Common Challenges in Light Wood-Frame Gravity Structural Design

Floor Framing Considerations

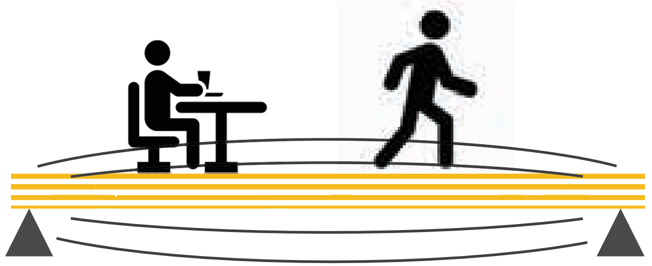
Mike Romanowski, SE

WoodWorks

Landing Apartments, Russell Scott Steedle & Capione Architects, photo Gregory Folkins

Structural Floor Design – Vibration vs. Acoustics

Structural Vibrations	Acoustic Vibrations
1 Hz – 100 Hz	20 Hz – 15,000 Hz
Transmitted through structure or through ground	Transmitted through air, walls, floors, windows
Physical effects	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

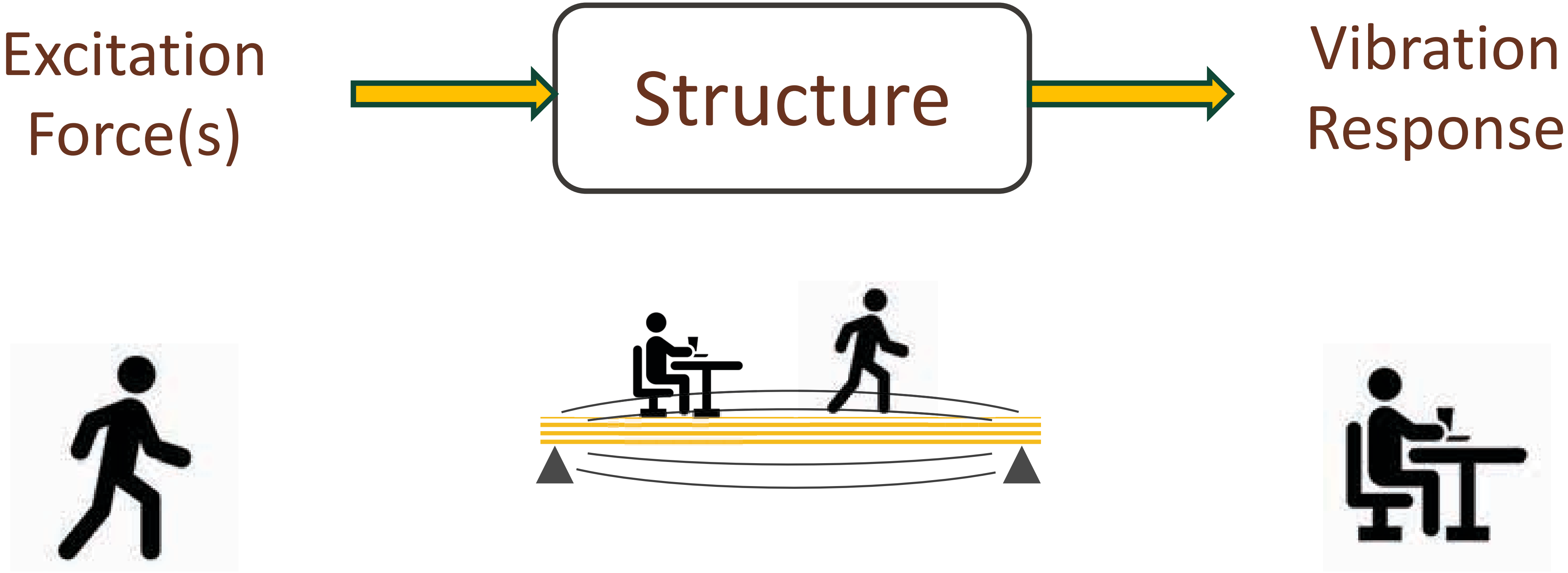
US Building Code Requirements for Deflection

Deflection performance does not necessarily equal vibration performance

TABLE 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	—	—	$l/120$

Systems View of Vibration



Framing Materials Properties for Vibration

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

Vibration Design Methods

Rules of Thumb → Empirical Methods → Simplified Analytical → FEM/Modal Superposition → FEM/Time History

$\Delta \leq L/360$ for floor live load

IBC code limit on floor deflection

Wood Frame

Joists:

$\Delta \leq L/360$ for $L < 15$ ft

$\Delta < 0.5''$ for $L \geq 15$ ft

Trusses:

$\Delta \leq L/480$ 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 Hz for occupied (e.g. furnished) floors
$f_n \geq$ 15 Hz for unoccupied floors

Dolan, Murray, et al.
Preventing Annoying Wood Floor Vibration
1999, Journal of Structural Engineering

Proprietary rating systems from Joist Manufacturers

Vibration Design Methods

AMERICAN WOOD COUNCIL

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

Vibration Design Methods

IS A "SPRING IN YOUR STEP" CAUSING PROBLEMS?

June 2007 » Feature Article

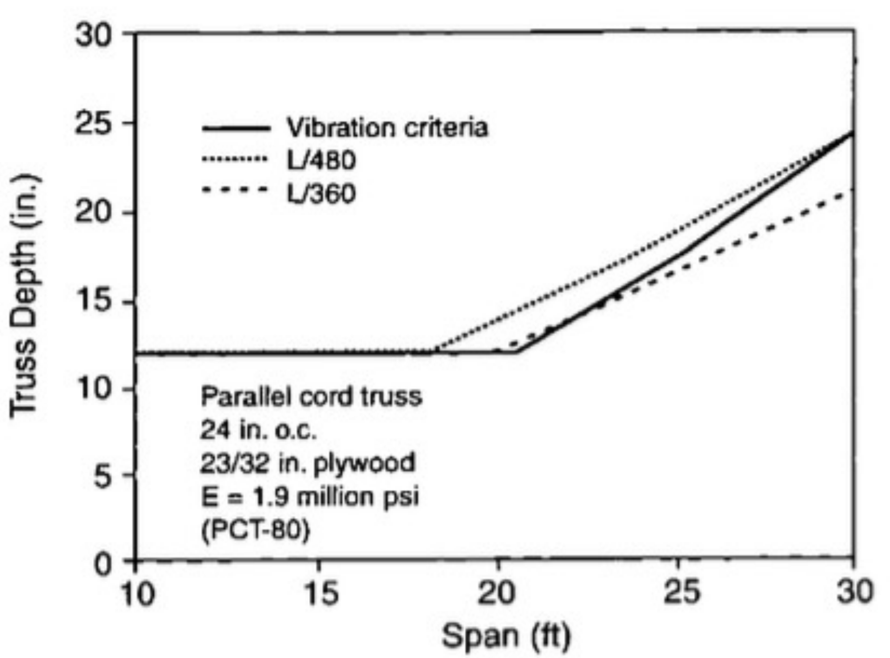
Annoying vibration is probably the most common performance complaint for light-frame wood floors.

