SBC ASSOCIATION

Research Report

Deflection Limits for Floor Trusses

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Structural Building Components Association (SBCA)

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SBCA is an APPROVED SOURCE

This research report is based on practical scientific research (literature review, testing, analysis, etc.). This research report complies with the following sections of the building code:

- *IBC* Section 104.11.1 and Section 1703.4.2 – "**Research reports.** Supporting data, where necessary to assist in the approval of materials or assemblies not specifically provided for in this code, shall consist of valid research reports from *approved sources*."
- *IBC* Section 202 – "**APPROVED SOURCE.** An independent person, firm or corporation, *approved* by the *building official*, who is competent and experienced in the application of engineering principles to materials, methods or systems analyses."

Structural Building Components Association (SBCA) | 6300 Enterprise Lane, Madison, WI 53719 | 608-274-4849 | sbcindustry.com

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Introduction:

There are circumstances when the deflection requirements for a specific structure that utilizes floor trusses as structural members are questioned. This is especially the case when either floor toppings and/or brittle floor coverings are specified or were not included in the specification but are installed after the floor trusses have been installed.

The current residential and commercial building codes provide minimum design requirements for loads and for deflection of structural floor members, which also apply to floor trusses. The building designer may specify more stringent requirements.

This research report will focus on manufacturer or trade association deflection requirements for a number of floor topping/covering related products: gypsum floor topping, light-weight concrete topping, ceramic or porcelain floor tile, natural stone flooring (including marble), and composite stone flooring. These are all products where deflection may have an impact on serviceability or appearance.

Each of these products may have different deflection considerations that should be considered in the overall building design as well as in the design of the floor trusses. There are two types of deflection that must be considered: the deflection of the individual structural members and the deflection of the subfloor material that spans the structural members. Only the deflection of floor trusses is within the scope of this report, although references are made to resources regarding subfloor deflection.

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.

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.

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:

The *IBC* is fairly specific about the information required on construction documents.

107.2 Construction documents. Construction documents shall be in accordance with Sections 107.2.1 through 107.2.6.

107.2.1 Information on construction documents. Construction documents shall be dimensioned and drawn upon suitable material. Electronic media documents are permitted to be submitted where approved by the building official. Construction documents shall be of sufficient clarity to indicate the location, nature and extent of the work proposed and show in detail that it will conform to the provisions of this code and relevant laws, ordinances, rules and regulations, as determined by the building official.

107.2.6 Structural information. The construction documents shall provide the information specified in Section 1603.

1603.1 General. Construction documents shall show the size, section and relative locations of structural members with floor levels, column centers and offsets dimensioned. The design loads and other information pertinent to the structural design required by Sections 1603.1.1 through 1603.1.8 shall be indicated on the construction documents.

Exception: Construction documents for buildings constructed in accordance with the conventional light-frame construction provisions of Section 2308 shall indicate the following structural design information:

1. Floor and roof live loads.
2. Ground snow load, P_g.
3. Ultimate design wind speed, V_{ult}, (3-second gust), miles per hour (mph) (km/hr) and nominal design wind speed, V_{asd}, as determined in accordance with Section 1609.3.1 and wind exposure.
4. Seismic design category and site class.
5. Flood design data, if located in flood hazard areas established in Section 1612.3.
6. Design load-bearing values of soils.

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

1604.3 Serviceability. Structural systems and members thereof shall be designed to have adequate stiffness to limit deflections and lateral drift. See Section 12.12.1 of ASCE 7 for drift limits applicable to earthquake loading.

1604.3.1 Deflections. The deflections of structural members shall not exceed the more restrictive of the limitations of Sections 1604.3.2 through 1604.3.5 or that permitted by Table 1604.3.

1604.3.6 Limits. The deflection limits of Section 1604.3.1 shall be used unless more restrictive deflection limits are required by a referenced standard for the element or finish material.

Table 1604.3 Deflection Limits: Floor Members L/360 for live loads and L/240 for dead plus live loads

Table 1604.3 also includes consideration of creep in footnote 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 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 AWC NDS provisions for long-term loading.

The *IRC* is less specific about what is to be included on construction documents, since it is more prescriptive in orientation.

R106.1 Submittal documents. Submittal documents consisting of construction documents, and other data shall be submitted in two or more sets with each application for a permit. The construction documents shall be prepared by a registered design professional where required by the statutes of the jurisdiction in which the project is to be constructed. Where special conditions exist, the building official is authorized to require additional construction documents to be prepared by a registered design professional.

Exception: The building official is authorized to waive the submission of construction documents and other data not required to be prepared by a registered design professional if it is found that the nature of the work applied for is such that reviewing of construction documents is not necessary to obtain compliance with this code.

