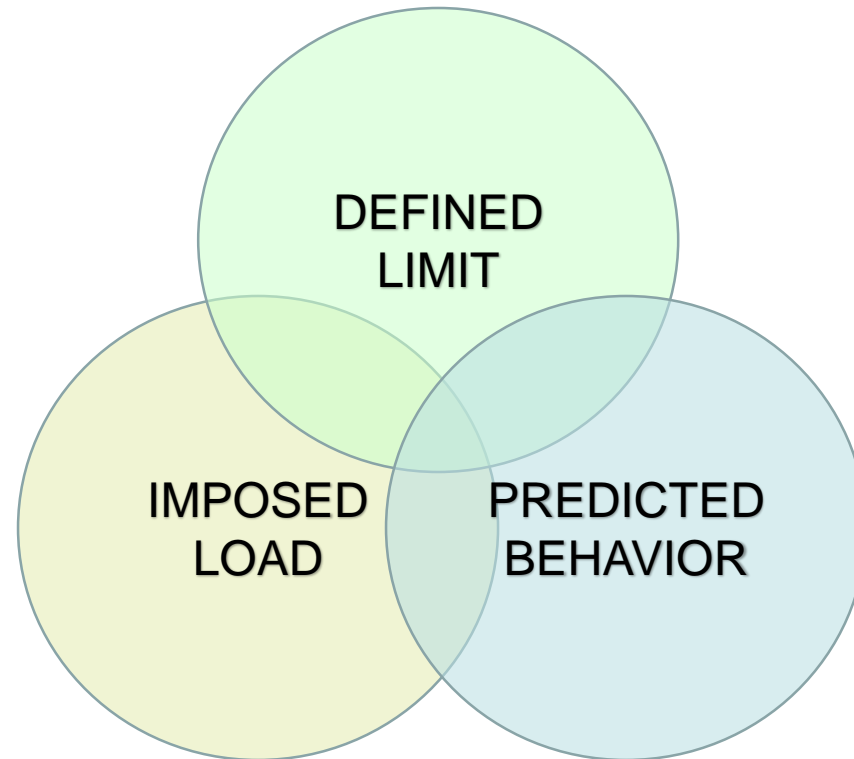


Serviceability Considerations for the Practicing Engineer



January 9, 2020
Emily Guglielmo, SE

Topics:

1. What is serviceability?
2. Serviceability load and limit states
3. Serviceability in concrete, steel, wood
4. Serviceability lessons learned
5. Serviceability and Building codes. Where do we go from here?

What is structural failure?

When a structure can no longer support the loads imposed by the intended use of the structure.



Photo credit: http://www.exponent.com/structural_failures/

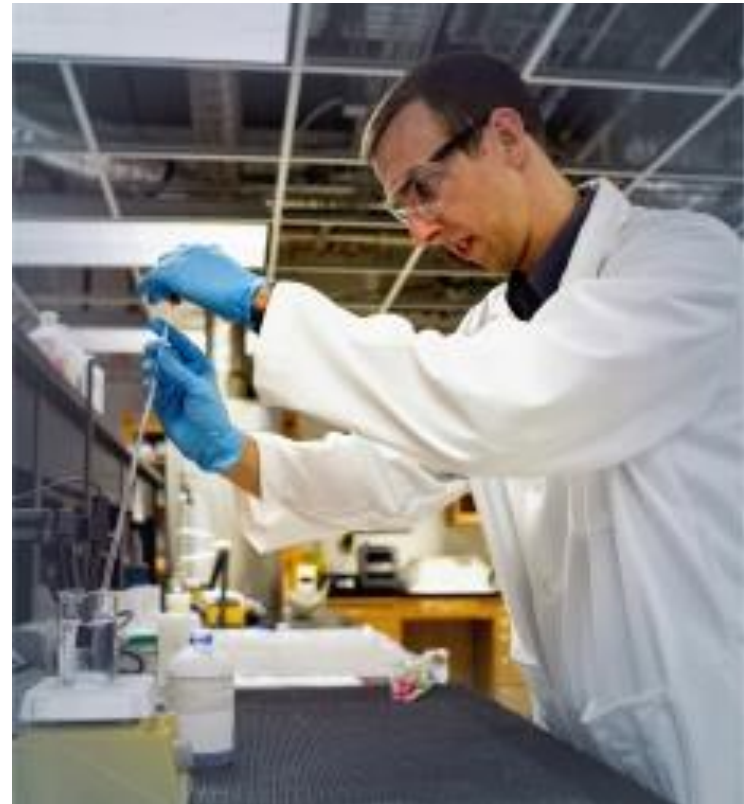
What is structural failure?

A significant reduction in the quality of the space caused by the movement or deterioration of the structural system.



What is structural failure to a lab technician?

The transient vibrations in the floor do not allow him to complete necessary experiments.



What is structural failure to an office building owner?

The floor deflections result in unlevel floors, which prevent the sale or lease of the building at a competitive price.