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

Recommendations to minimize annoying wood-floor vibrations

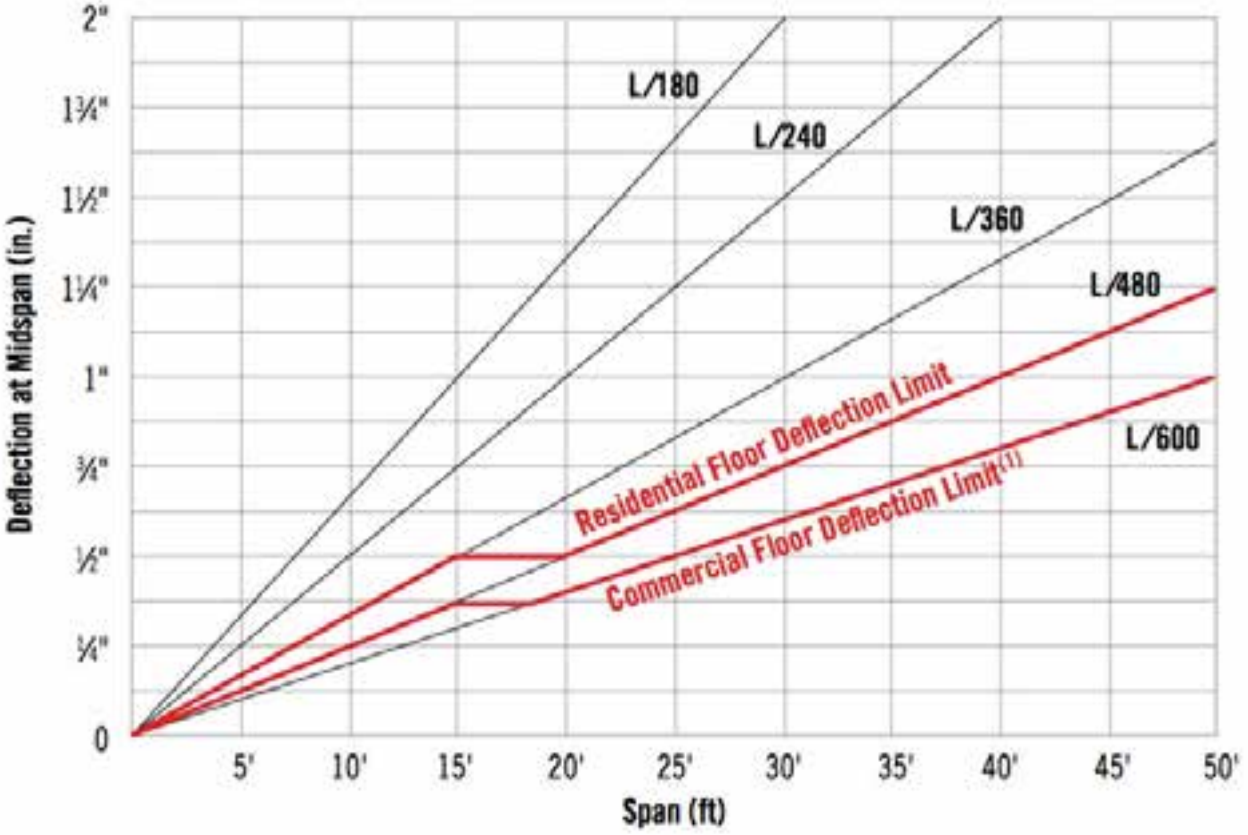
Annoying vibration is probably the most common performance complaint for light-frame wood floors. The International Code Council's 2006 International Residential Code (IRC) and its 2006 International Building Code (IBC) do not address this issue, yet the engineer-of-record for a project may face the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

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



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.

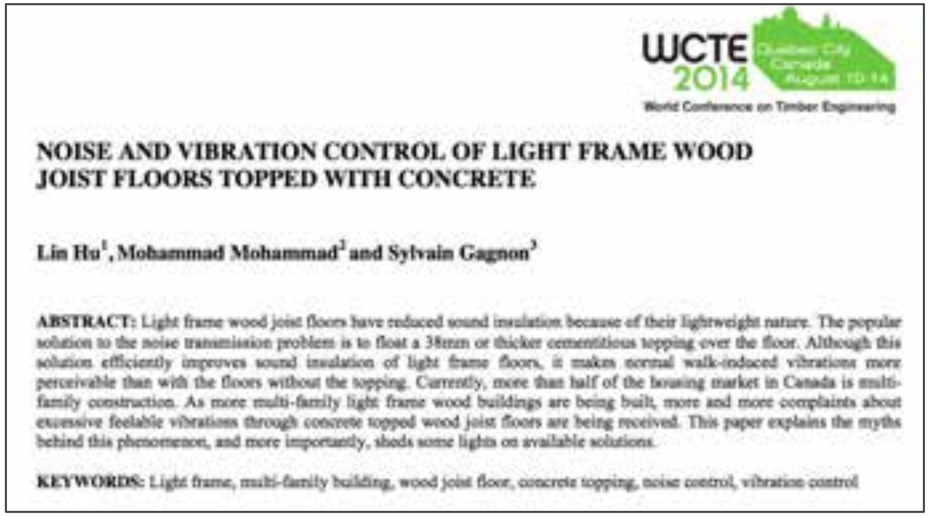


Live Load Deflection Chart, Courtesy: Redbuilt

Vibration Design Methods

Tools available to designers

Vibration Analysis: FP Innovations
(Spreadsheet available upon request)



