiling and roof-ceiling framing sizes or truss dimensions are minimums. Greater joist or truss sizes (depths) shall be permitted to be used in metal- or wood-framed systems.“*

Section 1.17 Gypsum Association's Fire Resistance Design Manual

*"Thus, larger and deeper trusses can be used under the auspices of the same design number. This approach has often been applied to roof truss applications since roof trusses are usually much deeper than the tested assemblies".*

WTCA's Metal Plate Connected Wood Truss Handbook

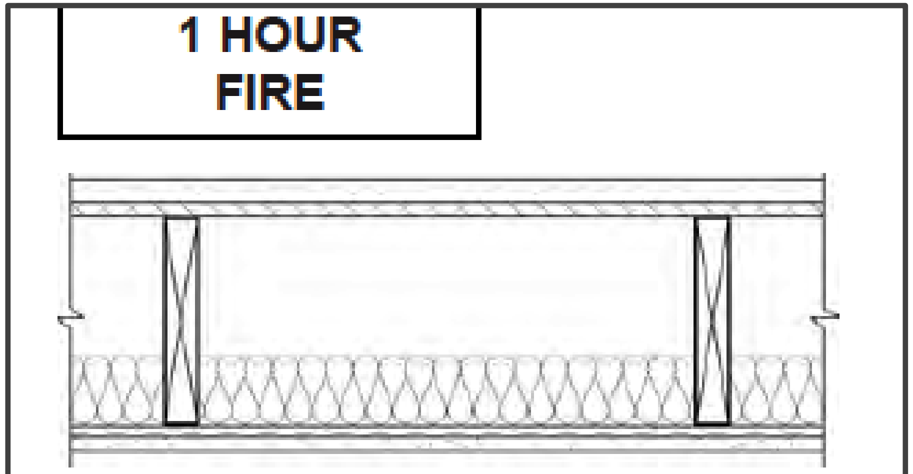



**TSC/FCA 60-10**

1. Topping (optional)
2. Flooring - min ¾" plywood
3. Truss – min depth 10", spaced at 24"oc
4. Bridging/Strongback
5. 2 layers ½" Type X Gyp
6. Insulation (optional) – supported by metal furring or 1x3 wood furring strips at 16" oc. "Equivalent methods that retain insulation above joist bottom flange are acceptable"

# Shallow Floor Depths

UL L502
GA FC5104




- 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 calculated method in IBC 722
- Use of Structural Composite Lumber
  - Manufacturer’s ESR shows equivalent fire performance to solid sawn

# Exposed Framing Fire Resistance

**IBC 703.3** Alternate Methods for determining fire resistance

Prescriptive designs per IBC 721.1

- **Calculations in accordance with IBC 722**
- Fire-resistance designs documented in sources
- Engineering analysis based on a comparison
- Alternate protection methods as allowed by 104.11

**IBC 722** Calculated Fire Resistance

"…The calculated *fire resistance* of exposed wood members and wood decking shall be permitted in accordance with **Chapter 16** of ANSI/AF&PA *National Design Specification for Wood Construction (**NDS**.)*"

**NDS Chapter 16** Fire Design of Wood Members

Limited to calculating fire resistance up to 2 hours.

Char rate varies based on endurance required, product type and lamination thickness. Equations and tables provided.

TR10 and NDS commentary are helpful in implementing permitted calculations.

# Exposed Framing Fire Resistance

**Table 16.2.1A Char Depth and Effective Char Depth (for $\beta_n$ = 1.5 in./hr.)**

| Required Fire Resistance (hr.) | Char Depth, $a_{char}$ (in.) | Effective Char Depth, $a_{eff}$ (in.) |
|---|---|---|
| 1-Hour | 1.5 | 1.8 |
| 1½-Hour | 2.1 | 2.5 |
| 2-Hour | 2.6 | 3.2 |

Source: 2018 NDS Chapter 16

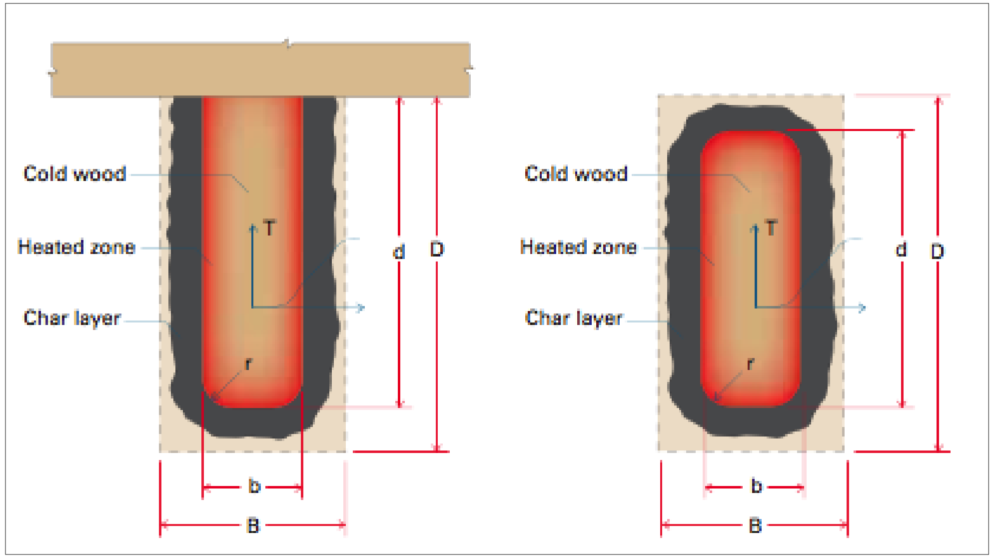
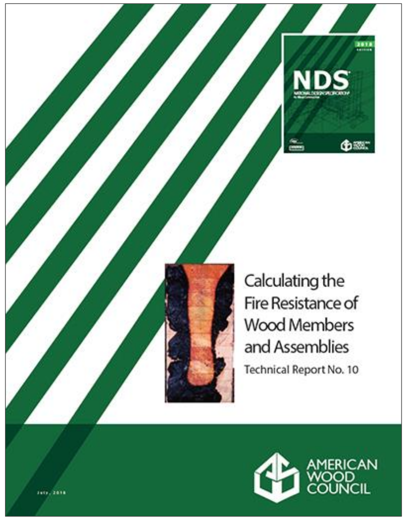



Image: AWC TR 10

https://awc.org/codes-standards/publications/tr10



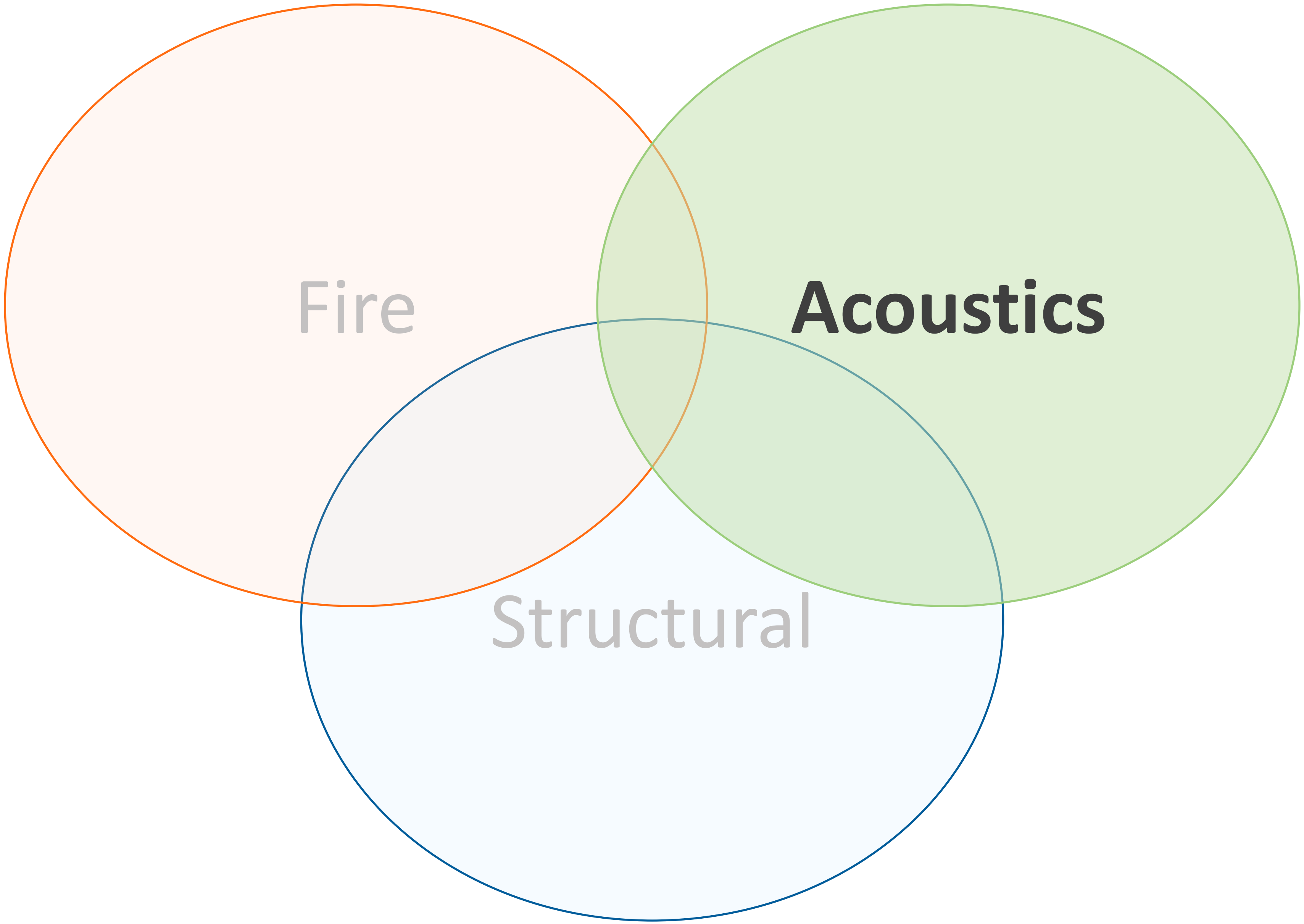

# Are sprinklers required in concealed spaces such as floor and roof cavities in multi-family wood-frame buildings?

The International Building Code (IBC) requires all buildings containing Group R occupancies to have sprinklers throughout; however, the need for sprinklers specifically located in the concealed spaces of floors and roofs is dependent on the type of sprinkler system specified (NFPA 13 or NFPA 13R) and the use of fireblocking and draftstopping.