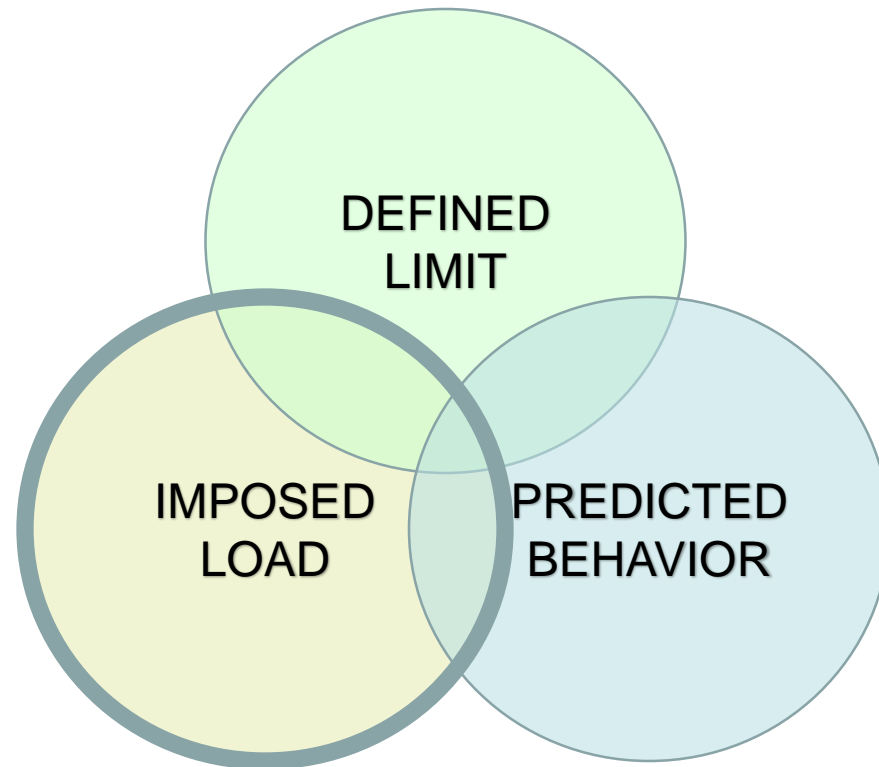


What is structural failure to an apartment building owner?

The number and size of cracks in the floors and walls of the apartment rooms result in lower occupancies and rent collected.



Photo credit: <http://www.diynetwork.com>



Service loads that may require consideration:

- Static loads from the occupants and their possessions
- Snow or rain on roofs
- Temperature fluctuations
- Dynamic loads from human activities, wind-induced effects, or the operation of building service equipment.



3 Limit States Loads

1. Ultimate Loads
2. Nominal Loads
3. Service Loads

Ultimate Loads

- Utilized for strength design in the IBC.
- Intended to be maximum loads imposed on the structure during its life.

$$1.4(D + F) \qquad \text{(Equation 16-1)}$$

$$1.2(D + F) + 1.6(L + H) + 0.5(L_r \text{ or } S \text{ or } R) \qquad \text{(Equation 16-2)}$$

$$1.2(D + F) + 1.6(L_r \text{ or } S \text{ or } R) + 1.6H + (f_1L \text{ or } 0.5W) \qquad \text{(Equation 16-3)}$$

$$1.2(D + F) + 1.0W + f_1L + 1.6H + 0.5(L_r \text{ or } S \text{ or } R) \qquad \text{(Equation 16-4)}$$

$$1.2(D + F) + 1.0E + f_1L + 1.6H + f_2S \qquad \text{(Equation 16-5)}$$

Nominal Loads

- Loads specified in Chapter 16 (except wind and seismic)
 - Live loads: Panel of experts
 - Snow loads: 50-year mean recurrence interval
 - Rain loads: Amount of rain water retained if the primary drainage system fails

Service Loads

- The service loads are those loads that act on the structure at an arbitrary point in time.
- Not defined or used in IBC.
- See ASCE 7-10, Appendix C Commentary

Appendix C

SERVICEABILITY CONSIDERATIONS

C. SERVICEABILITY CONSIDERATIONS

This appendix is not a mandatory part of the standard but provides guidance for design for serviceability in order to maintain the function of a building and the comfort of its occupants during normal usage. Serviceability limits (e.g., maximum static deformations, accelerations, etc.) shall be chosen with due regard to the intended function of the structure.

Serviceability shall be checked using appropriate loads for the limit state being considered.

discomfort or damage to the building, its appurtenances, or contents.