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

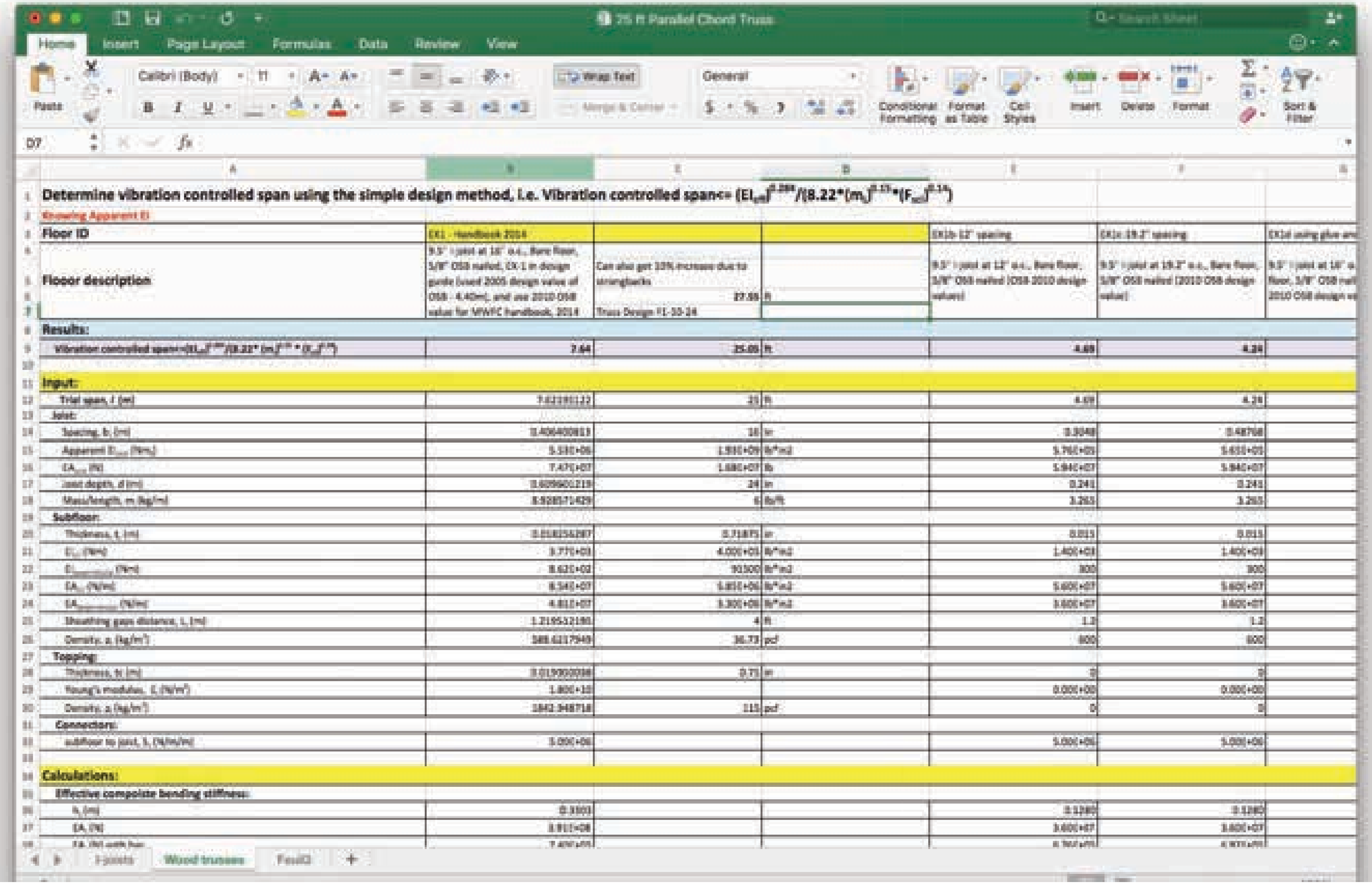
Lin Hu[1], Mohammad Mohammad[2] and Sylvain Gagnon[3]

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

Vibration Design Methods



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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/

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:

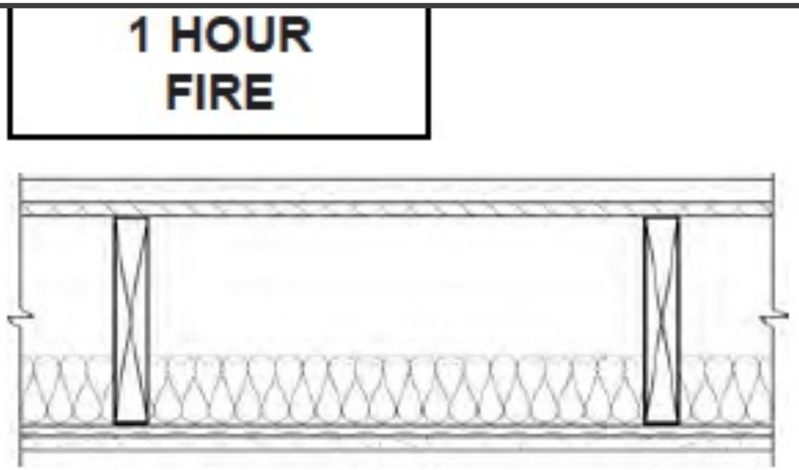
Shorter spans, room for MEP

Approximate Max Corridor Width for Solid Sawn Floor Framing Options		
	@ 16"	@ 24"
2x6	6'-2"	5'-0"
2x8	7'-10"	6'-4"
2x10	9'-6"	7'-10"
2x12	11'-0"	9'-0"