**IBC Requirements:**

View All Expert Tips

http://www.woodworks.org/ask-an-expert/


Fire
Acoustics
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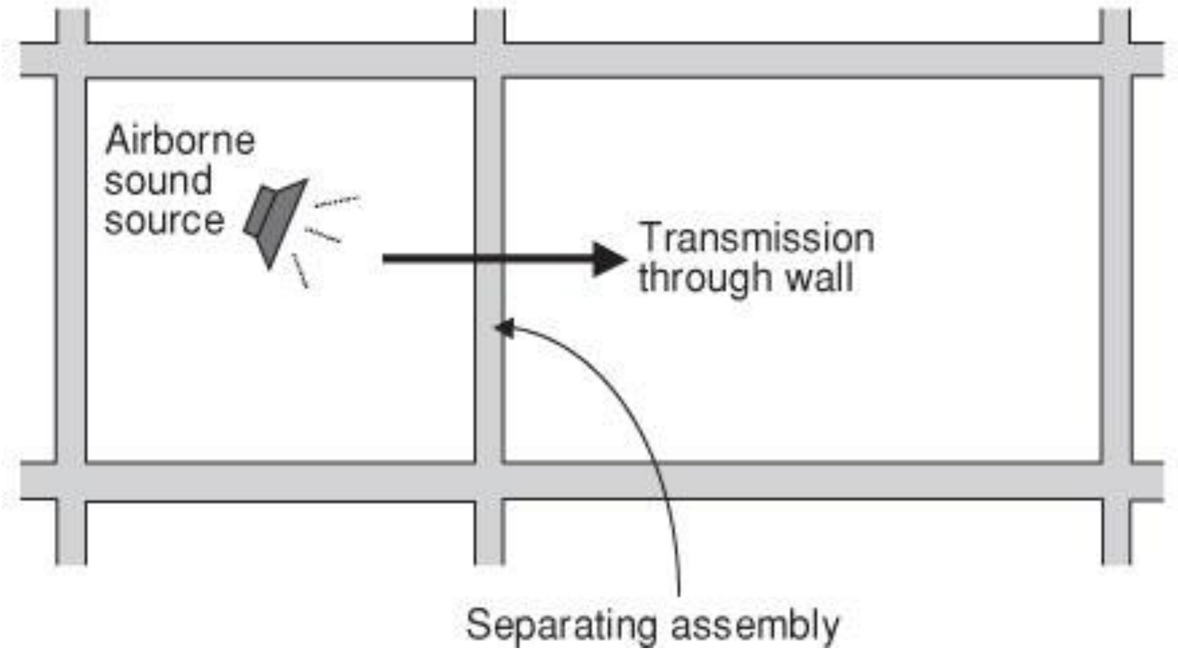
# Acoustical Design

**<u>Air-Borne Sound</u>: Sound Transmission Class (STC)**

Measures how effectively an assembly isolates air-borne sound and reduces the level that passes from one side to the other

Applies to walls and floor/ceiling assemblies

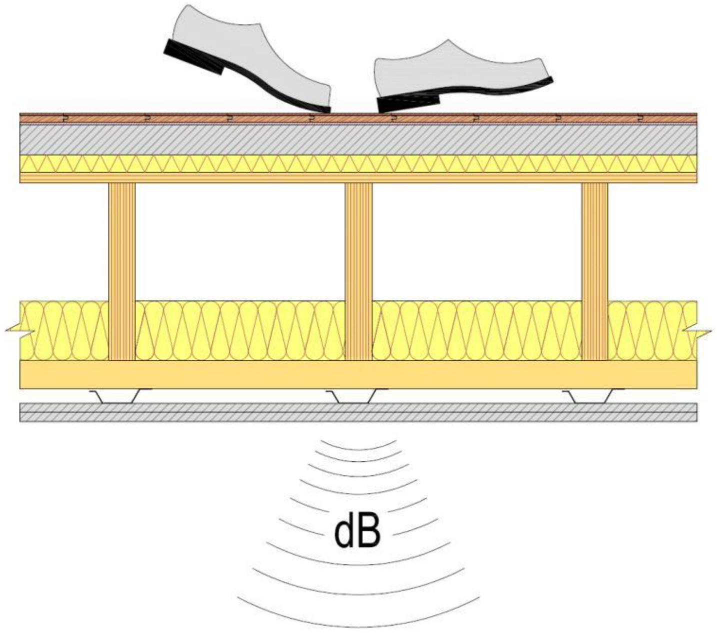



# Acoustical Design

**<u>Structure-borne sound</u>: Impact Insulation Class (IIC)**

Evaluates how effectively an assembly blocks impact sound from passing through it

Only applies to floor/ceiling assemblies




# Acoustical Criteria – IBC 1206

Code requirements only address residential occupancies:

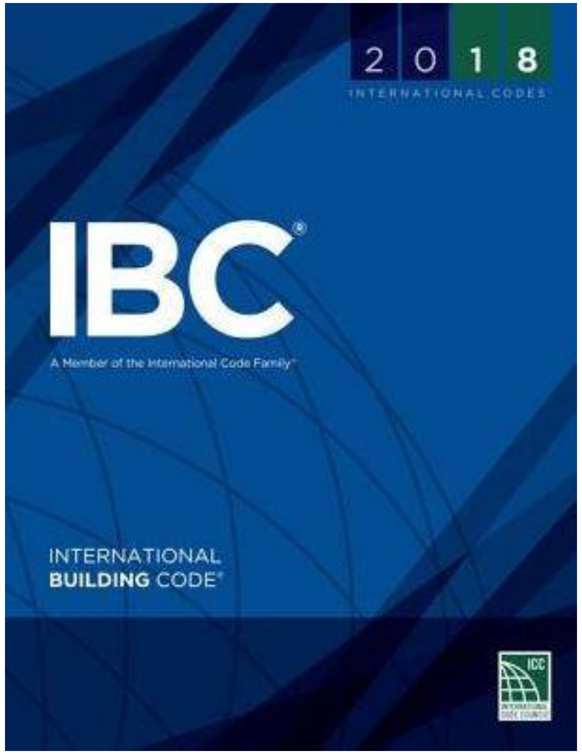
For unit to unit or unit to public or service areas:

**Min. STC of 50 (45 if field tested):**

- Walls, Partitions, and Floor/Ceiling Assemblies

**Min. IIC of 50 (45 if field tested) for:**

- Floor/Ceiling Assemblies



# Acoustical Criteria

| STC | What can be heard |
|---|---|
| 25 | Normal speech can be understood quite easily and distinctly through wall |
| 30 | Loud speech can be understood fairly well, normal speech heard but not understood |
| 35 | Loud speech audible but not intelligible |
| 40 | Onset of "privacy" |
| 42 | Loud speech audible as a murmur |
| 45 | Loud speech not audible; 90% of statistical population not annoyed |
| 50 | Very loud sounds such as musical instruments or a stereo can be faintly heard; 99% of population not annoyed. |
| 60+ | Superior soundproofing; most sounds inaudible |

# Choosing Acoustically Rated Assemblies

Common tested assemblies:

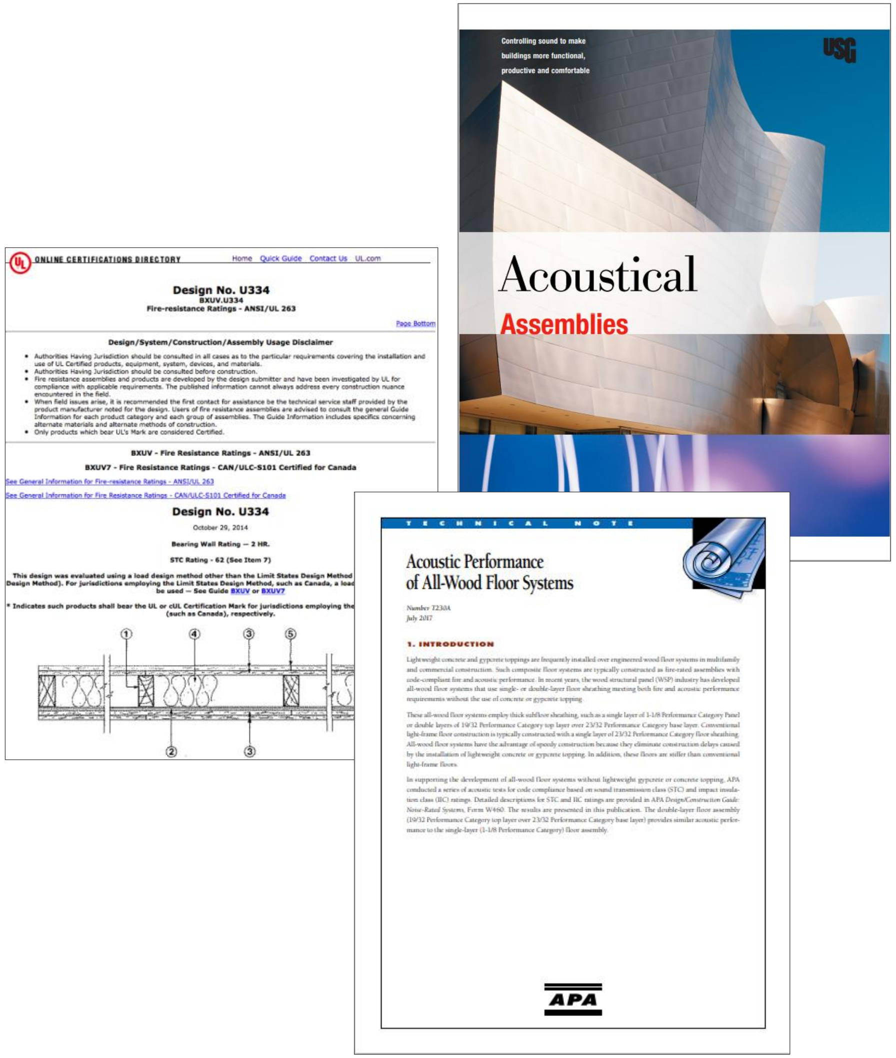
**STC:** ASTM E90, per IBC 1206.2

**IIC:** ASTM E492, per IBC 1206.3

- Manufacturers of gypsum, insulation, acoustical products (proprietary tests)
- UL Listings
- Gypsum Catalog
- Industry associations: AWC, APA, others
- Reach out to **WoodWorks**!

Alternate Method: IBC 1206.2 & 1206.3

- Both STC and IIC may be “established by engineering analysis based on a comparison of floor-ceiling assemblies having [STC/IIC] ratings as determined by the test procedures.”



# Acoustical Detailing

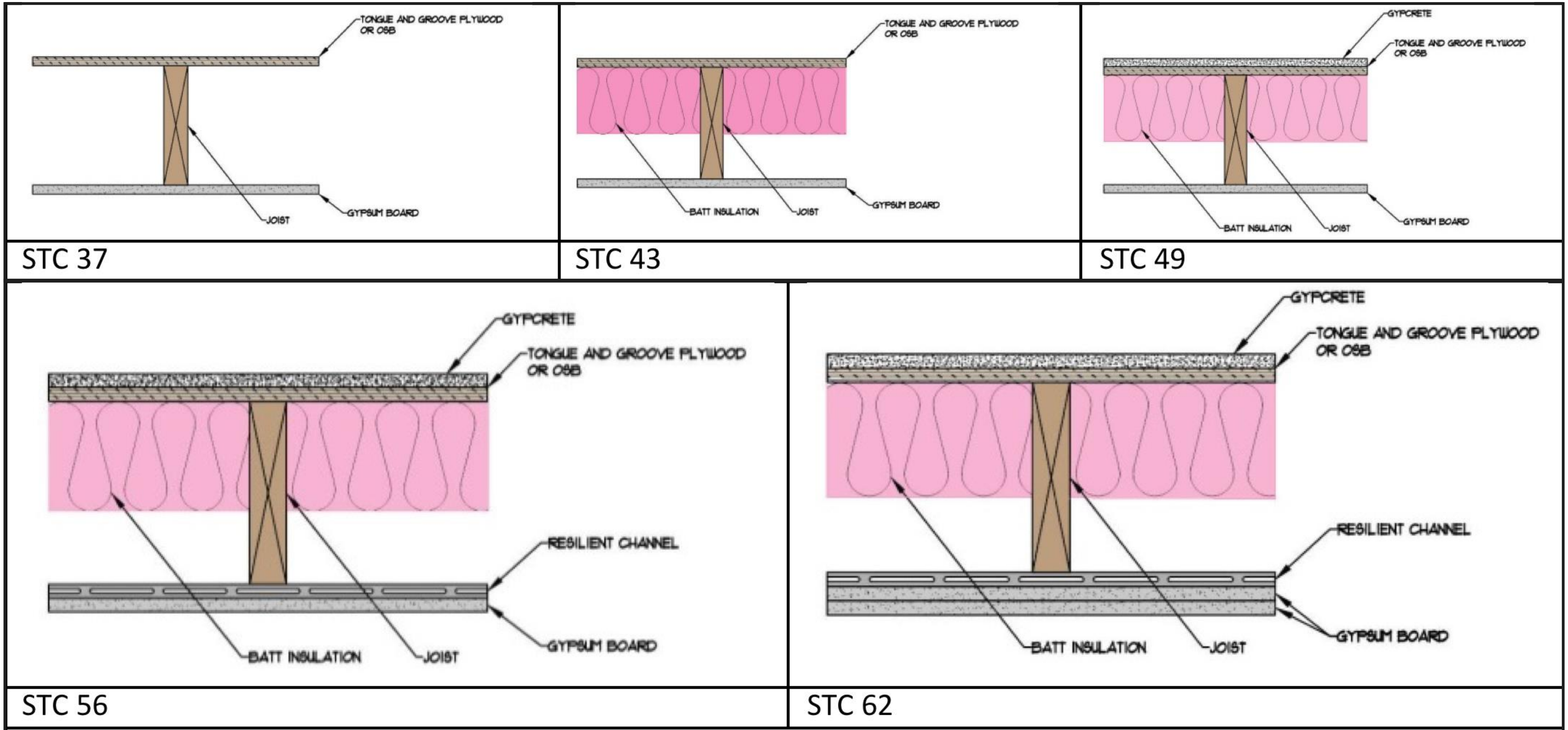
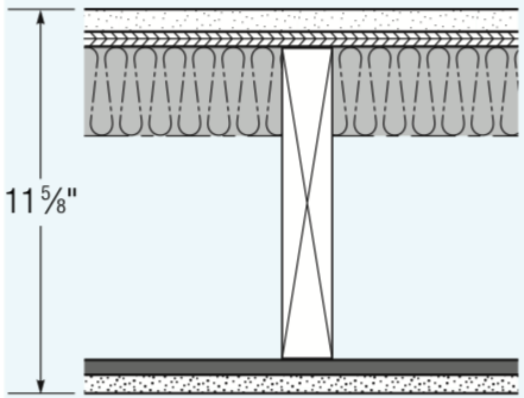



Figure 1 - Acoustical Progression in Wood Framed Floor / Ceilings

# Acoustical Detailing

| Dimensional Lumber | | Acoustical Performance | | |
|---|---|---|---|---|
| **Construction Detail** | **Description** | **STC** | **IIC** | **Test Number** |
| clg. wt. 3  | • 5/8″ SHEETROCK Brand FIRECODE C Core Gypsum Panels<br>– 2x10″ wood joist 16″ o.c.<br>– RC-1 channel or equivalent 16″ o.c.<br>– Insulation held up under subfloor by lightning clips<br>– 19/32″ T&G wood subfloor<br>• 3/4″ LEVELROCK Brand Floor Underlayment | 59 | 54 | **RAL-IN04-006/TL04-033** Cushioned vinyl floor, SRM-25, 1″ LEVELROCK |
| | | 58 | 55 | **RAL-IN04-007/TL04-034** Engineered wood-laminate floor SRM-25, 1″ LEVELROCK |
| | | 59 | 77 | **RAL-IN04-005/TL04-032** Carpet with SRM-25, 1″ LEVELROCK |
| | | 59 | 52 | **RAL-IN04-009/TL04-067** Ceramic tile with crack-isolation membrane, SRM-25, 1″ LEVELROCK |
| | | 58 | 50 | **RAL-IN04-013/TL04-100** Cushioned vinyl floor, SRB board |
| | | 58 | 51 | **RAL-IN04-012/TL04-099** Engineered wood-laminate floor, SRB board |
| | | 58 | 73 | **RAL-IN04-010/TL04-097** Carpet with SRB board |

Floor finish has a significant impact on IIC rating

# Acoustical Detailing

Lightweight concrete topping or other similar materials can provide improved acoustical performance, increased durability