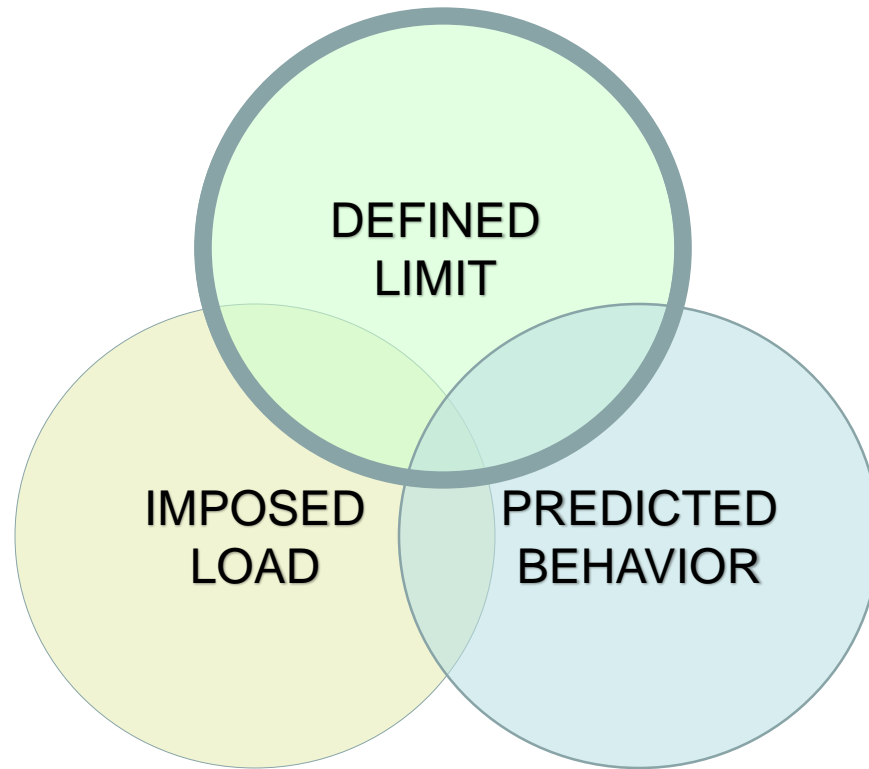
C.2 DESIGN FOR LONG-TERM DEFLECTION

Where required for acceptable building performance, members and systems shall be designed to accommodate long-term irreversible deflections under sustained load.

C.3 CAMBER

Special camber requirements that are necessary to

Ultimate	Nominal	Service
Small Probability of Being Exceeded in 50 Years	Small Probability of Being Exceeded in 1 Year	Loads Act on the Structure at an Arbitrary Point in Time



Serviceability Considerations

1. Short Term:

- Vertical Deflections
- Drift of Walls and Frames
- Vibrations

2. Long-Term Deflections

3. Expansion and Contraction

4. Durability

Load Combinations: Vertical Deflections

For serviceability limit states involving short-term effects, the suggested load combinations are:

$$D + L$$

$$D + 0.5S$$

For serviceability limit states involving creep, settlement, or similar long-term effects, the suggested load combination is:

$$D + 0.5L$$

** *Dead Load "D"* may be portion of dead load that occurs after attachment of nonstructural elements. **

Deflection Limits: Vertical Deflections

Limiting values of deformations depend on the type of structure, detailing, and intended use.

TABLE 1604.3
DEFLECTION LIMITS^{a, b, c, h, i}

CONSTRUCTION	<i>L</i>	<i>S</i> or <i>W</i> ^f	<i>D</i> + <i>L</i> ^{d, g}
Roof members: ^e			
Supporting plaster ceiling	<i>L</i> /360	<i>L</i> /360	<i>L</i> /240
Supporting nonplaster ceiling	<i>L</i> /240	<i>L</i> /240	<i>L</i> /180
Not supporting ceiling	<i>L</i> /180	<i>L</i> /180	<i>L</i> /120
Floor members	<i>L</i> /360	—	<i>L</i> /240
Exterior walls and interior partitions:			
With brittle finishes	—	<i>L</i> /240	—
With flexible finishes	—	<i>L</i> /120	—
Farm buildings	—	—	<i>L</i> /180
Greenhouses	—	—	<i>L</i> /120

General:		
<i>D</i> + <i>L</i>	→	<i>L</i> /240
<i>L</i>	→	<i>L</i> /360



Deflection Limits: Vertical Deflections

D+L: $L/240$

Except:

- Specific finishes may require alternate criteria
Ex: Members supporting marble, granite or ceramic
→ $L/720$ guidelines (verify with manufacturer)



- Metal roofing
→ $L/60$



Deflection Limits: Vertical Deflections

- Structural Steel or Joists, $DL = 0$
Generally only the live load limits are of concern.

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 ceiling	//360	//360	//240
Supporting nonplaster ceiling	//240	//240	//180
Not supporting ceiling	//180	//180	//120
Floor members	//360	—	//240
Exterior walls and interior partitions:			
With brittle finishes	—	//240	—
With flexible finishes	—	//120	—
Farm buildings	—	—	//180
Greenhouses	—	—	//120

- d. For wood structural members having a moisture content of less than 16 percent at time of installation and used under dry conditions, the deflection resulting from $L + 0.5D$ is permitted to be substituted for the deflection resulting from $L + D$.
- e. The above deflections do not ensure against ponding. Roofs that do not have sufficient slope or camber to assure adequate drainage shall be investigated for ponding. See Section 1611 for rain and ponding requirements and Section 1503.4 for roof drainage requirements.
- f. The wind load is permitted to be taken as 0.7 times the "component and cladding" loads for the purpose of determining deflection limits herein.
- g. For steel structural members, the dead load shall be taken as zero.
- h. For aluminum structural members or aluminum panels used in skylights and sloped glazing framing, roofs or walls of sunroom additions or patio covers,

Deflection Limits: Vertical Deflections

S17-99

T1604.3

Proponent: Hank Martin, American Iron and Steel Institute

Add a new footnote as follows:

TABLE 1604.3
DEFLECTION LIMITS ^{a,b,c}

CONSTRUCTION	L	S or W	D + L ^{d,f}
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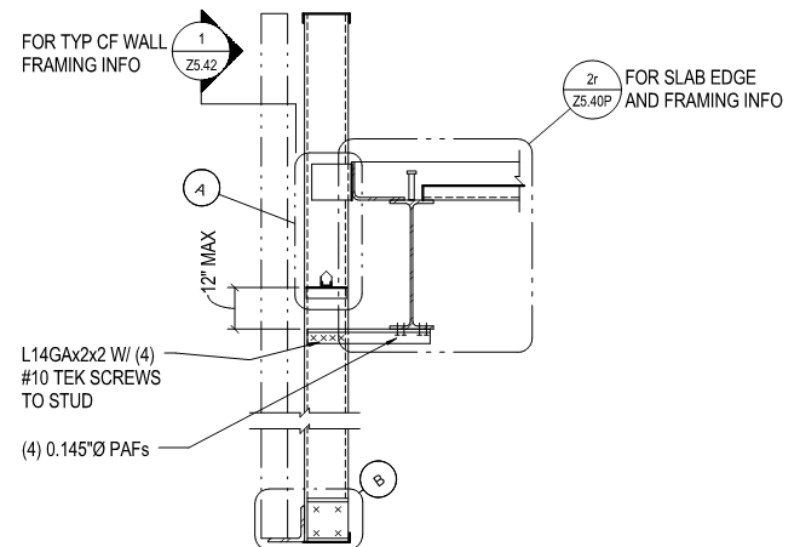
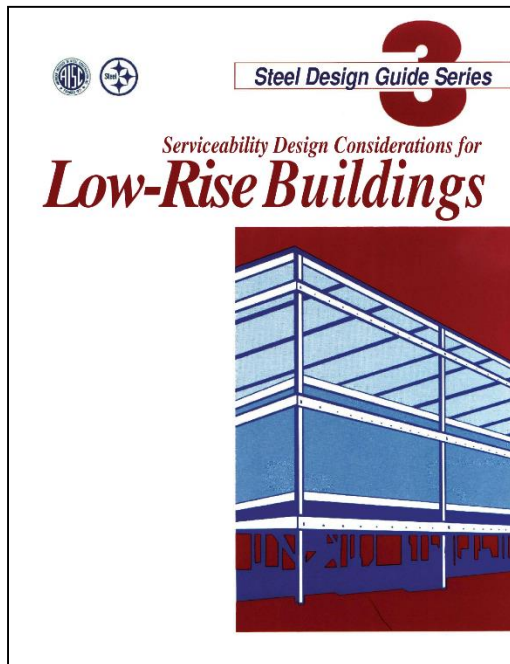
^f For steel structural members the dead load shall be taken as zero.

Reason: This table is a combination of the requirements in the *National Building Code* and the *Uniform Building Code*. Both the *National Building Code* and the *Standard Building Codes* establish deflection limits only under live load unless additional requirements are placed on a specific material by its associated design standards. The UBC establishes deflection limits under live load and dead load by the application of the load combination of L + KD. Table 16-E in the UBC establishes different K factors for wood, concrete and steel. The K factor for steel structures is set at zero. We believe the Table in the IBC has mistakenly added a requirement for steel structures that was never intended. The addition of Footnote "f" will bring the IBC back into conformance with current practice. To our knowledge steel structures have not nor are currently being designed to this more stringent criteria.

Deflection Limits: Vertical Deflections

D+L: $L/240$

- AISC design guide 3:
 - Partitions butting into perimeter walls, or
 - Spandrel panels are supported by floor framing.
→ More restrictive limits may be appropriate to mitigate non-structural damage to partitions and window frames.



Deflection Limits: Vertical Deflections

D+L: **L/240**

L/480 for concrete floors supporting brittle non-structural elements.

TABLE 9.5(b) — MAXIMUM PERMISSIBLE COMPUTED DEFLECTIONS

Type of member	Deflection to be considered	Deflection limitation
Flat roofs not supporting or attached to nonstructural elements likely to be damaged by large deflections	Immediate deflection due to live load L	$l/180^*$
Floors not supporting or attached to nonstructural elements likely to be damaged by large deflections	Immediate deflection due to live load L	$l/360$
Roof or floor construction supporting or attached to nonstructural elements likely to be damaged by large deflections	That part of the total deflection occurring after attachment of nonstructural elements (sum of the long-term deflection due to all sustained loads and the immediate deflection due to any additional live load) [†]	$l/480^‡$
Roof or floor construction supporting or attached to nonstructural elements not likely to be damaged by large deflections		$l/240^§$
<p>*Limit not intended to safeguard against ponding. Ponding should be checked by suitable calculations of deflection, including added deflections due to ponded water, and considering long-term effects of all sustained loads, camber, construction tolerances, and reliability of provisions for drainage.</p> <p>[†]Long-term deflection shall be determined in accordance with 9.5.2.5 or 9.5.4.3, but may be reduced by amount of deflection calculated to occur before attachment of nonstructural elements. This amount shall be determined on basis of accepted engineering data relating to time-deflection characteristics of members similar to those being considered.</p> <p>[‡]Limit may be exceeded if adequate measures are taken to prevent damage to supported or attached elements.</p> <p>[§]Limit shall not be greater than tolerance provided for nonstructural elements. Limit may be exceeded if camber is provided so that total deflection minus camber does not exceed limit.</p>		

