Deflection Limits for Floor Trusses

Overview

Revised 3/23/2017

SBCA

SBCA has been the voice of the structural building components industry since 1983, providing educational programs and technical information, disseminating industry news, and facilitating networking opportunities for manufacturers of roof trusses, wall panels and floor trusses. **SBCA** endeavors to expand component manufacturers' market share and enhance the professionalism of the component manufacturing industry.

Introduction

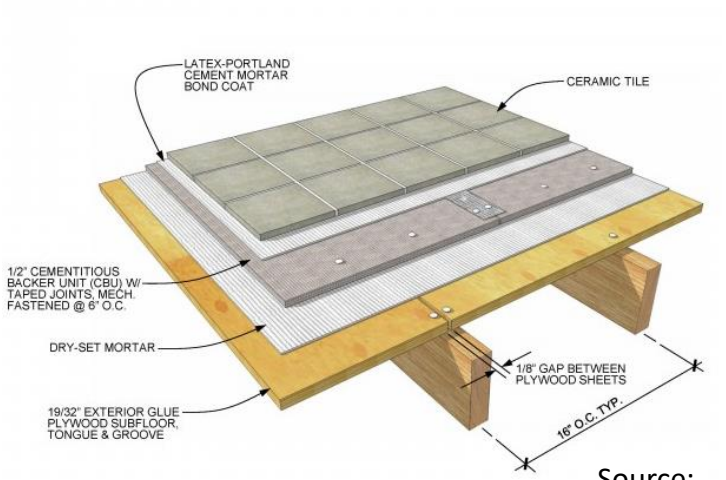
- Building codes require buildings, structures and parts thereof to be designed and constructed for strength and serviceability
  - Strength requirements ensure the structure or member will be safe
  - Serviceability requirements ensure the building or member remains useful
- Serviceability issues are often overshadowed by strength issues, as deflection concerns rarely affect life safety
- However, the vast majority of complaints received by component manufactures relate to serviceability issues

Introduction

- Current building codes provide minimum design requirements for floor deflection
- Manufacturers and trade associations often recommend more stringent deflection requirements to address serviceability or appearance for a variety of products including:
  - Gypsum floor topping
  - Light-weight concrete topping
  - Ceramic or porcelain floor tile
  - Natural stone flooring (including marble)
  - Composite stone flooring

Introduction

- Although both deflection of individual structural members (including floor trusses) and of the subfloor material must be considered, this presentation focuses solely on deflection of the structural members



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Key Definitions

- **AUTHORITY HAVING JURISDICTION** (*IBC* Section 104.1) **–** The building official authorized and directed to enforce the provisions of a building code who also has the authority to render interpretations of this code and to adopt policies and procedures in order to clarify the application of its provisions
- **BUILDING DESIGNER** (*ANSI/TPI 1* Section 2.2) **–** The owner of the building or the person that contracts with the owner for the design of the building structural system and/or who is responsible for the preparation of the construction documents. When mandated by the legal requirements, the Building Designer shall be a registered design professional
- **CONSTRUCTION DOCUMENTS** (*IBC* Section 2) **–** Written, graphic and pictorial documents prepared or assembled for describing the design, location and physical characteristics of the elements of a project necessary for obtaining a building permit

Key Definitions

- **CONCENTRATED LOAD** (*SBCA* Terminology) **–** Loading applied at a specific point, such as a load-bearing wall running perpendicular to a truss, or a roof-mounted A/C unit hanging from a truss.
- **CREEP** (*SBCA* Terminology) **–** Time-dependent deformation of a structural member under constant load
- **DEAD LOAD (*D*)** (*IBC* Section 2) **–** The weight of materials of construction incorporated into the building, including but not limited to walls, floors, roofs, ceilings, stairways, built-in partitions, finishes, cladding and other similarly incorporated architectural and structural items, and the weight of fixed service equipment, such as cranes, plumbing stacks and risers, electrical feeders, heating, ventilating and air-conditioning systems and automatic sprinkler systems

Key Definitions

- **DEFLECTION (Δ)** (*SBCA* Terminology) **–** Amount a member sags or displaces under the influence of forces
- **LIVE LOAD (*L*)** (*IBC* Section 2) **–** A load produced by the use and occupancy of the building or other structure that does not include construction or environmental loads such as wind load, snow load, rain load, earthquake load, flood load or dead load
- **LOADS** (*IBC* Section 2) **–** Forces or other actions that result from the weight of building materials, occupants and their possessions, environmental effects, differential movement and restrained dimensional changes. Permanent loads are those loads in which variations over time are rare or of small magnitude, such as dead loads. All other loads are variable loads (see "Nominal loads")
- **TRUSS DESIGN DRAWING** (*ANSI/TPI 1* Section 2.2) **–** Written, graphic and pictorial depiction of an individual truss that includes information required in *ANSI/TPI 1*.