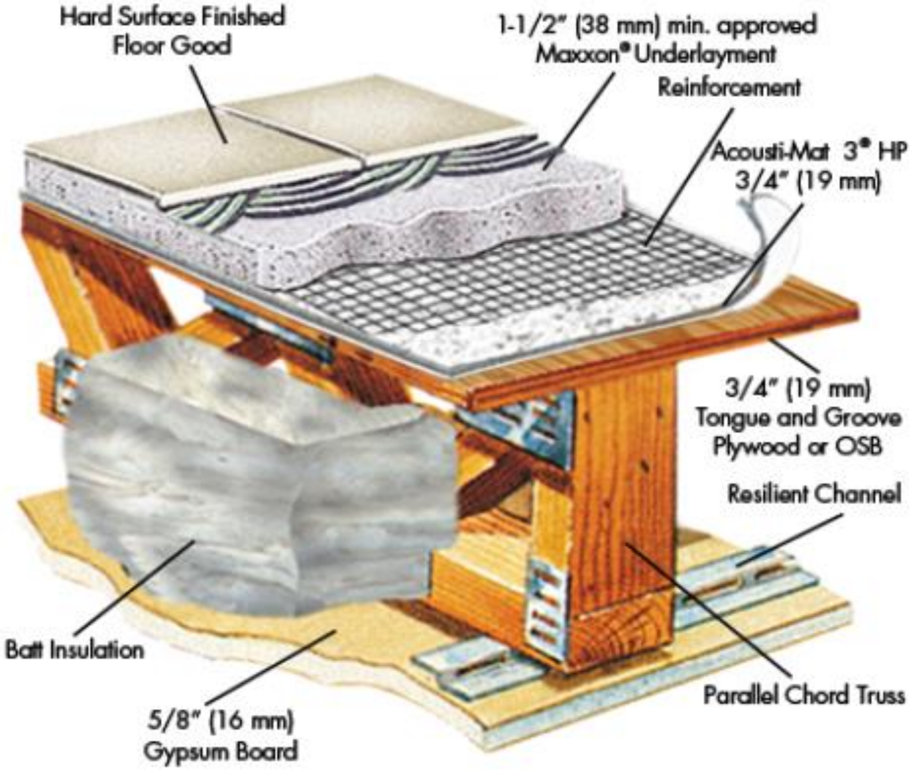
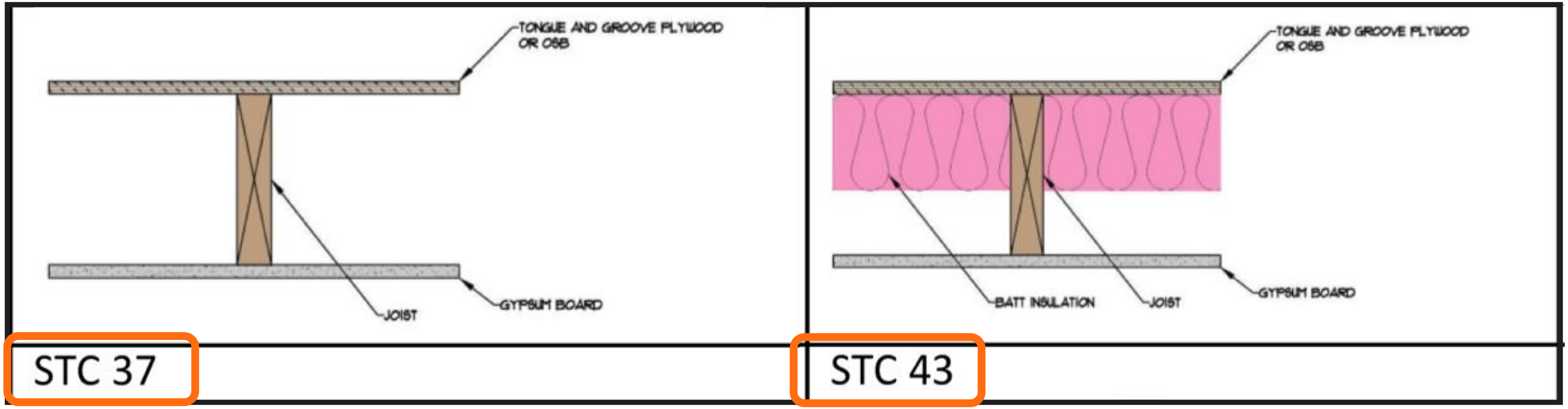



Image: Maxxon

# Acoustical Detailing

**Adding Noise Absorbers:** Batt Insulation




Without Insulation

With Insulation

# Acoustical Detailing

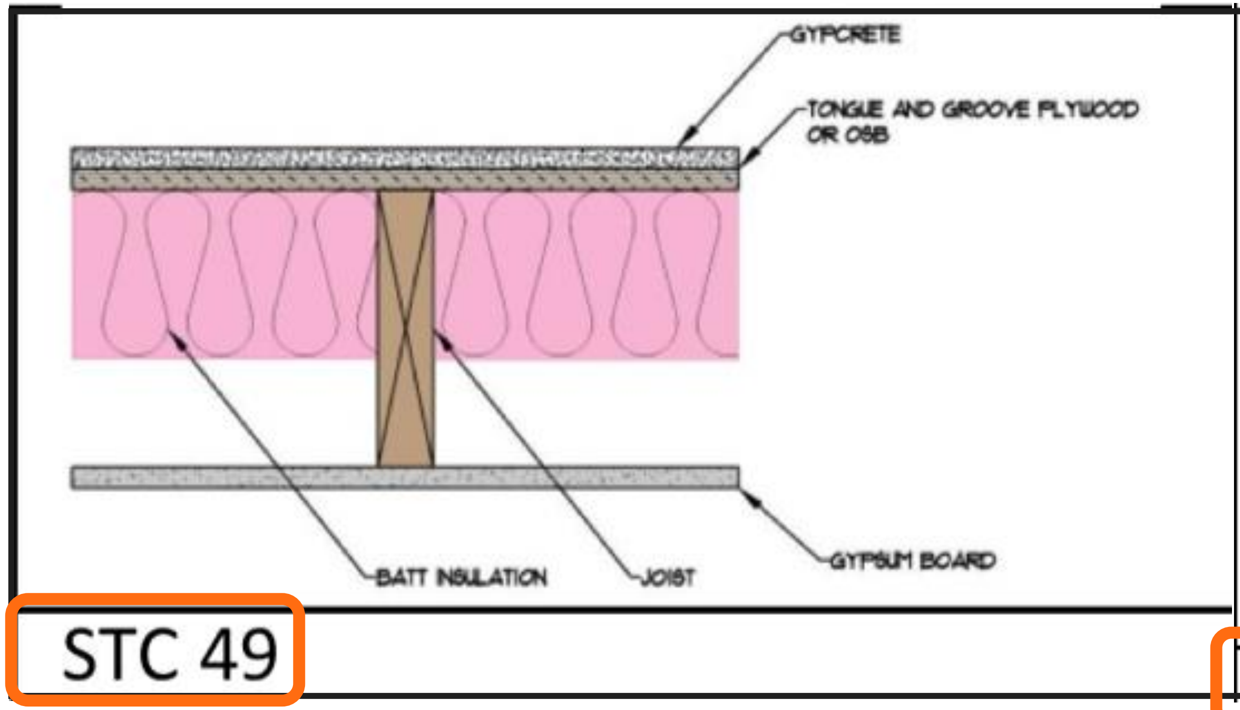
**Decoupled:**

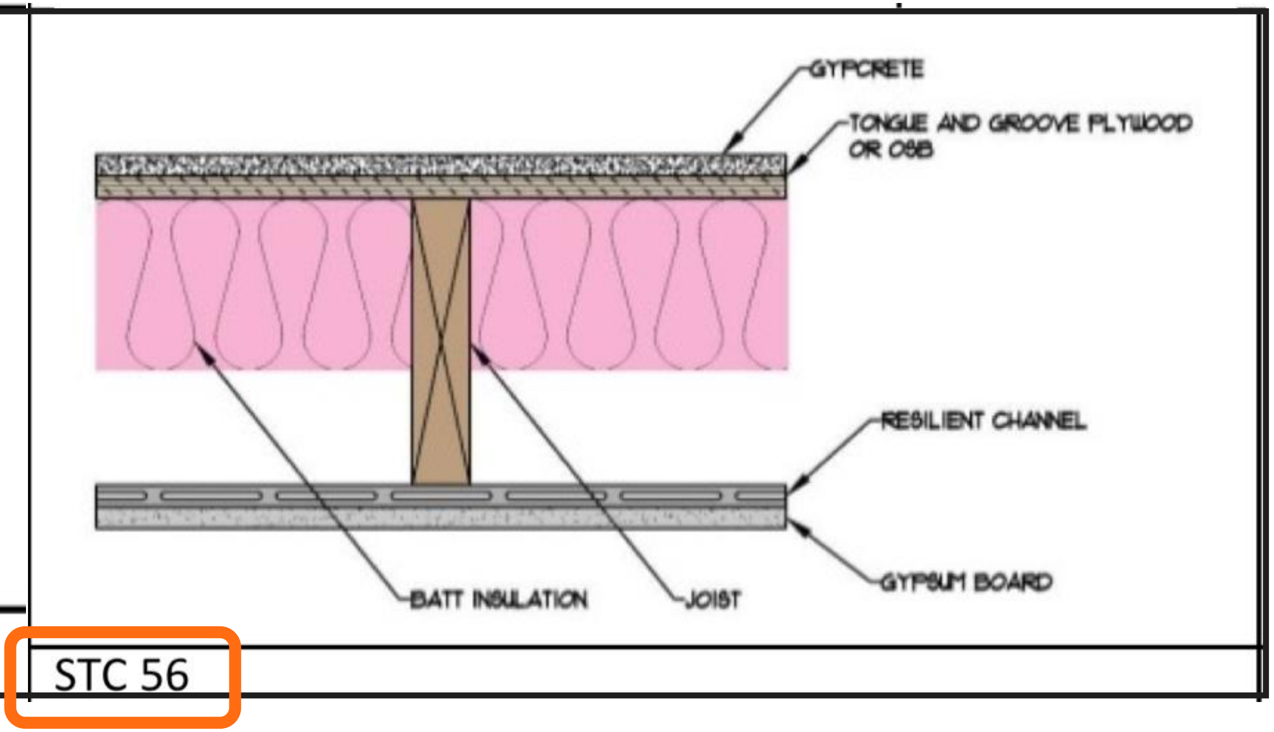
Acoustical mat - typically installed between subfloor and topping or flooring. Can use multiple decoupling layers in sandwich assembly