Deflection Limits: Vertical Deflections

ROOFS: Live Load

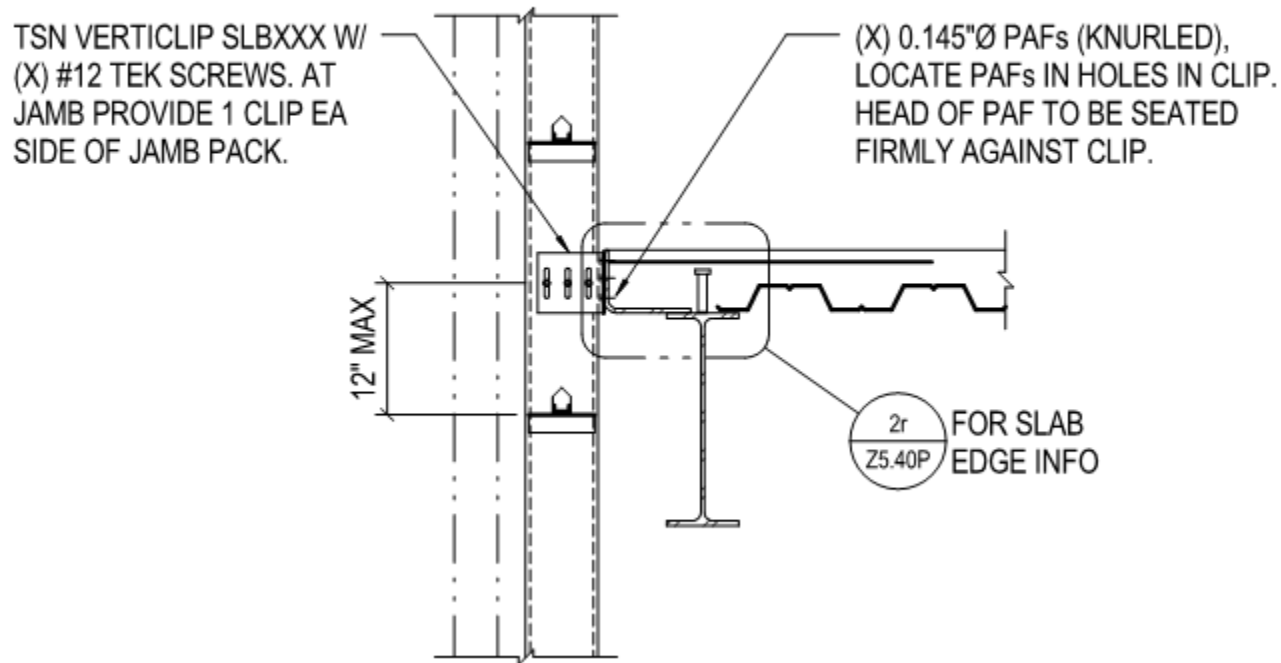
- Supporting plaster, Portland Cement stucco or gyp board ceilings
→ L/360
- Supporting other ceilings such as suspended ceilings
→ L/240
- No ceiling
→ L/180 for typical roofing
→ L/150 for metal roofing
- Concrete roofs supporting brittle non-structural elements
→ L/480

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 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 brittle finishes	—	L/240	—
With flexible finishes	—	L/120	—
Farm buildings	—	—	L/180
Greenhouses	—	—	L/120

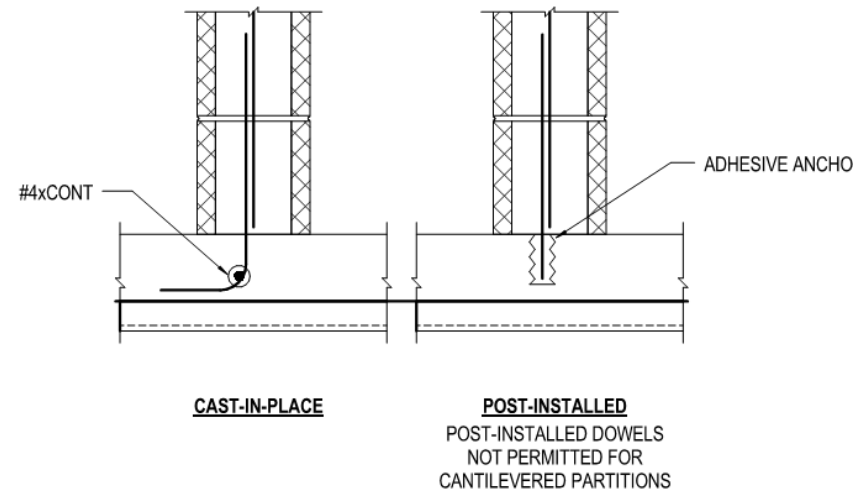
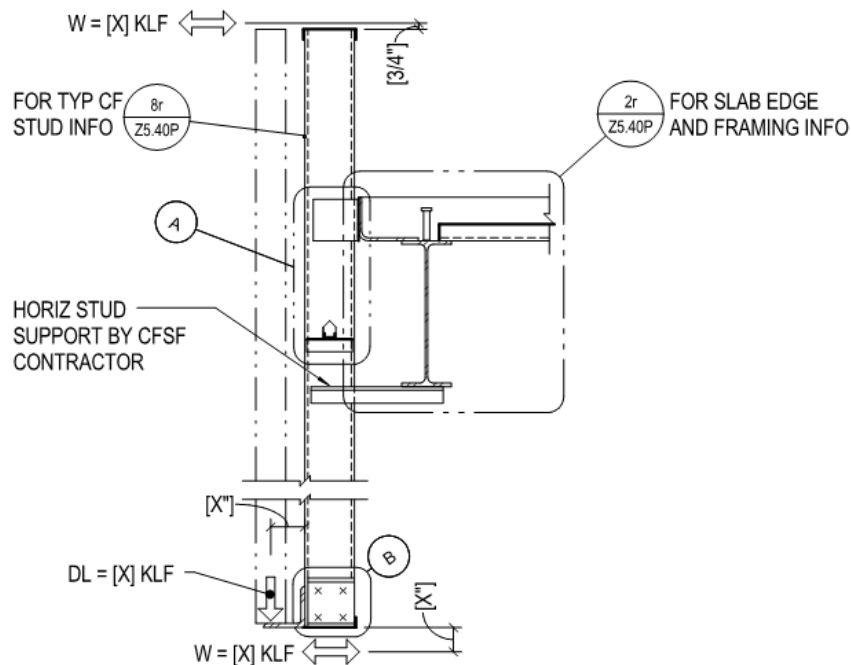
Deflection Limits: Vertical Deflections