Background – IBC

- The *IBC* includes specific requirements regarding deflection in Section 1604.3 and specific requirements for floor structural members in Table 1604.3.

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:			
With plaster or stucco finishes	—	l/360	—
With other brittle finishes	—	l/240	—
With flexible finishes	—	l/120	—
Interior partitions:[b]			
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

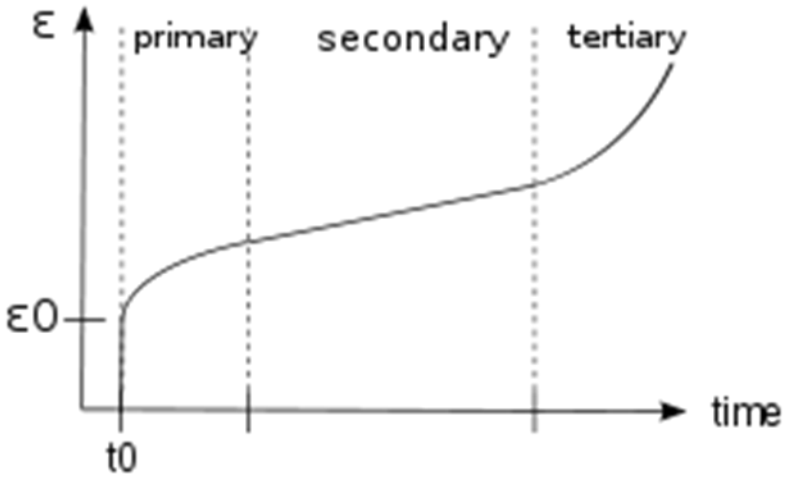
Background – IBC

- Table 1604.3 includes consideration of creep in footnote d

d. The deflection limit for the *D*+*L* load combination only applies to the deflection due to the creep component of long-term dead load deflection plus the shortterm live load deflection. For wood structural members that are dry at time of installation and used under dry conditions in accordance with the ANSI/AWC NDS, the creep component of the long-term deflection shall be permitted to be estimated as the immediate dead load deflection resulting from 0.5*D*. For wood structural members at all other moisture conditions, the creep component of the long-term deflection is permitted to be estimated as the immediate dead load deflection resulting from *D*. The value of 0.5*D* shall not be used in combination with ANSI/AWC NDS provisions for long-term loading.

Background – IBC

- Creep refers to time-dependent deformation of a structural member under constant load.
- Factors that cause an increase in creep include:
  - Increased stress level
  - Moisture content
  - Temperature

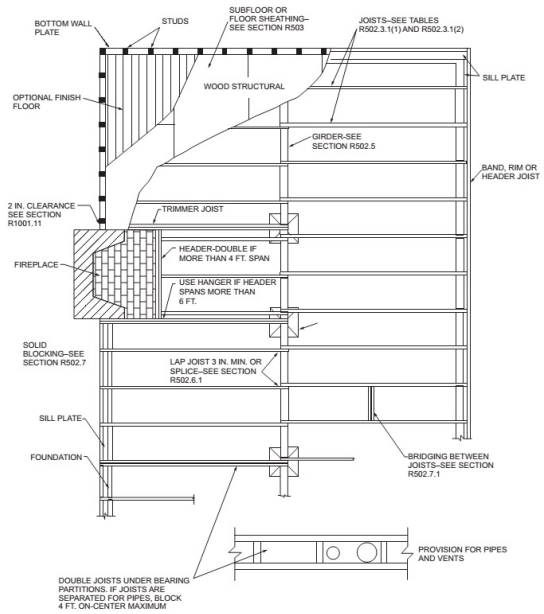


Background – IRC

- The IRC includes requirements for floor installation, including for floors with the floor topping products covered in this presentation
- The IRC does provide deflection requirements, but does not address creep.

R502.2 Design and Construction.

Floors shall be designed and constructed in accordance with the provisions of this chapter, Figure R502.2 and Sections R317 and R318 or in accordance with ANSI AWC NDS.



Background – TPI 1

- *ANSI/TPI 1* (referenced by the IBC and IRC) includes:
  - Section 7.6 provides guidance for deflection limits for trusses.
  - TPI 1-2014 has been updated to account for the recent clarifications in the IBC regarding creep.

Table 7.6-1 Deflection Limits for Non-Cantilevered Portions of Trusses.[3, 5]

Values given in the table are divisors that are applied to the clear span length, L_s, to establish a deflection limit (limit = L_s / specified value).