Image credit: Pliteq

# Acoustical Detailing

**Decoupled:** Resilient Channels




Without Resilient Channels

With Resilient Channels

# Acoustical Detailing

Discontinuous topping at unit partition

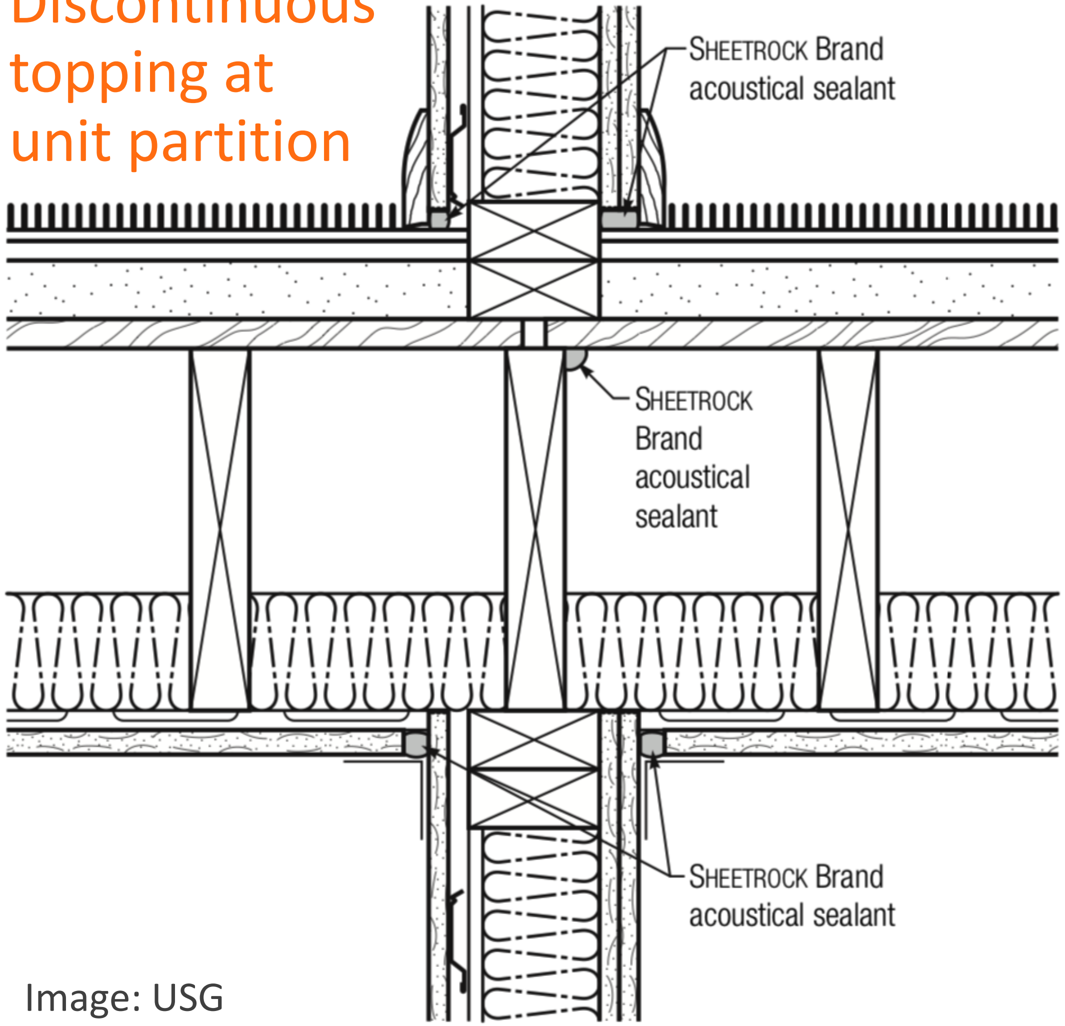
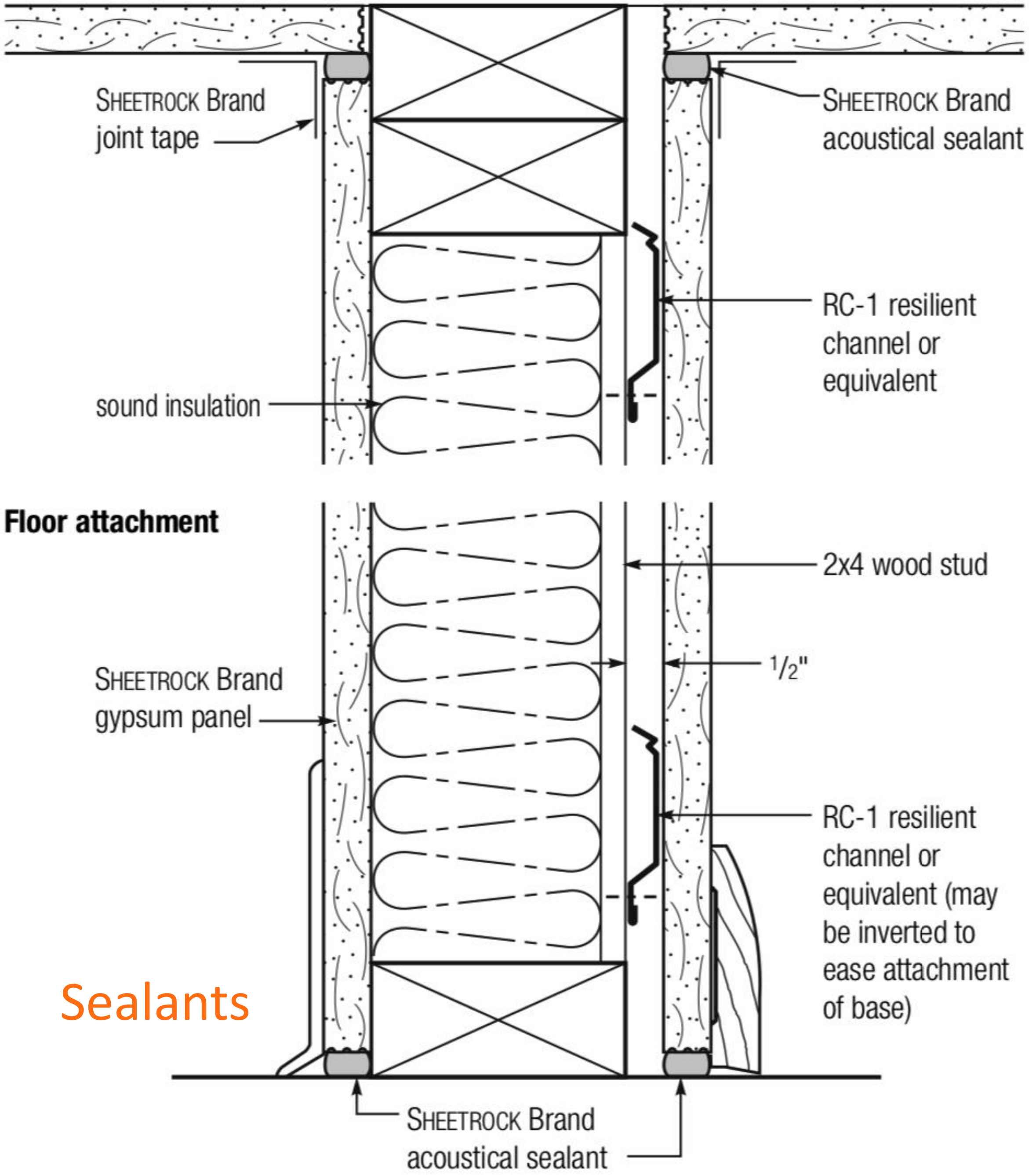
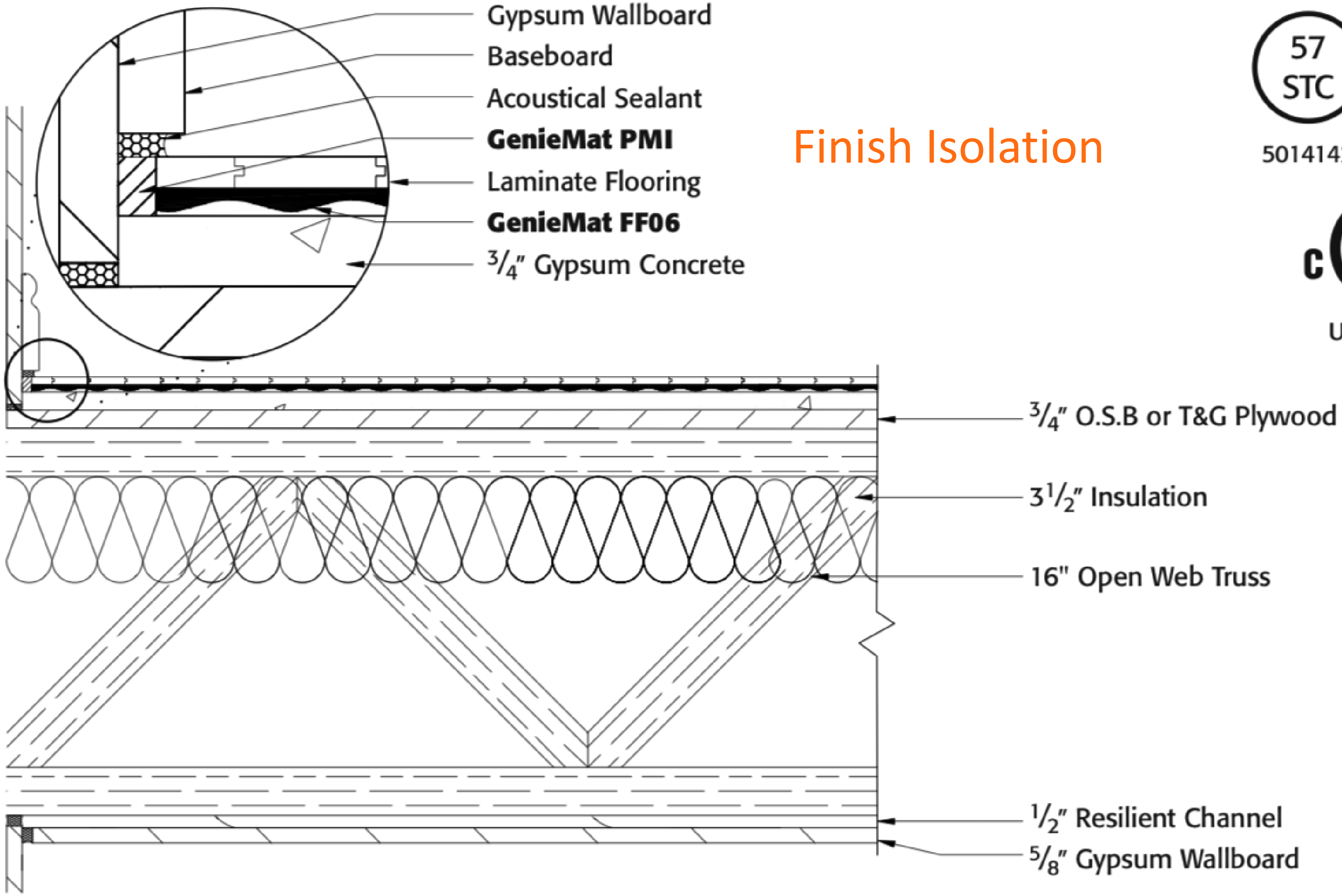