- Spandrels with bypass exterior wall:
→ Live Load: $L/360$ but not more than $3/8$ "



Deflection Limits: Vertical Deflections

- Members supporting unreinforced masonry, brick or stucco:
 - $L/600$
 - Consider added control joints to capture cracks.
- Members supporting reinforced masonry can be relaxed.
 - $L/600$ is often still used to limit cracking.



Deflection Limits: Vertical Deflections

- Elevator sheave beams and members supporting sheave beams
→ $L/1666$
- Elevator rails supports
→ Maximum deflection of $1/8''$ (Laterally under horizontal rail load)



Deflections/ Serviceability

General Serviceability/ Deflections References:

Ad Hoc Committee on Serviceability Research. (1986). "Structural serviceability: A critical appraisal and research needs." *J. Struct. Engrg.*, 112(12), 2646–2664.

Cooney, R. C., and King, A. B. (1988). "Serviceability criteria for buildings." BRANZ Report SR14, Building Research Association of New Zealand, Porirua, New Zealand.

Ellingwood, B. (1989). "Serviceability guidelines for steel structures." *Engineering J.*, 26(1), 1–8.

Freeman, S. A. (1977). "Racking tests of high-rise building partitions." *J. Struct. Div.*, 103(8), 1673–1685.

Galambos, T. U., and Ellingwood, B. (1986). "Serviceability limit states: Deflection." *J. Struct. Engrg.* 112(1), 67–84.

International Organization for Standardization (ISO). (1977). "Bases for the design of structures—Deformations of buildings at the serviceability limit states," ISO 4356, International Organization for Standardization.

National Building Code of Canada. (1990). Commentary A, serviceability criteria for deflections and vibrations, National Research Council, Ottawa, Ontario.

West, Michael, and Fisher, James. (2003). *Serviceability design considerations for steel buildings*, second ed., Steel Design Guide No. 3, American Institute of Steel Construction, Chicago.

Drift of Walls and Frames

Appendix C

SERVICEABILITY CONSIDERATIONS

C. SERVICEABILITY CONSIDERATIONS

This appendix is not a mandatory part of the standard but provides guidance for design for serviceability in order to maintain the function of a building and the comfort of its occupants during normal usage. Serviceability limits (e.g., maximum static deformations, accelerations, etc.) shall be chosen with due regard to the intended function of the structure.

Serviceability shall be checked using appropriate loads for the limit state being considered.

C.1 DEFLECTION, VIBRATION, AND DRIFT

C.1.1 Vertical Deflections

Deformations of floor and roof members and systems due to service loads shall not impair the serviceability of the structure.

C.1.2 Drift of Walls and Frames

Lateral deflection or drift of structures and deformation of horizontal diaphragms and bracing systems due to wind effects shall not impair the serviceability of the structure.

C.1.3 Vibrations

Floor systems supporting large open areas free of partitions or other sources of damping, where vibration due to pedestrian traffic might be objectionable, shall be designed with due regard for such vibration.

Mechanical equipment that can produce objectionable vibrations in any portion of an inhabited structure shall be isolated to minimize the transmission of such vibrations to the structure.

Building structural systems shall be designed so that wind-induced vibrations do not cause occupant

discomfort or damage to the building, its appearances, or contents.

C.2 DESIGN FOR LONG-TERM DEFLECTION

Where required for acceptable building performance, members and systems shall be designed to accommodate long-term irreversible deflections under sustained load.

C.3 CAMBER

Special camber requirements that are necessary to bring a loaded member into proper relations with the work of other trades shall be set forth in the design documents.

Beams detailed without specified camber shall be positioned during erection so that any minor camber is upward. If camber involves the erection of any member under preload, this shall be noted in the design documents.

C.4 EXPANSION AND CONTRACTION

Dimensional changes in a structure and its elements due to variations in temperature, relative humidity, or other effects shall not impair the serviceability of the structure.

Provision shall be made either to control crack widths or to limit cracking by providing relief joints.

C.5 DURABILITY

Buildings and other structures shall be designed to tolerate long-term environmental effects or shall be protected against such effects.