Member	Deflection due to Live Load Only (Δ_{LL})	Deflection due to Live Load Plus Creep Component of Deflection due to Dead Load (Δ_{CR})	Deflection due to Total Load (Δ_{TL}), when specified[7]
Roof Truss supporting plaster[1]	360	240	240
Roof Truss supporting drywall[1]	240	180	180
Roof Truss not supporting ceilings[1]	180	120	120
Floor Trusses[2] (see footnotes for Trusses supporting ceramic tile)	360	240	240
Top Chord panel[4]	180	120	120
Habitable spaces in Trusses[6]	360		

1. Roofs not having sufficient slope or camber to assure adequate drainage shall be investigated for ponding.
2. Certain floor coverings require more restrictive deflection criteria. For ceramic tile, Truss spacing and appropriate dead load for the installation method, and other aspects of design per *ANSI A108/A118/A136* shall be such that the system passes the requirements of the Building Designer per Chapter 2 of this Standard.
3. Cantilevered and overhang portions of Trusses are subject to deflection limits using the values shown above applied to twice the length of the cantilever, L_c.
4. Span length for Top Chord panel limits shall be the panel length.
5. Where required by *ACI 530/TMS 402* for Trusses used as a beam or lintel providing support of vertical masonry veneer, a minimum of 1/600 deflection limit shall apply.
6. Limit is for panel deflection of the loaded panel when loaded with 30 psf (14.4 KPa) or greater of live load.
7. The limits for Δ_{LL} and Δ_{CR} correspond to limits established by typical building codes and shall be applied to all trusses. The limit for Δ_{TL} is provided for application when building designers specify such a check due to total load be performed.

Application

- Truss design software typically addresses code deflection requirements by default; the building designer may specify more stringent criteria.
- Dead loads associated with floor covering products may significantly affect design limitations (strength, deflection and creep)
- Thus, it is important for the building designer to provide all the information required in ANSI/TPI 1 Section 2.3.2.4, especially relating to serviceability.

2.3.2.4 Required Information in the Construction Documents.

The Building Designer, through the Construction Documents, shall provide information sufficiently accurate and reliable to be used for facilitating the supply of the Structural Elements and other information for developing the design of the Trusses for the Building, and shall provide the following:

(a) All Truss and Structural Element orientations and locations.

(b) Information to fully determine all Truss profiles.

(c) All Structural Element and Truss support loca-

(g) Criteria related to serviceability issues including:

(1) Allowable vertical, horizontal or other required deflection criteria.

(2) Any dead load, live load, and in-service creep deflection criteria for roofs subject to ponding loads.

(3) Any Truss camber requirements.

(4) Any differential deflection criteria from Truss-to-Truss or Truss-to-adjacent Structural Element.

User (non-mandatory) note: See Commentary section §2.3.2.4(h)(4) regarding methods to address differential deflection.

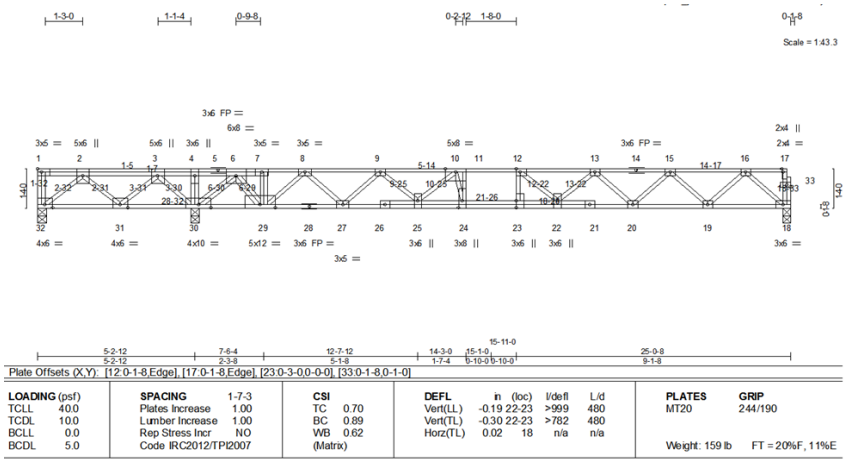
(5) Any deflection and vibration criteria for floor Trusses including:

(i) Any strongback bridging requirements.

(ii) Any dead load, live load, and in-service creep deflection criteria for floor Trusses supporting stone or ceramic tile finishes.