Image: USG




Sealants

# Acoustical Detailing




Finish Isolation

57 STC
5014142

53 IIC
7014195

UL Assembly
L546, etc.

Credit: Pliteq

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# Acoustical Considerations for Mixed-Use Wood-Frame Buildings

*Steve Thorburn, PE, LEED AP, CTS-I, CTS-D, Thorburn Associates*

Acoustics are just one aspect of building performance and must be considered in combination with requirements such as fire protection, structural systems and energy efficiency. To determine an optimal design solution, it is critically important to understand how the design and detailing for each individual system affects the others. Specifically, in addition to meeting the appropriate acoustical rating(s), the assemblies chosen must achieve the required fire ratings and accommodate the structural and energy needs of the project. Understanding the effects of each performance area enables the design team to more easily navigate the decisions and trade-offs required when evaluating different assembly options.

## Multi-Family Housing Acoustical Expectations

As with any issue of building performance, the acoustics of a mixed-use wood-frame structure can be designed to meet or exceed minimal requirements, depending on the expectations of the developer, buyers and tenants.

In residential buildings, the *International Building Code* (IBC) provides a minimum design requirement for unit-to-unit acoustical protection between floors. It requires a Sound Transmission Class (STC) rating or Impact Insulation Class (IIC) rating of 50, unless the "Authority Having Jurisdiction" has its own more stringent requirement, which is rarely the case. The *International Residential Code* (IRC) requires a minimum design separation of STC 45 for townhouses.

*University of Washington West Campus Student Housing – Phase One*
For this student housing project, the acoustical engineer recommended a strategic combination of staggered stud and double stud walls to minimize sound transmission.
Mahlum Architects; photo Benjamin Benschneider

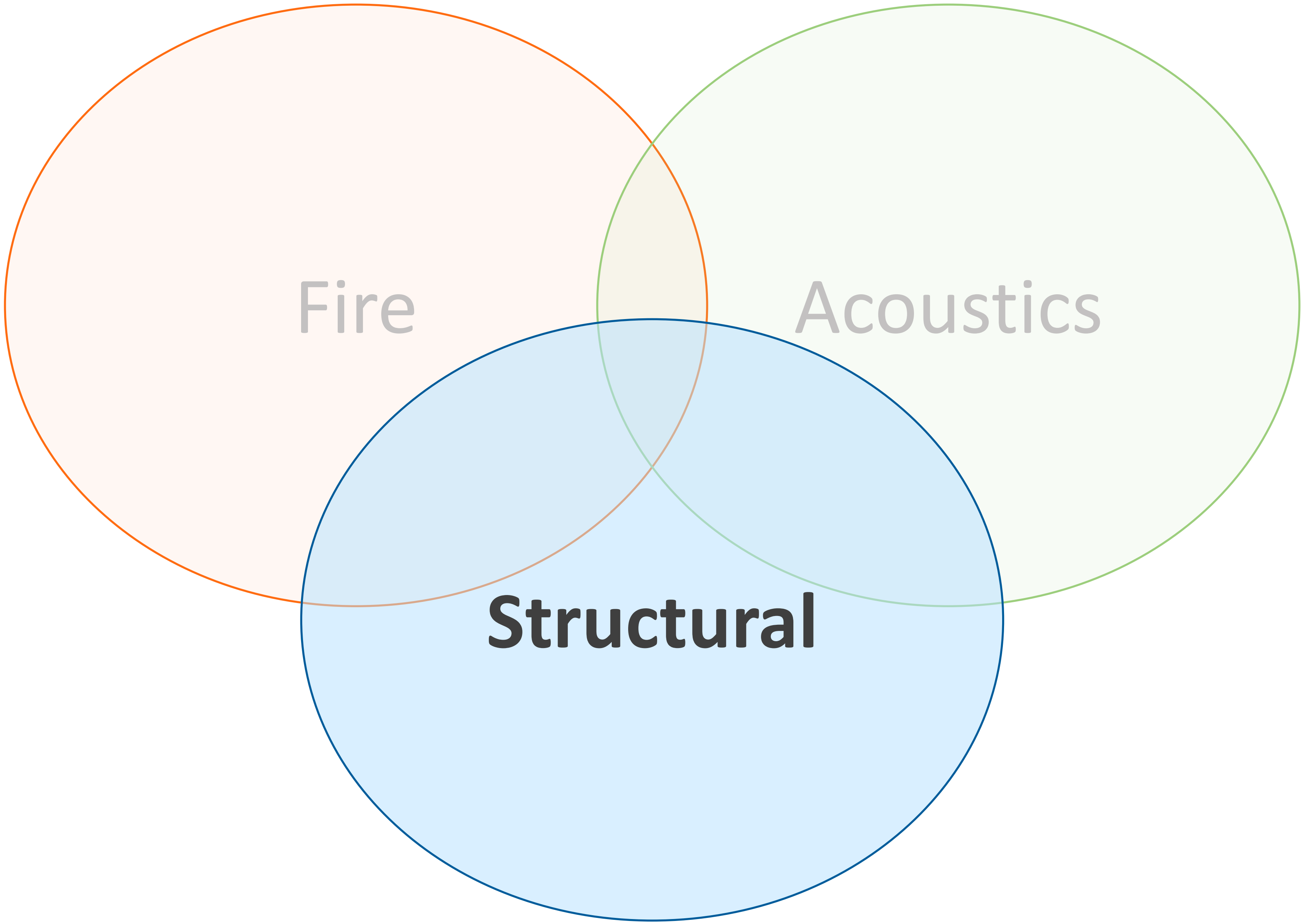
**For wood-frame mixed-use buildings, Section 1207 of the 2012 IBC includes the following:**

**1207.1 Scope.** This section shall apply to common interior walls, partitions and floor/ceiling assemblies between adjacent dwelling units or between dwelling units and adjacent public areas such as halls, corridors, stairs or service areas.

**1207.2 Airborne sound.** Walls, partitions and floor/ceiling assemblies separating dwelling units from each other or from public or service areas shall have a sound transmission class (STC) of not less than 50 (45 if field tested) for air-borne noise when tested in accordance with ASTM E 90. Penetrations or openings in construction assemblies for piping; electrical devices; recessed cabinets; bathtubs; soffits; or heating, ventilating or exhaust ducts shall be sealed, lined, insulated or otherwise treated to maintain the required ratings. This requirement shall not apply to dwelling unit entrance doors; however, such doors shall be tight fitting to the frame and sill.