SPF #2, DL = 30, LL = 100

Corridor Floor Framing Options

UL L502
GA FC5104



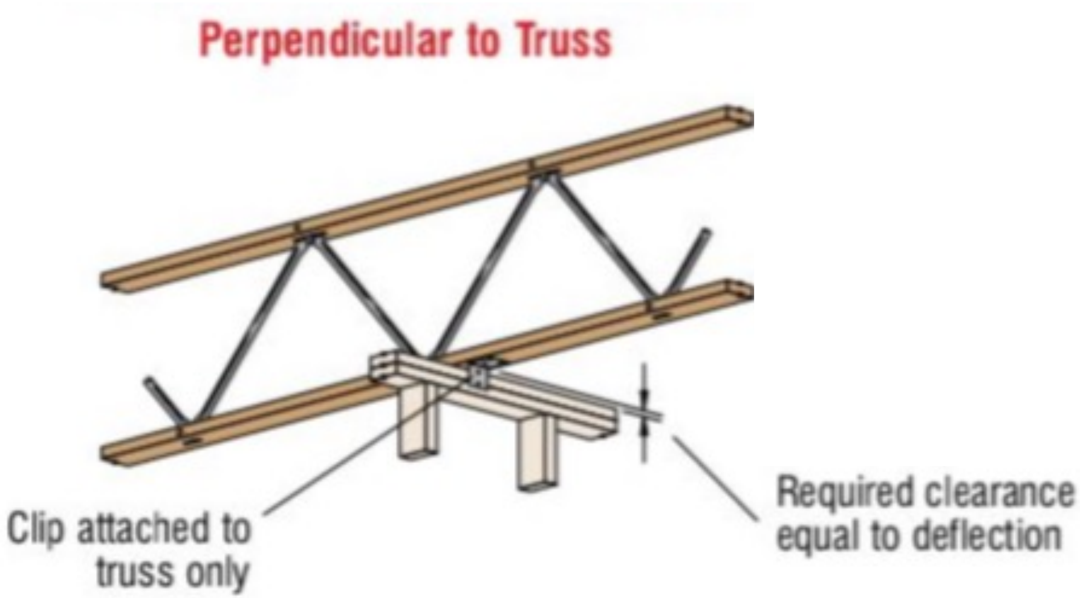
- 1” gypsum underlayment
- 19/32” WSP
- 3 ½” Fiberglass Batt
- 2x10 joists @24 “ oc
- Resilient channel
- 5/8” Type-X Gyp

Common issues with UL approved assemblies:

- Shallow Floor depth
  - Use prescriptive assemblies: IBC 721.1(3) assembly 21-1.1
  - Or use the 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

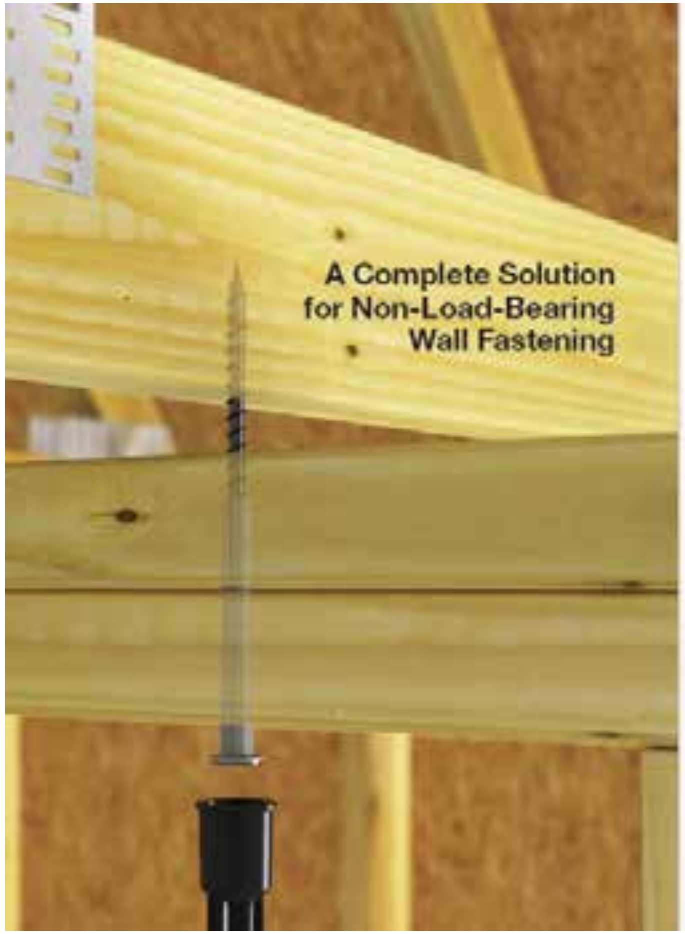
Options for connection of non-bearing partition to wood frame floor/roof structure:

- 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

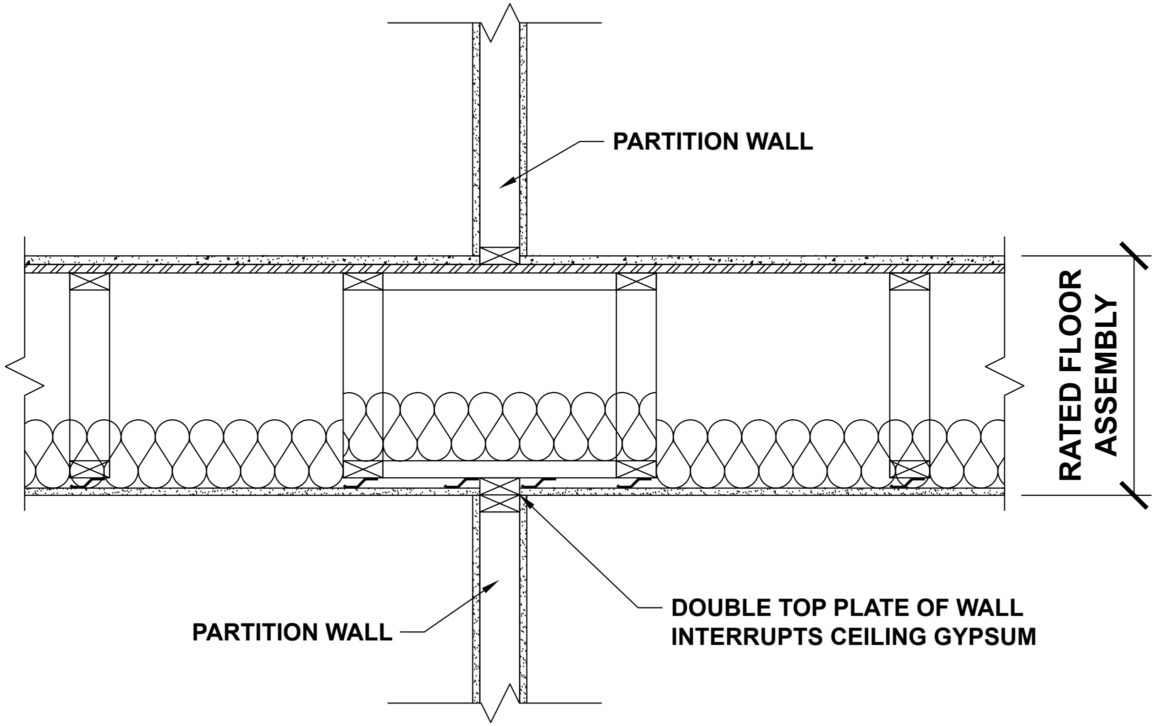


Head of Partition Wall Detailing

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

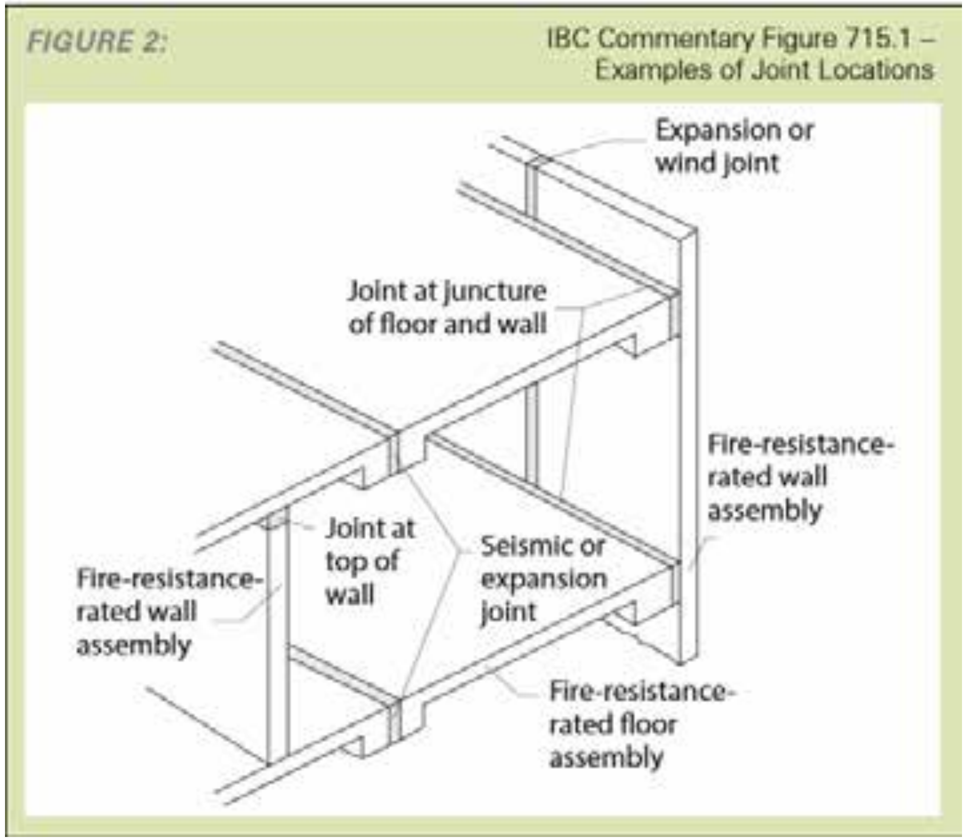


INTERIOR WALL TO FLOOR INTERSECTION

Joint vs. Assembly Intersection

SECTION 202
DEFINITIONS

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



Joints – IBC 715

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

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Joint Systems (XHBN & XHBO)

A joint system is a specific construction consisting of adjacent wall and/or floor assemblies and the materials designed to prevent the spread of fire through a linear opening between the wall and/or floor assemblies.

Numbering System

The systems are identified in this category by an alpha-alpha-numeric identification system. The alpha components identify the type of joint system and whether the joint system has movement capabilities. The numeric components identify the nominal joint width. In the case of head of wall joint systems, the width of the joint does not include the voids created under the crests of metal deck floor or roof systems.

The first two alpha characters identify the type of joint system as follows:

Alpha Characters	Description of Joint System
FF	Floor-to-Floor
WW	Wall-to-Wall
FW	Floor-to-Wall
HW	Head-of-Wall
BW	Bottom-of-Wall
CG	Wall-to-Wall Joints Intended for use as Corner Guards
CJ	Continuity Head-of-Wall

The third alpha character is either S or D. The S signifies joint systems that do not have movement capabilities. This D signifies joint systems that do have movement capabilities.

The numeric component uses sequential numbers to identify the nominal width of the joint systems. The significance of the number used is:

No. Range	Nominal Joint Width
0000 - 0999	Less than or equal to 2 in.
1000 - 1999	Greater than 2 in. and less than or equal to 6 in.
2000 - 2999	Greater than 6 in. and less than or equal to 12 in.
3000 - 3999	Greater than 12 in. and less than or equal to 24 in.
4000 - 4999	Greater than 24 in.

Joint Systems


ONLINE CERTIFICATIONS DIRECTORY

System No. HW-S-0088
XHBN.HW-S-0088
Joint Systems

Page Bottom

Design/System/Construction/Assembly Usage Disclaimer

- Authorities Having Jurisdiction should be consulted in all cases as to the particular requirements covering the installation and use of UL Certified products, equipment, system, devices, and materials.
- Authorities Having Jurisdiction should be consulted before construction.
- Fire resistance assemblies and products are developed by the design submitter and have been investigated by UL for compliance with applicable requirements. The published information cannot always address every construction nuance encountered in the field.
- When field issues arise, it is recommended the first contact for assistance be the technical service staff provided by the product manufacturer noted for the design. Users of fire resistance assemblies are advised to consult the general Guide Information for each product category and each group of assemblies. The Guide Information includes specifics concerning alternate materials and alternate methods of construction.
- Only products which bear UL's Mark are considered Certified.