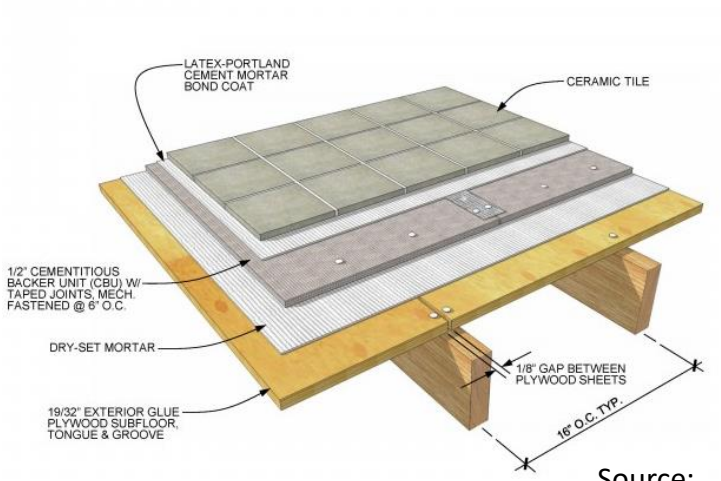
Application

- Live loads and concentrated loads are typically code specified or included in a referenced document like *SEI/ASCE 7*.
- Given complete and accurate loading and serviceability information, truss designs will account for all the considerations and include pertinent information on the Truss Design Drawing.



Application – Types of Deflection

- Deflection in a floor assembly can occur in multiple ways:
  - Along the truss
  - In the sheathing between the trusses
  - Differential movement between adjacent trusses
- Deflection criteria are applicable to each component



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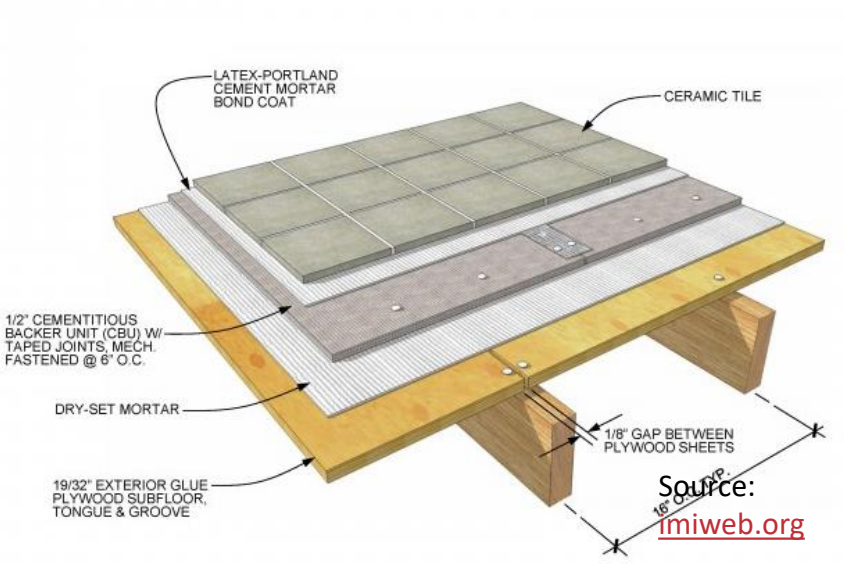
Application – Differential Expansion Causes

- Moisture
  - Few tile installations are waterproof.
  - Unless a waterproof membrane is installed, moisture from repeated mopping or heavy wetting can eventually cause problems
- Radiant Heating Systems
  - Heating elements can create weak points in the concrete leading to cracking that can transmit to the grout or tile unless an anti-fracture membrane is used



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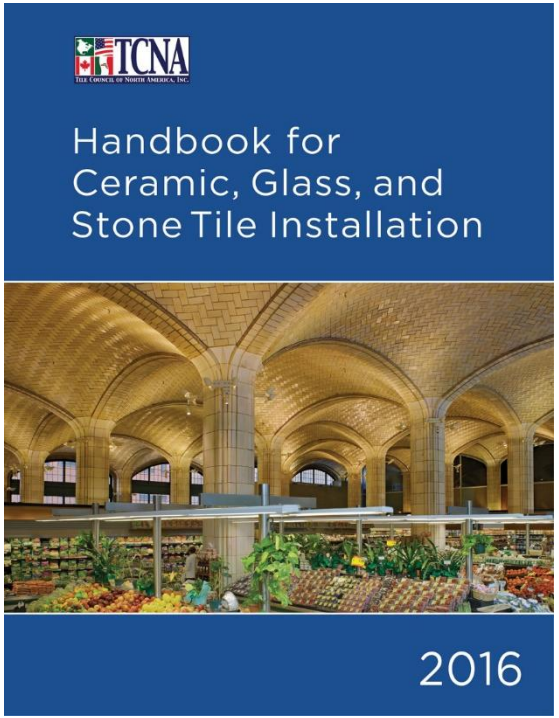
Application – Poured Topping