**1207.3 Structure-borne sound.** Floor/ceiling assemblies between dwelling units or between a dwelling unit and a public or service area within the structure shall have an impact insulation class (IIC) rating of not less than 50 (45 if field tested) when tested in accordance with ASTM E 492*(09)*.

https://www.woodworks.org/wp-content/uploads/Acoustics_Solutions_Paper.pdf


Fire
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# Structural Floor Design


<u>Common Wood Floor Assembly:</u>

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

# Structural Floor Design - Vibration

The code is silent on floor vibration criteria and analysis

**TABLE 1604.3**
**DEFLECTION LIMITS[a, b, c, h, i]**

| CONSTRUCTION | *L* | *S* or *W* [f] | *D* + *L* [d, g] |
|---|---|---|---|
| Roof members:[e] | | | |
| Supporting plaster or stucco ceiling | *l*/360 | *l*/360 | *l*/240 |
| Supporting nonplaster ceiling | *l*/240 | *l*/240 | *l*/180 |
| Not supporting ceiling | *l*/180 | *l*/180 | *l*/120 |
| Floor members | *l*/360 | — | *l*/240 |
| Exterior walls and interior partitions: | | | |
| With plaster or stucco finishes | — | *l*/360 | — |
| With other brittle finishes | — | *l*/240 | — |
| With flexible finishes | — | *l*/120 | — |
| Farm buildings | — | — | *l*/180 |
| Greenhouses | — | — | *l*/120 |

# Structural Floor Design - Vibration

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## 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* http://www.apawood.org/SearchResults.aspx?q=E710&tid=1
- *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

# Structural Floor Design - Vibration

## IS A "SPRING IN YOUR STEP" CAUSING PROBLEMS?

June 2007 » Feature Article

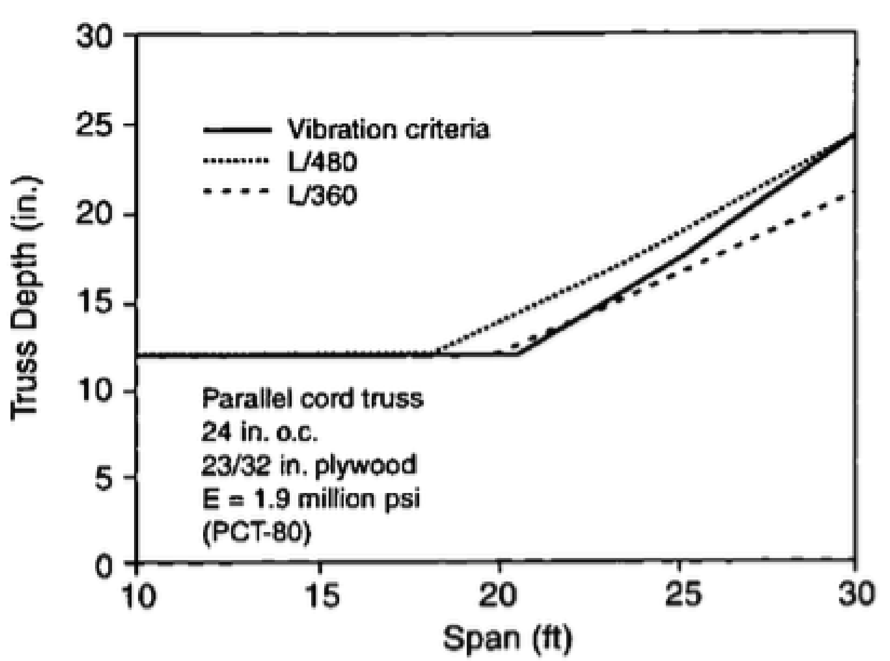
**Annoying vibration is probably the most common performance complaint for light-frame wood floors.**

*Frank Woeste, 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 perform
Code Council's 2006 International Residential Code (IRC)
this issue, yet the engineer-of-record for a project may fac
engineer may be engaged to determine the cause of an a
under the prescriptive provisions of the IRC. While wood f
deserves attention by the design professional at the desig
impossible to fix.

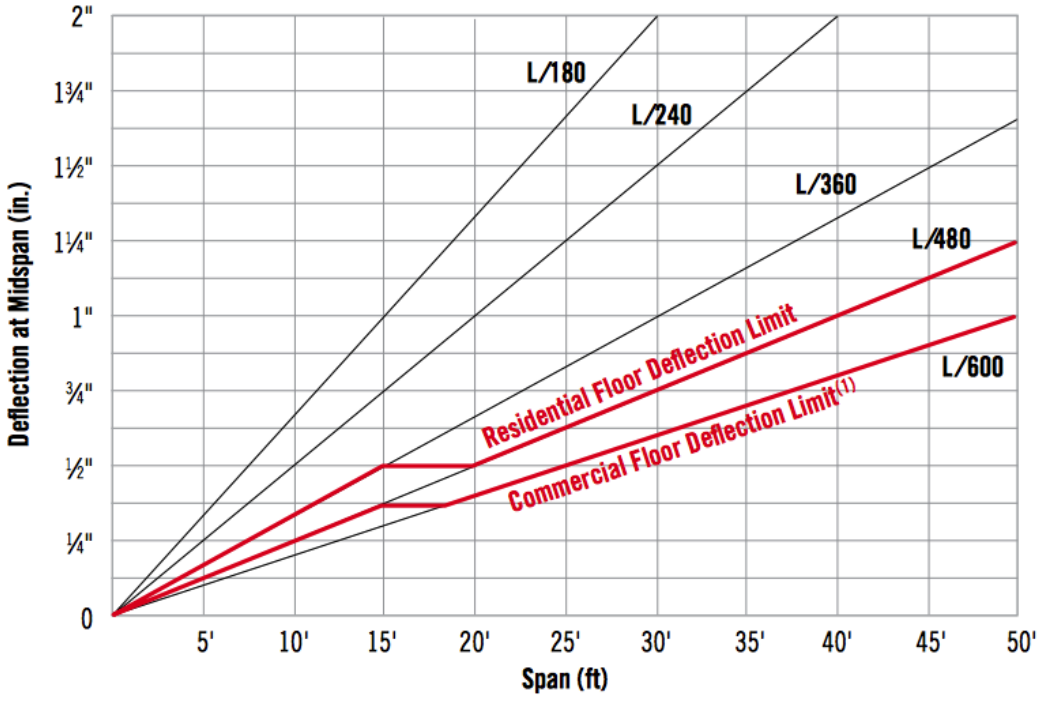
$$f = 1.57\sqrt{\frac{386EI}{WL^3}} \qquad \text{(Equation 1)}$$



# Floor Design: Occupant Comfort

Vibration & Deflection Control

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.

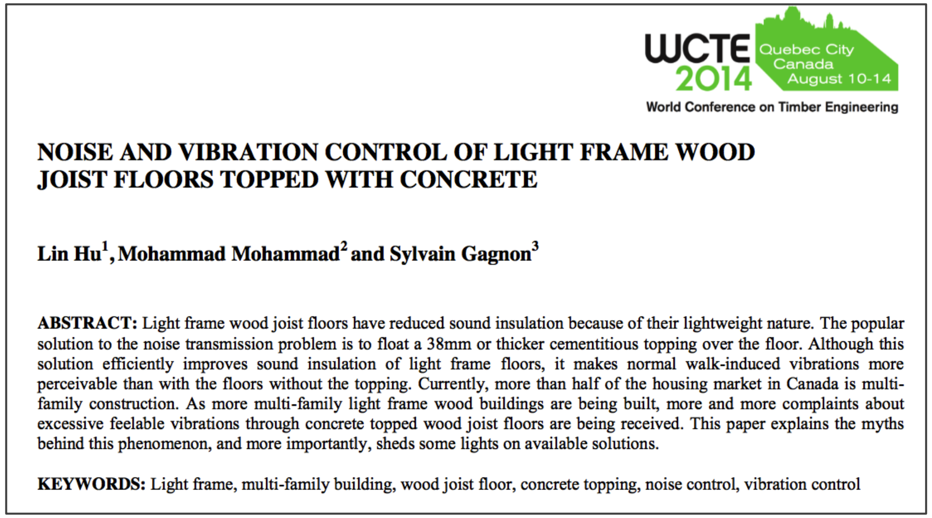



Live Load Deflection Chart, Courtesy: Redbuilt

# Floor Design: Occupant Comfort

## *Tools available to designers*

### Vibration Analysis: FP Innovations (Spreadsheet available upon request)



WCTE 2014 Quebec City Canada August 10-14

World Conference on Timber Engineering

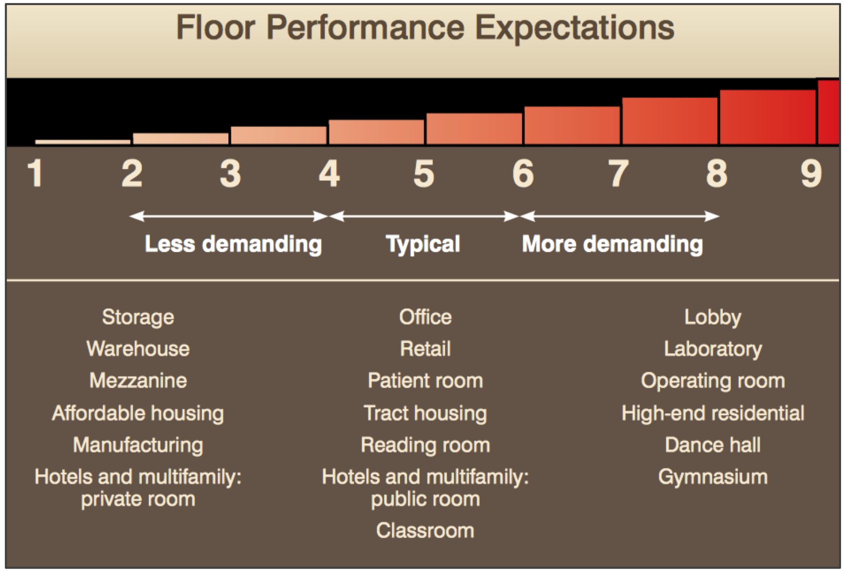
**NOISE AND VIBRATION CONTROL OF LIGHT FRAME WOOD JOIST FLOORS TOPPED WITH CONCRETE**