R106.1.1 Information on construction documents. Construction documents shall be drawn upon suitable material. Electronic media documents are permitted to be submitted where approved by the building official. Construction documents shall be of sufficient clarity to indicate the location, nature and extent of the work proposed and show in detail that it will conform to the provisions of this code and relevant laws, ordinances, rules and regulations, as determined by the building official.

The *IRC* does include requirements for installation instructions, which would include instructions regarding the floor topping or covering products which are the subject of this research report.

R106.1.2 Manufacturer's installation instructions. Manufacturer's installation instructions, as required by this code, shall be available on the job site at the time of inspection.

The *IRC* does provide deflection requirements but does not address creep.

R301.7 Deflection. The allowable deflection of any structural member under the live load listed in Sections R301.5 and R301.6 or wind loads determined by Section R301.2.1 shall not exceed the values in Table R301.7.

Table R301.7 Allowable Deflection of Structural Members: Floors L/360

ANSI/TPI 1, the National Design Standard for Metal Plate Connected Wood Truss Construction is reference by both the *IRC* and the *IBC*. It includes additional information required on the construction documents in order to effectively design trusses for serviceability, as well as detailed information regarding deflection and creep in floor trusses[1].

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:

(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.

(6) Moisture, temperature, corrosive chemicals and gases expected to result in:

(i) Wood moisture content exceeding 19 percent,

(ii) Sustained temperatures exceeding 150 degrees F, and/or

(iii) Corrosion potential from wood preservatives or other sources that can be detrimental to Trusses.

2.3.5.5 Information on Truss Design Drawings.

Truss Design Drawings shall include, at a minimum, the information specified below:

(l) Calculated span to deflection ratio and/or maximum vertical and horizontal deflection for live load and for live plus dead load and K_{CR} as applicable per Section 7.6.

7.6 DEFLECTION

7.6.1 Method of Calculation.

Truss deflection shall be determined by structural analysis in accordance with section 6.1.1.2, except as permitted in section 7.6.2.2 – 7.6.2.3. Deflection due to live load (Δ_{LL}) shall be based on the live load, deflection due to dead load (Δ_{DL}) shall be based on the dead load, and deflection due to total load (Δ_{TL}) shall be based on the full load including both dead and live loads, for each load case. Time dependent deformation under long term loading shall be determined as follows, except for purposes of deflection limitation in accordance with the International Building Code as noted in the next paragraph.

$\Delta_{LongTerm} = K_{cr} \times \Delta_{LT} + \Delta_{ST}$

where:

K_{cr} = Creep factor

≥ 2.0 for trusses using seasoned lumber used in dry service conditions

≥ 3.0 for trusses using green lumber or for wet service conditions

$\Delta_{LongTerm}$ = Total Long Term Deflection due to immediate deflection of both short-term and long-term loads and creep deflection of long-term loads

Δ_{LT} = Immediate deflection due to the long term component of the design load (immediate deflection due to the portion of load considered to be present over a sustained time period, typically dead load or a portion of dead load)

Δ_{ST} = deflection due to short term or normal component of the design load (deflection due to transient loads, typically live load)

For purposes of deflection limitations in accordance with the International Building Code, trusses using only seasoned lumber used in dry service conditions shall determine the deflection for the total load check as follows.

Δ_{CR} = Deflection due to Live Load plus Creep Component of Deflection due to Dead Load

$= \Delta_{LL} + (K_{CR}\text{-}1) \times \Delta_{DL}$

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

Floor Trusses:

Deflection due to Live Load Only (Δ_L) = L_S / 360

Deflection due to Live Load plus creep component of deflection due to Dead Load (Δ_{CR}) = L_S / 240

Deflection due to Total Load (Δ_{TL}), when specified = L_S / 240 (see footnote 7)

(see footnote 2 for trusses supporting ceramic tile)

[1] For a detailed discussion of deflection and creep as well as a comparison of ANSI?TPI 1 2014 to earlier editions, see the SBCA Load Guide, Section A3-Serviceability.

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.
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 applications when building designers specify such a check due to total load be performed.

Application:

Truss design software is quite sophisticated and typically addresses code required deflection requirements by default. It can also address specific requirements communicated by the building designer on the construction documents.

When the floor covering products within the scope of this research report are used in conjunction with metal plate connected wood trusses, 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. Live loads and concentrated loads are typically code specified or included in a referenced document like *SEI/ASCE 7*. The dead loads related to these floor covering materials contribute significantly to design limitations (strength, deflection and creep), so it is crucial that they be communicated accurately.

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.