- Although the poured topping industry does not appear to provide generic design information via a trade association, typical deflection requirements for both structural members and subfloor are as follows:
  - Live Load deflection L/360
  - Total Load deflection L/240
- Poured topping installed thickness and weight can vary widely. Typical values include:
  - ¾” gypsum-based topping ~ 7 psf.
  - 1” concrete-based topping ~ 12 psf

Application – Brittle Floor Coverings

- The *IRC* and *IBC* both reference ceramic tile installation to be in accordance with ANSI A108.1 A/B, A108.4, A108.5, A108.6, A118.1, A118.3, A136.1 and A137.1.
- The Tile Council of North America (TCNA) publishes a *Handbook for Ceramic, Glass, and Stone Tile Installation* which provides guidance, although it is not referenced by the building codes.



Application – Brittle Floor Coverings

- TCNA substrate requirements include:
  - Follow applicable building codes
  - Ceramic tile – live load deflection shall not exceed L/360
  - Stone tile – live load deflection shall not exceed L/720
  - The owner should communicate loading requirements to the designer
  - Designer and contractor must make allowances for all live and concentrated loads, including during construction and maintenance, such as heavy vehicles
  - See Typical Weight of Tile Installation for dead loads including tile and setting bed. Typically, a 1/2"-thick mortar bed will weigh about 6 psf.
  - Tile contractor responsibilities with respect to subfloor adequacy and installation

Application – Brittle Floor Coverings

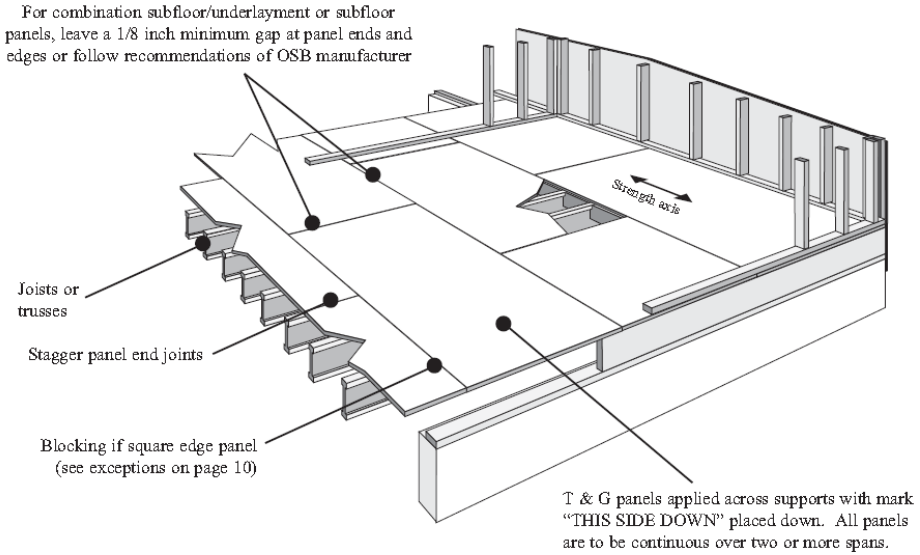
- In a technical service bulletin, TCNA states the following:
  - Recent research has shown tile to fail, under some conditions, when the floor is more rigid than L/360. In fact, failures at L/600 have been observed. It is for this reason that recommendations for floor rigidity are not based on deflection measurements but on empirically established methods found to work over normal code construction.

Application – Brittle Floor Coverings

- The TCNA Handbook includes assemblies with tile over wood which specify:
  - Structural members
  - Stated maximum on center spacing
  - Specific subfloor & underlayment requirements
  - Maximum tile size
  - Other details as required
- Amongst TCNA listed assemblies:
  - 23 floor systems utilize **plywood**. One **OSB**
  - Eight require two-layer **all plywood** (i.e., subfloor & underlayment)
  - Six allow supporting members to be spaced at 24” oc.
    - Two permit supporting members to be spaced at 19.2” oc.
    - The remaining require supports to be spaced at 16” oc or less.

Application – Brittle Floor Coverings

- TCNA also gives installation guidelines:
  - Subflooring and underlayment should be installed with the strength axis perpendicular to the supports and 1/8” spacing (gap) between sheets
  - Underlayment panel edges should be offset from edges of subflooring by six inches
  - Underlayment panel ends should be offset from subfloor panels ends by one or more joist spaces plus at least 2” (6” optimum)
  - Attach underlayment to the subflooring with ring shank nails or screws and not to the floor joists or trusses