XHBN - Joint Systems

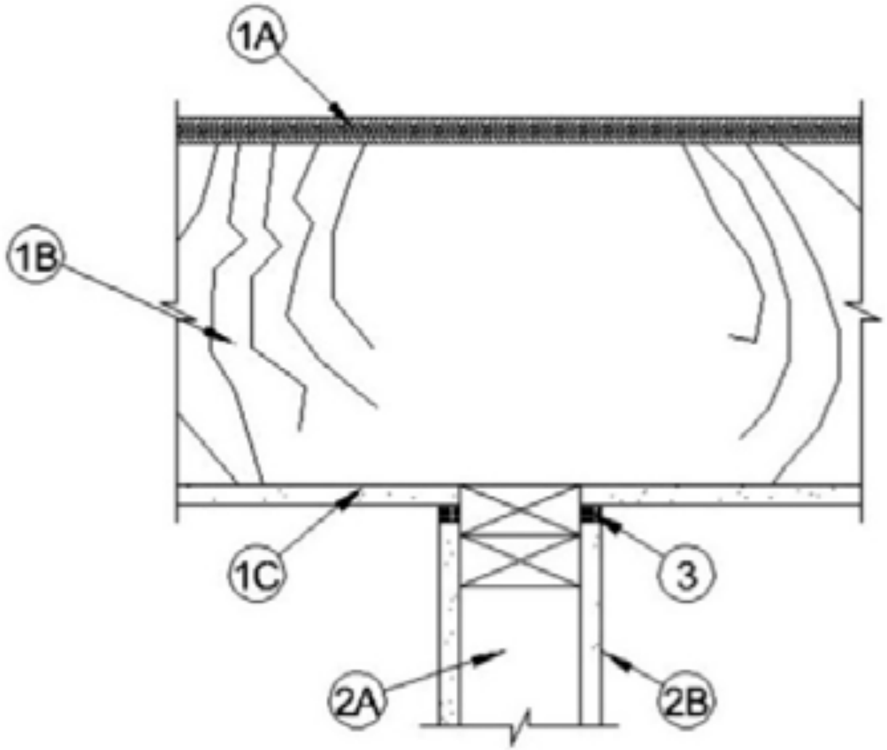
See General Information for Joint Systems

System No. HW-S-0088

December 05, 2008

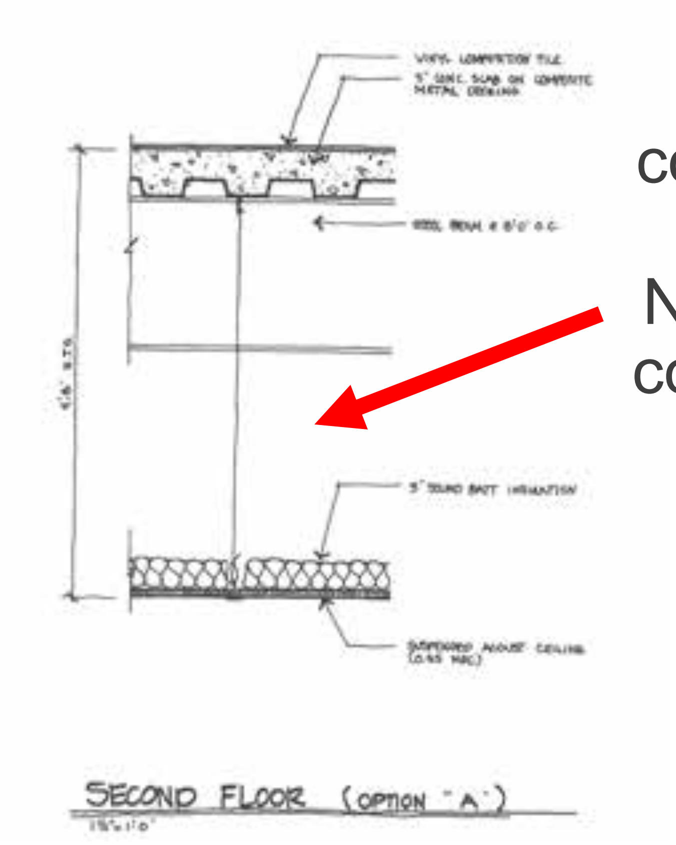
Assembly Rating — 1 Hr

Joint Width — 1/2 In. (13 mm) Max



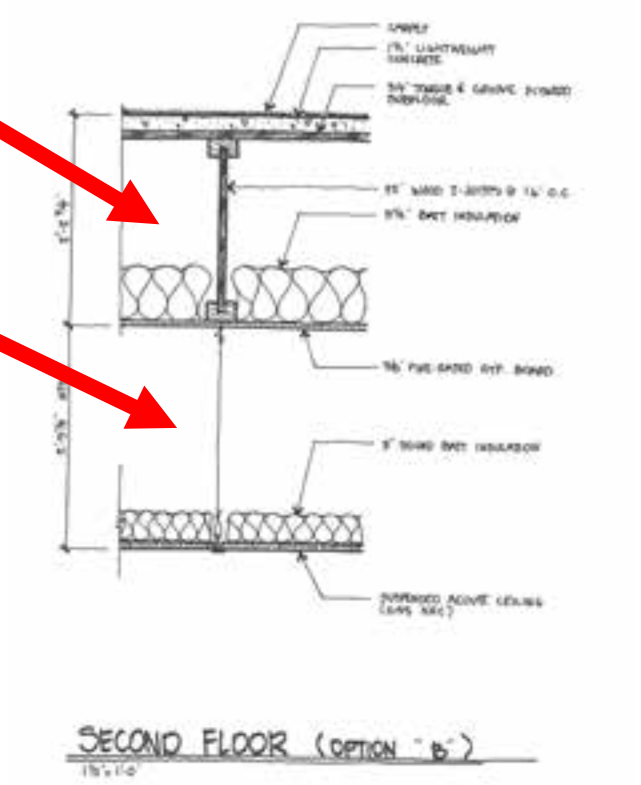
Do we need sprinkler protection in floor cavities?