Commentary Appendix C

SERVICEABILITY CONSIDERATIONS

CC. SERVICEABILITY CONSIDERATIONS

Serviceability limit states are conditions in which the functions of a building or other structure are impaired because of local damage, deterioration, or deformation of building components, or because of occupant discomfort. Although safety generally is not an issue with serviceability limit states (one exception would be for cladding that falls off a building due to excessive story drift under wind load), they nonetheless may have severe economic consequences. The increasing use of the computer as a design tool, the use of stronger (but not stiffer) construction materials, the use of lighter architectural elements, and the uncoupling of the nonstructural elements from the structural frame may result in building systems that are relatively flexible and lightly damped. Limit state design emphasizes the fact that serviceability criteria (as they always have been) are essential to ensure functional performance and economy of design for such building structural systems (Ad Hoc Committee on Serviceability Research 1986, National Building Code of Canada 1990, and West and Fisher 2003).

In general, serviceability is diminished by

1. Excessive deflections or rotation that may affect the appearance, functional use, or drainage of the structure or may cause damaging transfer of load to nonload supporting elements and attachments;
2. Excessive vibrations produced by the activities of building occupants, mechanical equipment, or the wind, which may cause occupant discomfort or malfunction of building service equipment; and
3. Deterioration, including weathering, corrosion, rotting, and discoloration.

In checking serviceability, the designer is advised to consider appropriate service loads, the response

of a small probability of being exceeded in 50 years.) Appropriate service loads for checking serviceability limit states may be only a fraction of the nominal loads.

The response of the structure to service loads normally can be analyzed assuming linear elastic behavior. However, members that accumulate residual deformations under service loads may require examination with respect to this long-term behavior. Service loads used in analyzing creep or other long-term effects may not be the same as those used to analyze elastic deflections or other short-term or reversible structural behavior.

Serviceability limits depend on the function of the building and on the perceptions of its occupants. In contrast to the ultimate limit states, it is difficult to specify general serviceability limits that are applicable to all building structures. The serviceability limits presented in Sections CC.1.1, CC.1.2, and CC.1.3 provide general guidance and have usually led to acceptable performance in the past. However, serviceability limits for a specific building should be determined only after a careful analysis by the engineer and architect of all functional and economic requirements and constraints in conjunction with the building owner. It should be recognized that building occupants are able to perceive structural deflections, motion, cracking, and other signs of possible distress at levels that are much lower than those that would indicate that structural failure was impending. Such signs of distress may be taken incorrectly as an indication that the building is unsafe and diminish its commercial value.

CC.1.1 Vertical Deflections

Excessive vertical deflections and misalignment arise primarily from three causes: (1) gravity loads

Drift of Walls and Frames

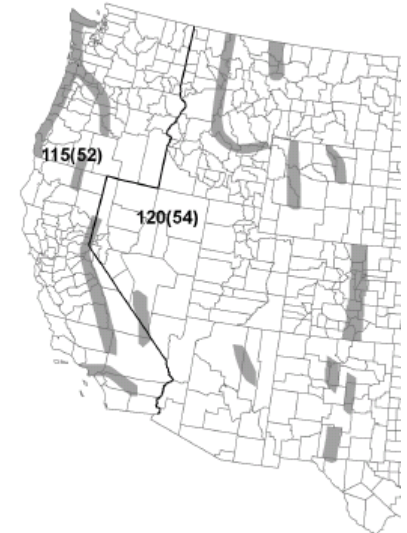
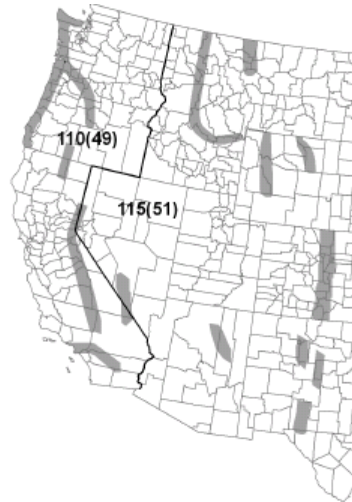
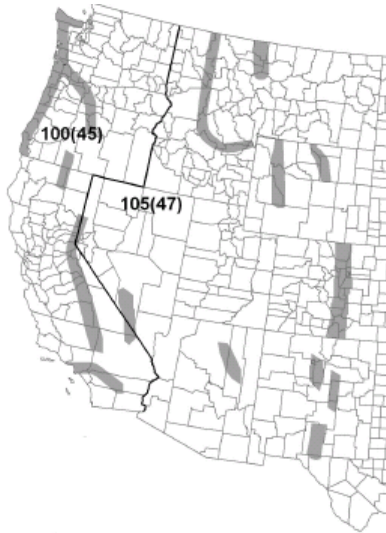
Use of the nominal (700-year mean recurrence interval (MRI) or 1,700-year MRI) wind load in checking serviceability is excessively conservative. The following load combination, derived similarly to Eqs. CC-1a and CC-1b, can be used to check short-term effects:

$$D + 0.5L + W_a \quad (\text{CC-3})$$

in which W_a is wind load based on serviceability wind speeds in Figs. CC-1 through CC-4. Some designers have used a 10-year MRI (annual probability of 0.1) for checking drift under wind loads for typical buildings (Griffis 1993), whereas others have used a 50-year MRI (annual probability of 0.02) or a 100-year MRI (annual probability of 0.01) for more drift-sensitive buildings. The selection of the MRI for serviceability evaluation is a matter of engineering judgment that should be exercised in consultation with the building client.