**Lin Hu[1], Mohammad Mohammad[2] and Sylvain Gagnon[3]**

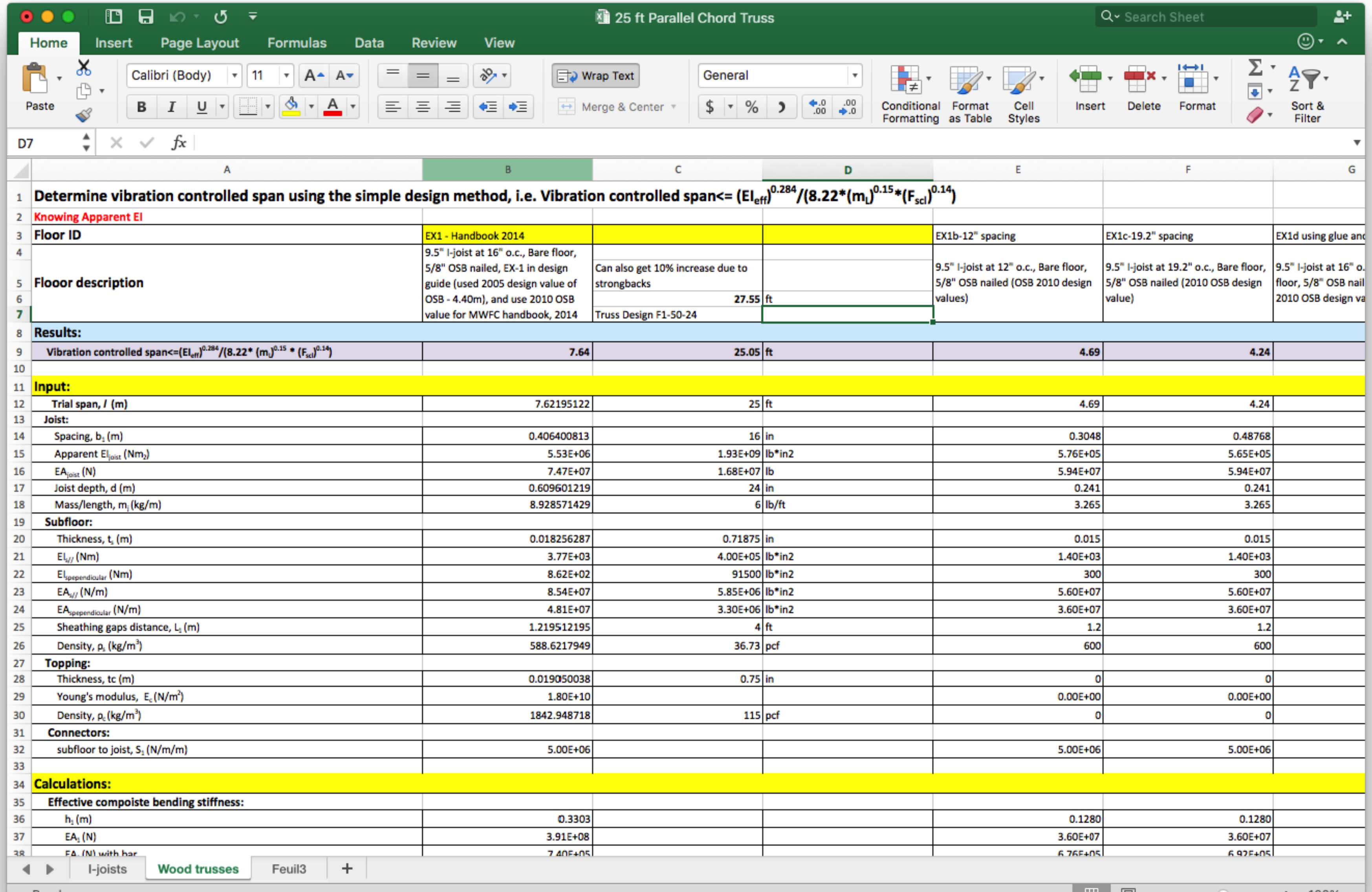
**ABSTRACT:** Light frame wood joist floors have reduced sound insulation because of their lightweight nature. The popular solution to the noise transmission problem is to float a 38mm or thicker cementitious topping over the floor. Although this solution efficiently improves sound insulation of light 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 feelable vibrations through concrete topped wood joist 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 joist floor, concrete topping, noise control, vibration control

### Joist Manufacturer's Rating Systems



# Structural Floor Design - Vibration



25 ft Parallel Chord Truss

| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| 1 | Determine vibration controlled span using the simple design method, i.e. Vibration controlled span<= $(EI_{eff})^{0.284}/(8.22*(m_l)^{0.15}*(F_{scl})^{0.14})$ | | | | | | |
| 2 | Knowing Apparent EI | | | | | | |
| 3 | Floor ID | EX1 - Handbook 2014 | | | EX1b-12" spacing | EX1c-19.2" spacing | EX1d using glue and |
| 4–7 | Flooor description | 9.5" I-joist at 16" o.c., Bare floor, 5/8" OSB nailed, EX-1 in design guide (used 2005 design value of OSB - 4.40m), and use 2010 OSB value for MWFC handbook, 2014 | Can also get 10% increase due to strongbacks / 27.55 / Truss Design F1-50-24 | ft | 9.5" I-joist at 12" o.c., Bare floor, 5/8" OSB nailed (OSB 2010 design values) | 9.5" I-joist at 19.2" o.c., Bare floor, 5/8" OSB nailed (2010 OSB design value) | 9.5" I-joist at 16" o. floor, 5/8" OSB nail 2010 OSB design va |
| 8 | Results: | | | | | | |
| 9 | Vibration controlled span<=$(EI_{eff})^{0.284}/(8.22*(m_l)^{0.15}*(F_{scl})^{0.14})$ | 7.64 | 25.05 | ft | 4.69 | 4.24 | |
| 10 | | | | | | | |
| 11 | Input: | | | | | | |
| 12 | Trial span, *l* (m) | 7.62195122 | 25 | ft | 4.69 | 4.24 | |
| 13 | Joist: | | | | | | |
| 14 | Spacing, $b_1$ (m) | 0.406400813 | 16 | in | 0.3048 | 0.48768 | |
| 15 | Apparent $EI_{joist}$ ($Nm_2$) | 5.53E+06 | 1.93E+09 | lb*in2 | 5.76E+05 | 5.65E+05 | |
| 16 | $EA_{joist}$ (N) | 7.47E+07 | 1.68E+07 | lb | 5.94E+07 | 5.94E+07 | |
| 17 | Joist depth, d (m) | 0.609601219 | 24 | in | 0.241 | 0.241 | |
| 18 | Mass/length, $m_j$ (kg/m) | 8.928571429 | 6 | lb/ft | 3.265 | 3.265 | |
| 19 | Subfloor: | | | | | | |
| 20 | Thickness, $t_s$ (m) | 0.018256287 | 0.71875 | in | 0.015 | 0.015 | |
| 21 | $EI_{s//}$ (Nm) | 3.77E+03 | 4.00E+05 | lb*in2 | 1.40E+03 | 1.40E+03 | |
| 22 | $EI_{spependicular}$ (Nm) | 8.62E+02 | 91500 | lb*in2 | 300 | 300 | |
| 23 | $EA_{s//}$ (N/m) | 8.54E+07 | 5.85E+06 | lb*in2 | 5.60E+07 | 5.60E+07 | |
| 24 | $EA_{spependicular}$ (N/m) | 4.81E+07 | 3.30E+06 | lb*in2 | 3.60E+07 | 3.60E+07 | |
| 25 | Sheathing gaps distance, $L_1$ (m) | 1.219512195 | 4 | ft | 1.2 | 1.2 | |
| 26 | Density, $\rho_s$ ($kg/m^3$) | 588.6217949 | 36.73 | pcf | 600 | 600 | |
| 27 | Topping: | | | | | | |
| 28 | Thickness, tc (m) | 0.019050038 | 0.75 | in | 0 | 0 | |
| 29 | Young's modulus, $E_c$ ($N/m^2$) | 1.80E+10 | | | 0.00E+00 | 0.00E+00 | |
| 30 | Density, $\rho_c$ ($kg/m^3$) | 1842.948718 | 115 | pcf | 0 | 0 | |
| 31 | Connectors: | | | | | | |
| 32 | subfloor to joist, $S_1$ (N/m/m) | 5.00E+06 | | | 5.00E+06 | 5.00E+06 | |
| 33 | | | | | | | |
| 34 | Calculations: | | | | | | |
| 35 | Effective compoiste bending stiffness: | | | | | | |
| 36 | $h_1$ (m) | 0.3303 | | | 0.1280 | 0.1280 | |
| 37 | $EA_1$ (N) | 3.91E+08 | | | 3.60E+07 | 3.60E+07 | |
| 38 | $EA_1$ (N) with bar | 7.40E+05 | | | 6.76E+05 | 6.92E+05 | |

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# 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/trusses
- 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 vib 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 joisted floor with a concrete topping can have frequency below 14Hz, but

http://www.woodworks.org/ask-an-expert/

# THANK YOU!

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