Topping Materials Deflection Requirements:
The poured topping industry does not appear to have a trade association which provide generic design information. Each manufacturer's product installation requirements must be reviewed individually for deflection and weight information. Although there is variance in the language used, the following deflection requirements are typical: Live load deflection L/360, combined Dead + Live load deflection L/240. These requirements apply to both structural members and subfloor.

This requirement for the structural member is the same as the *IBC* and *IRC* requirements for deflection, as well as those of *ANSI/TPI 1*. Deflection of the subfloor is typically addressed by the span rating of the product and is outside the scope of truss design.

Installation thickness and weight of individual product installations can vary widely. At ¾" thickness an average weight of gypsum-base products is about 7 psf. For concrete-based products the average weight is 12 psf per inch of thickness.

Brittle Floor Covering Deflection Requirements:
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*. It, however, is not referenced by the building codes. It includes the following guidance in Substrate Requirements:

> Floor systems, whether wood framed or concrete, over which the tile will be installed using the appropriate TCNA method, according to the Floor Tiling Installation Guide, shall be in conformance with the International Residential Code (IRC) for residential applications, the International Building Code (IBC) for commercial applications, or applicable building codes. For ceramic tile installations maximum allowable floor member live load and concentrated load deflection for framed floor systems shall not exceed L/360, where "L" is the clear span length of the supporting member per applicable building code. For natural stone tile installations, maximum allowable floor member live load and concentrated load deflection for wood framed floor systems shall not exceed L/720, where "L" is the clear span length of the supporting member, per applicable building code.
>
> The owner should communicate In writing to the project design professional and general contractor the intended uses of the tile installation, including in-service loads or information to allow a project design professional to calculate such. Project design professional and general contractor must make necessary allowances for the expected live load, concentrated loads, impact loads, and dead loads, including maximum allowable loads during construction and maintenance. When concentrated loads such as scissor lifts, pallet jacks, automobiles, forklifts, etc., will be utilized on a tile or stone floor, the project design professional shall include their use in the determination of the appropriate substrate. For the weight of the tile and setting bed (contribution to dead load), see Typical Weight of Tile Installation in the method being specified.
>
> The tile contractor shall not be responsible for problems resulting from any structural subfloor installation not compliant with applicable building codes, unless structural subfloor was designed and installed by tile contractor, nor for problems from overloading. As tile is a finish applied to and relying upon the underlying structure, an inadequate substructure can cause a tile failure. In many cases, problems in the substructure may not be obvious, and the tile contractor cannot be expected to discover such and tile contractor shall not be responsible for designing flooring assembly, unless specifically engaged to do so in writing. Tile contractor cannot determine possibility of an overloaded condition.

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.

The TCNA Handbook includes specific assemblies with tile over wood with structural members at stated maximum on center spacing, specific subfloor & underlayment requirements, and maximum tile size, along with other details as required. The following is a summary of listed assemblies for interior applications of tile over wood that allow the structural members to be spaced at 24" on center (there are others with spacing at 16" or 19.2" on center). Assemblies with tile over wood with radiant heating (spacing 16" on center and one with spacing 19.2" on center are also included in the Handbook.

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.

The Engineered Wood Association (APA) in cooperation with TCNA, has tested a number of floor systems with joists spaced 24" on center 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.

The Marble Institute of America (MIA) also publishes installation requirements which includes the following:

> **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.

Building code minimum requirement for deflection do not account for the dead loads from these products which can range widely in weight.

Deflection of Subfloor Material

Although out of scope of this report, for further information on this topic 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

Building Designer Responsibility:

Unless the AHJ allows otherwise, the Construction Documents shall be prepared by a Building Designer (e.g., Owner, Registered Design Professional, etc.) for the Building and shall be in accordance with *IRC* Section R106 and *IBC* Section 107. The Construction Documents shall be accurate and reliable and shall provide the location, direction and magnitude of all applied loads and shall be in accordance with *IRC* Section 301 and *IBC* Section 1603. Construction Documents shall be submitted to the Building Official for approval and shall contain the plans, specifications and details needed for the Building Official to approve such documents.

Responsibilities:

- The information contained herein is a product, engineering or building code compliance research report prepared in accordance with the referenced building codes, testing and/or analysis using accepted engineering procedures, experience, and good technical judgment.
- Product design and code compliance quality control are the responsibility of the referenced company. Consult the referenced company for the proper detailing and application for the intended purpose. Consult your local jurisdiction or design professional to assure compliance with the local building code.
- SBCA Research Reports provide an assessment of only those attributes specifically addressed within a given report.
- The engineering evaluation was performed on the dates provided in this report, within SBCA's scope of work.

This research report is subject to periodic review and revision. For the most recent version of this report, visit sbcindustry.com. For information on the current status of this report, contact SBCA.

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

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