Application – Brittle Floor Coverings

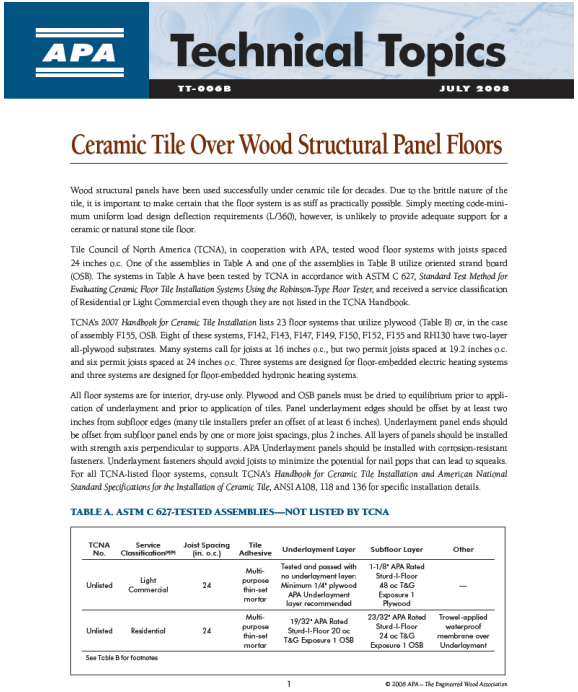
- The following listed assemblies allow wood structural members (including trusses) spaced at 24” o.c.

TCNA No	Service Class	Subfloor	Underlayment	Other Considerations
F160-15	Lt. Comm.	23/32" T&G Ply	3/8" 7 ply birch	8x8 or larger tile
F147-15	Residential	23/32" T&G Ply	3/8" ply	4x4 or larger tile[1]
F149-15	Residential	23/32" ply	19/32" ply	8x8 or larger tile[2]
F151-15	Residential	7/8" T&G	Coated glass mat water resistant gypsum backer board	8x8 or larger tile
F152-15	Residential	23/32" T&G	3/8" ply	4x4 or larger tile[1]
F155-15	Residential	23/32" T&G OSB or ply	19/32" ply	8x8 or larger tile[2]

[1]Trusses or I-joists with a minimum 2-1/4” top flange (1-1/2” top flange permissible with 8x8 and larger tile); cross-bracing recommended.
[2]Trusses or I-joists with a minimum 1-1/2” top flange or sawn lumber joists; cross-bracing recommended.

Application – Brittle Floor Coverings

- The Engineered Wood Association (APA) in cooperation with TCNA, has tested a number of floor systems with joists spaced 24" o.c. with both plywood and OSB (see APA Technical Topic TT-006, Ceramic Tile Over Wood Structural Panel Floors, Revised May 1, 2014).
- It includes many of the same assemblies as are listed in the TCNA Handbook and some additional.



APA **Technical Topics**

TT-006B JULY 2008

Ceramic Tile Over Wood Structural Panel Floors

Wood structural panels have been used successfully under ceramic tile for decades. Due to the brittle nature of the tile, it is important to make certain that the floor system is as stiff as practically possible. Simply meeting code-minimum uniform load design deflection requirements (L/360), however, is unlikely to provide adequate support for a ceramic or natural stone tile floor.

Tile Council of North America (TCNA), in cooperation with APA, tested wood floor systems with joists spaced 24 inches o.c. One of the assemblies in Table A and one of the assemblies in Table B utilize oriented strand board (OSB). The systems in Table A have been tested by TCNA in accordance with ASTM C 627, *Standard Test Method for Evaluating Ceramic Floor Tile Installation Systems Using the Robinson-Type Floor Tester*, and received a service classification of Residential or Light Commercial even though they are not listed in the TCNA Handbook.

TCNA's *2007 Handbook for Ceramic Tile Installation* lists 23 floor systems that utilize plywood (Table B) or, in the case of assembly F135, OSB. Eight of these systems, F142, F143, F147, F149, F150, F152, F155 and RH130 have two-layer all-plywood substrates. Many systems call for joists at 16 inches o.c., but two permit joists spaced at 19.2 inches o.c. and six permit joists spaced at 24 inches o.c. Three systems are designed for floor-embedded electric heating systems and three systems are designed for floor-embedded hydronic heating systems.

All floor systems are for interior, dry-use only. Plywood and OSB panels must be dried to equilibrium prior to application of underlayment and prior to application of tiles. Panel underlayment edges should be offset by at least two inches from subfloor edges (many tile installers prefer an offset of at least 6 inches). Underlayment panel ends should be offset from subfloor panel ends by one or more joist spacings, plus 2 inches. All layers of panels should be installed with strength axis perpendicular to supports. APA Underlayment panels should be installed with corrosion-resistant fasteners. Underlayment fasteners should avoid joists to minimize the potential for nail pops that can lead to squeaks. For all TCNA-listed floor systems, consult TCNA's *Handbook for Ceramic Tile Installation and American National Standard Specifications for the Installation of Ceramic Tile*, ANSI A108, 118 and 136 for specific installation details.