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



Combustible concealed space

Noncombustible concealed space

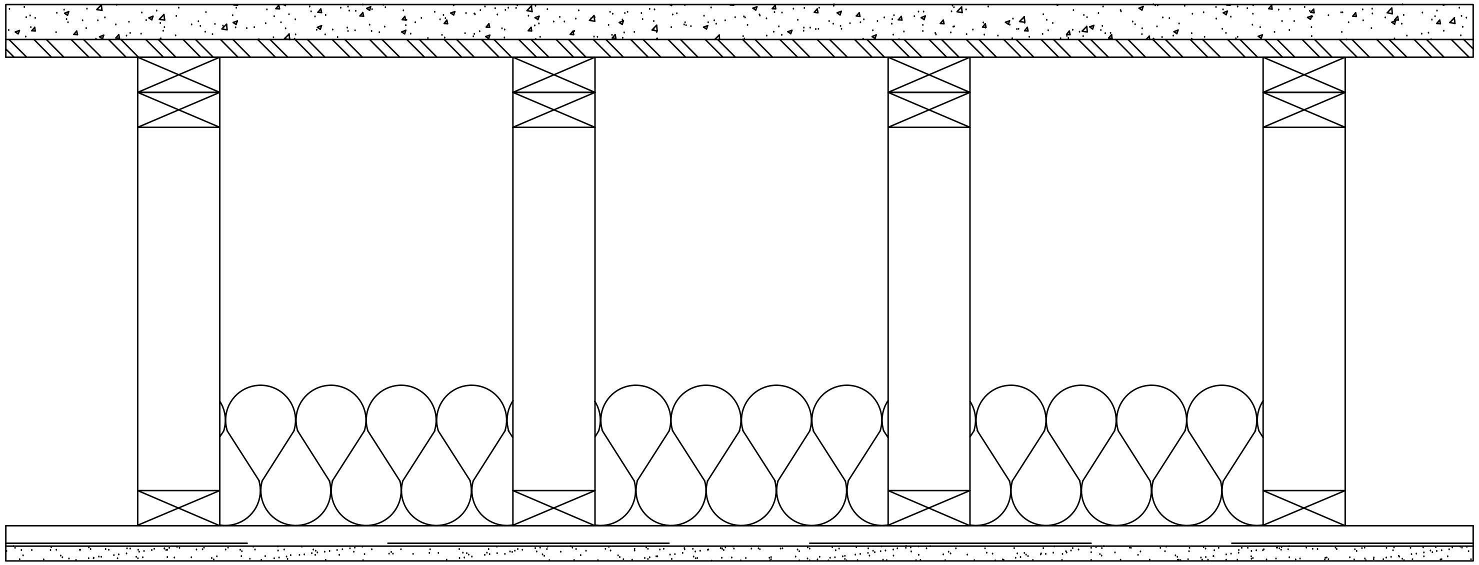


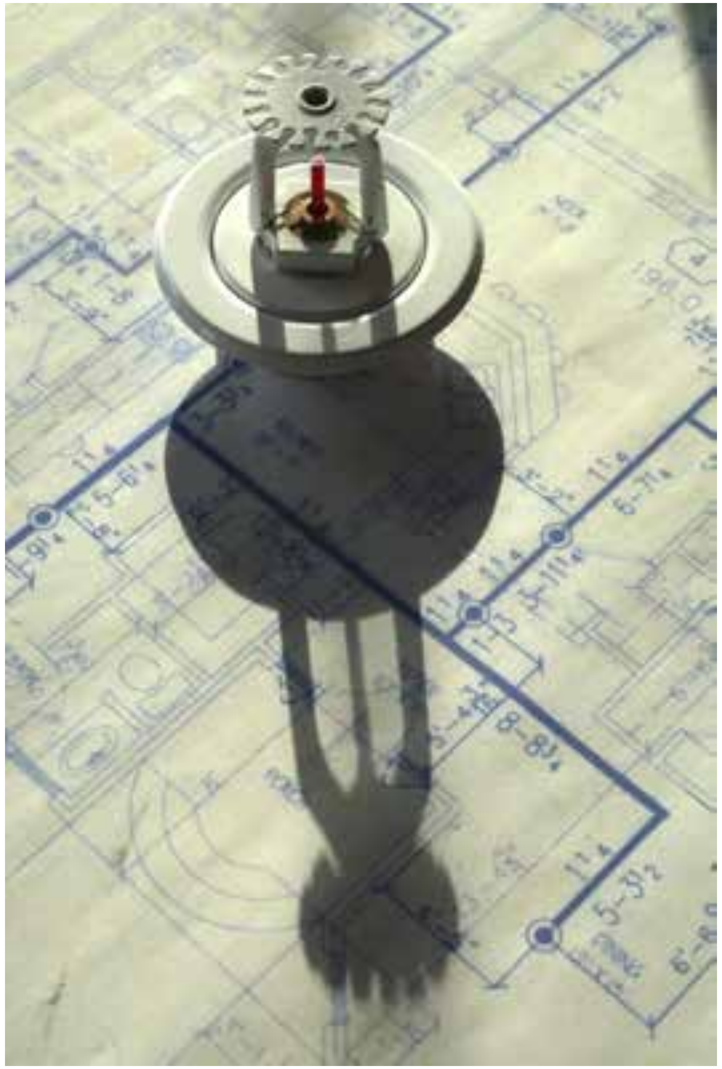
Credit: CADM Architecture

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

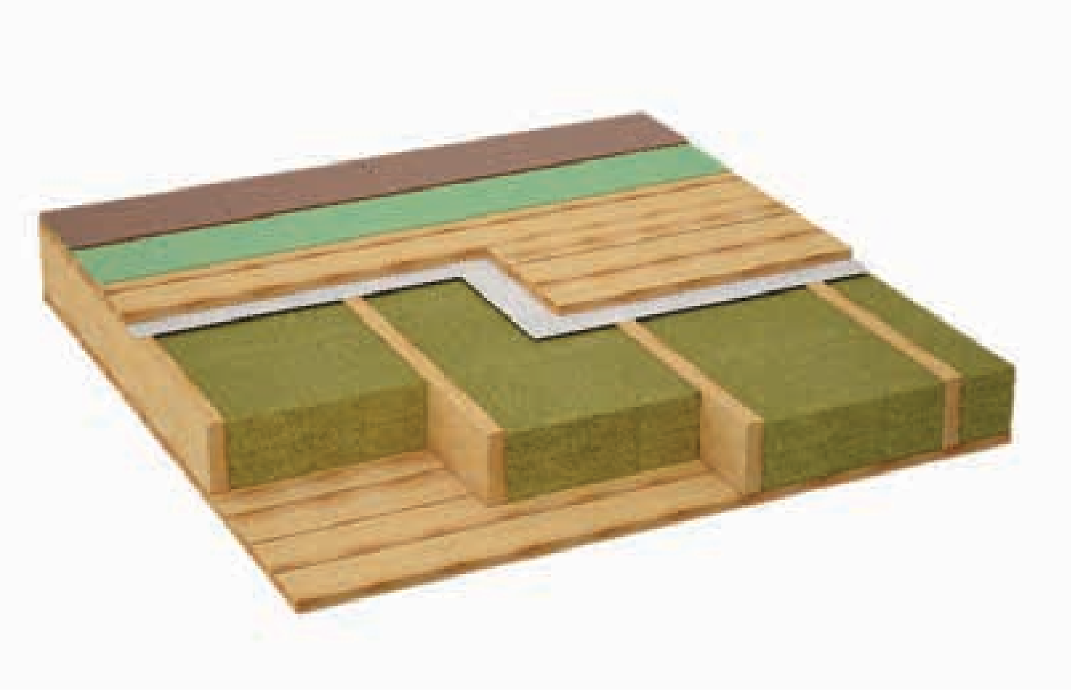




Concealed Spaces: NFPA 13

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 ft^3 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

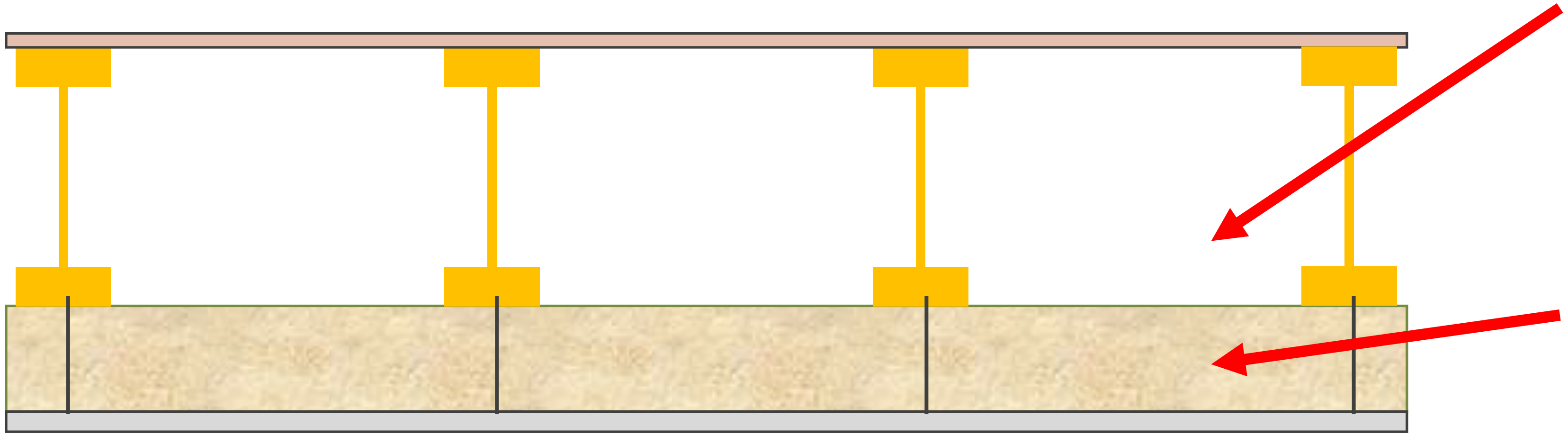
NFPA 13 options for omitting sprinklers in concealed spaces

- 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

