Deflection Limits for Floor Trusses

Overview
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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.

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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.

Source: imiweb.org
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>
<thead>
<tr>
<th>TABLE 1604.3 DEFLECTION LIMITS</th>
<th>$L$</th>
<th>$S$ or $W^f$</th>
<th>$D + L^{d,g}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof members: $^e$</td>
<td>$\frac{1}{360}$</td>
<td>$\frac{1}{360}$</td>
<td>$\frac{1}{240}$</td>
</tr>
<tr>
<td>Supporting plaster or stucco ceiling</td>
<td>$\frac{1}{240}$</td>
<td>$\frac{1}{240}$</td>
<td>$\frac{1}{180}$</td>
</tr>
<tr>
<td>Supporting nonplaster ceiling</td>
<td>$\frac{1}{180}$</td>
<td>$\frac{1}{180}$</td>
<td>$\frac{1}{120}$</td>
</tr>
<tr>
<td>Not supporting ceiling</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Floor members</td>
<td>$\frac{1}{360}$</td>
<td>—</td>
<td>$\frac{1}{240}$</td>
</tr>
<tr>
<td>Exterior walls:</td>
<td>—</td>
<td>$\frac{1}{360}$</td>
<td>—</td>
</tr>
<tr>
<td>With plaster or stucco finishes</td>
<td>—</td>
<td>$\frac{1}{240}$</td>
<td>—</td>
</tr>
<tr>
<td>With other brittle finishes</td>
<td>—</td>
<td>$\frac{1}{120}$</td>
<td>—</td>
</tr>
<tr>
<td>With flexible finishes</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Interior partitions: $^b$</td>
<td>—</td>
<td>—</td>
<td>$\frac{1}{180}$</td>
</tr>
<tr>
<td>With plaster or stucco finishes</td>
<td>$\frac{1}{360}$</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>With other brittle finishes</td>
<td>$\frac{1}{240}$</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>With flexible finishes</td>
<td>$\frac{1}{120}$</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Farm buildings</td>
<td>—</td>
<td>—</td>
<td>$\frac{1}{120}$</td>
</tr>
<tr>
<td>Greenhouses</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>
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 short-term 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 $0.5D$. 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 $0.5D$ 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.
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.

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**Table 7.6-1 Deflection Limits for Non-Cantilevered Portions of Trusses.**

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

<table>
<thead>
<tr>
<th>Member</th>
<th>Deflection due to Live Load Only (( \Delta_{LL} ))</th>
<th>Deflection due to Live Load Plus Creep Component of Deflection due to Dead Load (( \Delta_{LL} + \Delta_{CL} ))</th>
<th>Deflection due to Total Load (( \Delta_{LT} )) when specified'</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof Truss supporting plasters</td>
<td>360</td>
<td>240</td>
<td>240</td>
</tr>
<tr>
<td>Roof Truss supporting drywall</td>
<td>240</td>
<td>180</td>
<td>180</td>
</tr>
<tr>
<td>Roof Truss not supporting ceilings</td>
<td>180</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>Floor Trusses (see footnotes for Trusses supporting ceramic tile)</td>
<td>360</td>
<td>240</td>
<td>240</td>
</tr>
<tr>
<td>Top Chord panel</td>
<td>180</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>Habitable spaces in Trusses</td>
<td>360</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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1. Roof not having sufficient slope or camber to assure adequate drainage shall be investigated for ponding.
2. Certain floor coverings may require more restrictive deflection criteria. For ceramic tile, Truss spacing and appropriate load for the installation method, and other aspects of design per ANSI A119.6/A119.16 shall be such that the system passes the requirements of the Building Designer per Chapter 2 of this Standard.
3. Cantilevered and overhanging portions of Trusses are subject to deflection limits using the values shown above applied to twice the length of the cantilever, \( L \).
4. Span length for Top Chord panel limits shall be the panel length.
5. Where required by ACI 318/318-08 for Trusses used as a beam or lintel providing support of vertical masonry veneer, a minimum of 1/800 deflection limit shall apply.
6. Limit for panel deflection of the loaded panel when loaded with 30 psf (144 kPa) or greater of live load.
7. The limits for \( \Delta_{LL} \) and \( \Delta_{LL} + \Delta_{CL} \) correspond to limits established by typical building codes and shall be applied to all trusses. The limit for \( \Delta_{LT} \) is provided for application when building designers specify such a check due to total load to be performed.

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**Footnotes:**

- Footnote for deflection limits.
- Footnote for specific applications.
- Footnote for structural considerations.

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SBCA
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.
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

Source: imiweb.org
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

Source: imiweb.org
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.
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.

<table>
<thead>
<tr>
<th>TCNA No</th>
<th>Service Class</th>
<th>Subfloor</th>
<th>Underlayment</th>
<th>Other Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>F160-15</td>
<td>Lt. Comm.</td>
<td>23/32&quot; T&amp;G Ply</td>
<td>3/8&quot; 7 ply birch</td>
<td>8x8 or larger tile</td>
</tr>
<tr>
<td>F147-15</td>
<td>Residential</td>
<td>23/32&quot; T&amp;G Ply</td>
<td>3/8&quot; ply</td>
<td>4x4 or larger tile¹</td>
</tr>
<tr>
<td>F149-15</td>
<td>Residential</td>
<td>23/32&quot; ply</td>
<td>19/32&quot; ply</td>
<td>8x8 or larger tile²</td>
</tr>
<tr>
<td>F151-15</td>
<td>Residential</td>
<td>7/8&quot; T&amp;G</td>
<td>Coated glass mat water resistant gypsum backer board</td>
<td>8x8 or larger tile</td>
</tr>
<tr>
<td>F152-15</td>
<td>Residential</td>
<td>23/32&quot; T&amp;G</td>
<td>3/8&quot; ply</td>
<td>4x4 or larger tile⁴</td>
</tr>
<tr>
<td>F155-15</td>
<td>Residential</td>
<td>23/32&quot; T&amp;G OSB or ply</td>
<td>19/32&quot; ply</td>
<td>8x8 or larger tile²</td>
</tr>
</tbody>
</table>

¹Trusses 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.

²Trusses 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.
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