TABLE A. ASTM C 627-TESTED ASSEMBLIES—NOT LISTED BY TCNA

TCNA No.	Service Classification(a)(b)	Joist Spacing (in. o.c.)	Tile Adhesive	Underlayment Layer	Subfloor Layer	Other
Unlisted	Light Commercial	24	Multi-purpose thin-set mortar	Tested and passed with no underlayment layer. Minimum 1/4" plywood APA Underlayment layer recommended	1-1/8" APA Rated Sturd-I-Floor 48 oc T&G Exposure 1 Plywood	—
Unlisted	Residential	24	Multi-purpose thin-set mortar	19/32" APA Rated Sturd-I-Floor 20 oc T&G Exposure 1 OSB	23/32" APA Rated Sturd-I-Floor 24 oc T&G Exposure 1 OSB	Trowel-applied waterproof membrane over Underlayment

See Table B for footnotes

1 © 2008 APA – *The Engineered Wood Association*

Application – Marble Flooring

- The Marble Institute of America (MIA) also publishes installation requirements
- The dead loads for stone flooring products vary widely, and must be accounted for in addition to building code minimum requirements

3.8 Deflection of Surfaces

3.8.1 General Contractor Responsibility. It is the responsibility of the General Contractor to provide a rigid, code-compliant structure that is adequate to accommodate the stone and its anchorage including all associated loads and forces.

3.8.2 Cast-in-Place Concrete Floors. Design substrate for total load deflection not exceeding L/360, as measured between control or expansion joints.

3.8.3 Frame Construction. The subfloor areas over which stone tile is to be applied must be designed to have a deflection not exceeding **L/720** of the span. In calculating load, the weight of the stone and setting bed must be considered.

3.8.3.1 Strongbacks, cross-bridging or other reinforcement shall be used to limit differential deflection between adjacent framing members.

3.8.4 Maximum variation of a concrete slab or subfloor shall not exceed 1/8" in 10' from the required plane when thin set systems are applied.

3.8.5 Allowance should be made for live load and impact, as well as all dead load, including weight of stone and setting bed.

3.8.5.1 Mortar Bed Weight. For estimating purposes, mortar bed weight can be approximated as 0.75 lb per square foot per each 1/16” of thickness.

3.8.5.2 Stone Weight. For estimating purposes, stone weight can be approximated as 1 lb per square foot per each 1/16” of thickness.

Differential Deflection

- Differential Deflection refers to the relative deflection of adjacent trusses
- The Building Designer is responsible for specifying any limitations regarding differential deflection between adjacent trusses (Section 2.3.2.4 of TPI 1)

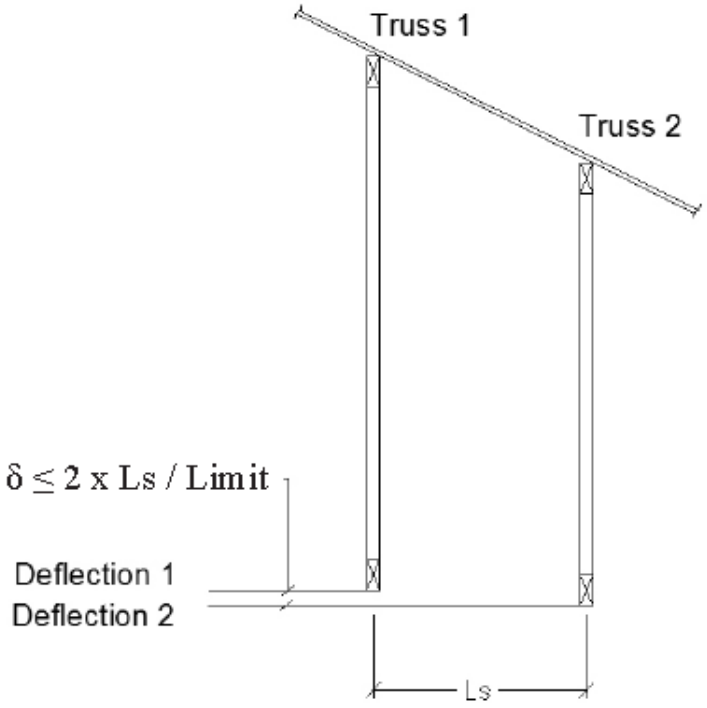
Differential Deflection

- Conditions where differential deflection may be objectionable:
  - A bearing wall continuously supports one truss in a series of trusses otherwise supported only at their ends
  - Trusses in hip systems where a shallower and more heavily loaded girder truss is adjacent to deeper “common” trusses
  - Truss with flat bottom chord is adjacent to a scissors truss
  - Partition walls oriented parallel to the floor trusses, especially those supporting cabinets or tile