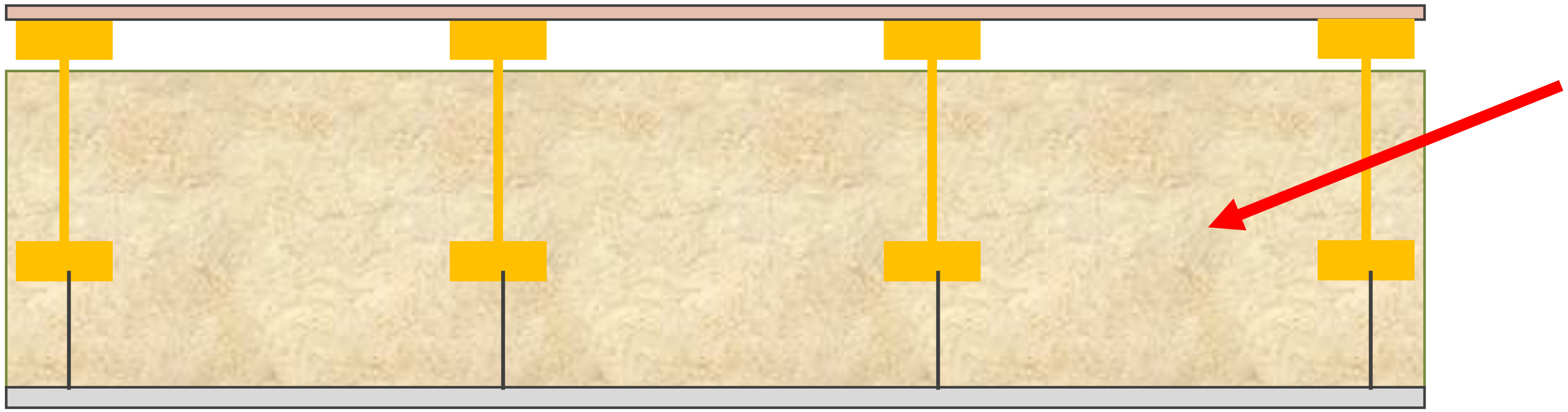
- Concealed spaces with wood joists or composite wood joists, with noncombustible insulation filling the space from ceiling to underside of joists.
- Requires that composite joist cavities are firestopped into volumes not exceeding 160 ft^3 with materials equivalent to web construction (NFPA 8.15.1.2.8)



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)



Noncombustible insulation from ceiling to within 2” of underside of sheathing

QUESTIONS?

This concludes The American Institute of Architects Continuing Education Systems Course

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