Differential Deflection – TPI 1

- TPI 1 Commentary Section §7.6.2 provides a method for addressing differential deflection

$$\partial \leq 2 \times L_s/\text{Limit}$$



Differential Deflection – TPI 1

6.2.2.1 Non-Bearing Partitions.

The weight of non-bearing partitions shall be permitted to be ignored for Truss design purposes given the following conditions:

(a) Trusses are spaced less than or equal to 24 in. (610 mm) on center;

(b) All Top Chord panel lengths of supporting Trusses are less than or equal to 30 in. (760 mm) when the lumber is oriented in the flat direction;

(c) Design live load of supporting Trusses results from a residential occupancy and is not more than 40 psf (1920 Pa); and

(d) Partition weight is less than or equal to 60 pounds per linear foot (875 N/m).

6.2.2.1.1 Non-Bearing Partition Weight Not Permitted to be Ignored.

If the conditions listed above do not exist, the Building Designer shall specify in the structural design documents the non-bearing partition loads that need to be applied to the Trusses.

6.2.2.1.2 Non-Load Bearing Partitions Parallel to Supporting Trusses.

When non-load bearing partitions parallel to supporting Trusses are not located on or immediately adjacent to a Truss, the sub-floor shall be of adequate strength and stiffness to support the non-load bearing partition load, or other provisions shall be made by the Building Designer to distribute the non-load bearing partition weight to the supporting Trusses.

Subfloor Deflection

- For information on the deflection of subfloor material see the following resources:
  - Ceramic Tile on Wood Floors, Frank E. Woeste Ph.D., P.E. & Peter Nielson
  - Position of Underlayment to Prevent Cracked Tile and Grout, Frank E. Woeste P.E. & Peter Nielson
  - Preventing Cracked Tile and Grout, Frank E. Woeste & Peter Nielson
  - Investigating Tile Failures on Wood-Frame Floor Systems, Frank E. Woeste & Peter Nielson
  - CTIOA Field Report 2001-11-19 Ceramic Tile Over Wood Sub-Floors Regarding Deflection, David deBear, CTC
  - Deflection Limitations, Dale Kempster
  - Universal Floor Tester: An Opportunity for Improved Ceramic Tile Assembly Evaluations, Sean Gerolimatos, Dale Kempster, Peter Nielsen, Frank Woeste

References

- *2015 International Building Code*
- *2015 International Residential Code*
- *ANSI A108.01 – General Requirements: Subsurfaces and Preparations by Other Trades*
- *ANSI A108.02 – General Requirements: Materials, Environmental, and Workmanship*
- *ANSI A108.1A – Installation of Ceramic Tile in the Wet-Set Method, with Portland Cement Mortar*
- *A108.1B – Installation of Ceramic Tile on a Cured Portland Cement Mortar Setting Bed with Dry-Set or Latex-Portland Cement Mortar*
- *ANSI A108.4 – Installation of Ceramic Tile with Organic Adhesive or Water Cleanable Tile-Setting Epoxy Adhesive*
- *ANSI A108.5 – Ceramic Tile Installed with Dry-Set or Latex-Portland Cement Mortar*
- *ANSI A108.6 – Ceramic Tile Installed with Chemical Epoxy Mortar and Grout*
- *ANSI A108.8 – Installation of Ceramic Tile with Chemical Resistant Furan Resin Mortar and Grout*
- *ANSI A108.9 – Ceramic Tile Installed with Modified Epoxy Emulsion Mortar/Grout*

References

- *ANSI A118.1 – American National Standard Specifications for Dry-set Portland Cement Mortar*
- *ANSI A118.3 – American National Standard Specifications for Chemical-resistant, Water-cleanable Tile-setting and -grouting Epoxy and Water Cleanable Tile-setting Epoxy Adhesive*
- *ANSI A137.1 – American National Standard Specifications for Ceramic Tile*
- *For a complete listing of standards related to the tile industry see the TCNA website.*
- *ANSI/AWC – National Design Specification (NDS) for Wood Construction*
- *ANSI/TPI 1 – National Design Standard for Metal Plate Connected Wood Truss Construction*
- APA Technical Topic TT-006, Ceramic Tile Over Wood Structural Panel Floors
- *ASCE/SEI 7 – Minimum Design Loads for Buildings and Other Structures*
- *Dimension Stone Design Manual version 7.2*; Marble Institute of America
- SBCA Load Guide, version 2.02; Structural Building Components of America, 2016
- *TCNA Handbook for Ceramic, Glass, and Stone Tile Installation*; Tile Council of America. March 2015