Drift of Walls and Frames

$$D + 0.5L + W_a$$



Occupancy/ Risk
Category I

300-year return period

ASCE 7-05 $I=0.87$ or 0.77

Occupancy/ Risk
Category II

700-year return period

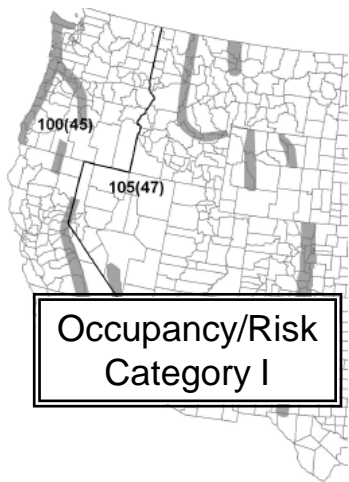
ASCE 7-05 $I=1.0$

Occupancy/ Risk Category
III, IV

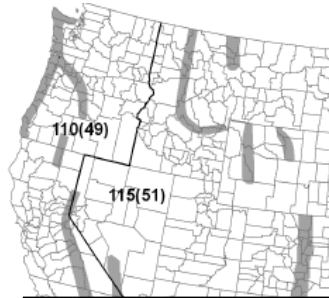
1700-year return period

ASCE 7-05 $I=1.15$

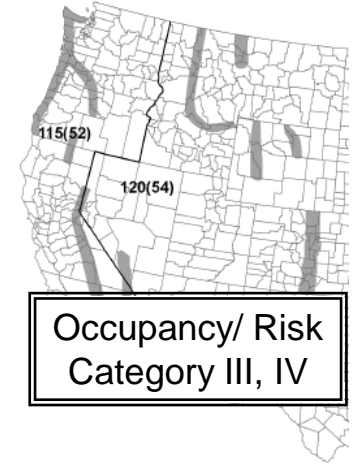
Drift of Walls and Frames



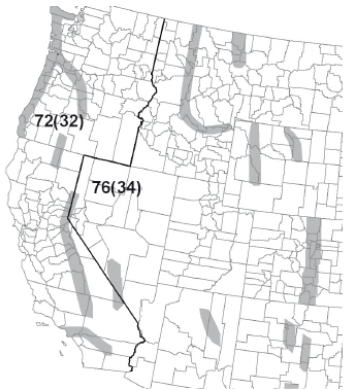
Occupancy/Risk
Category I



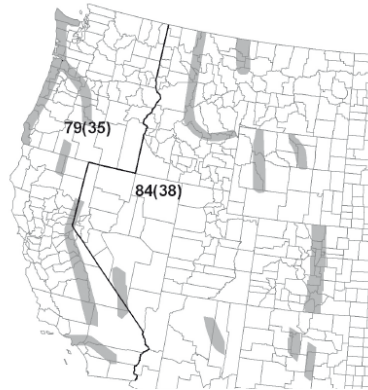
Occupancy/ Risk
Category II



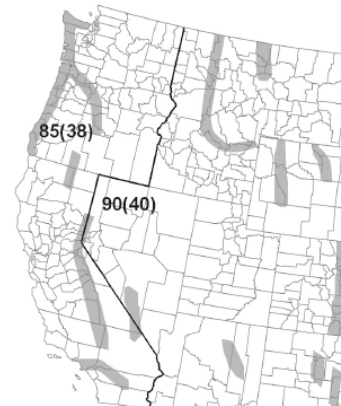
Occupancy/ Risk
Category III, IV



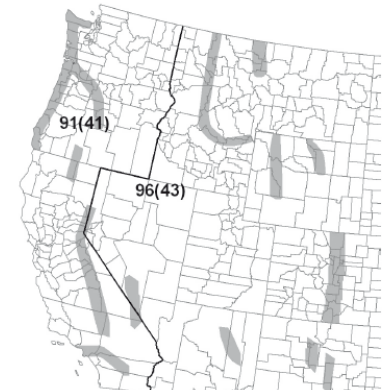
10-year return
period



25-year return
period



50-year return
period



100-year return
period

Drift of Walls and Frames

TABLE 1604.3
DEFLECTION LIMITS^{a, b, c, e, h, i}

CONSTRUCTION	<i>L</i>	<i>E, S or W^f</i>	<i>D + L^{d, g}</i>
Roof members: ^c			
Supporting plaster or stucco ceiling	<i>l</i> /360	<i>l</i> /360	<i>l</i> /240
Supporting nonplaster ceiling	<i>l</i> /240	<i>l</i> /240	<i>l</i> /180
Not supporting ceiling	<i>l</i> /180	<i>l</i> /180	<i>l</i> /120
Floor members	<i>l</i> /360	—	<i>l</i> /240
Exterior walls:			
With plaster or stucco finishes	—	<i>l</i> /360	—
With other brittle finishes	—	<i>l</i> /240	—
With flexible finishes	—	<i>l</i> /120	—
Interior partitions: ^b			
With plaster or stucco finishes	<i>l</i> /360	—	—
With other brittle finishes	<i>l</i> /240	—	—
With flexible finishes	<i>l</i> /120	—	—
Farm buildings	—	—	<i>l</i> /180
Greenhouses	—	—	<i>l</i> /120

For SI: 1 foot = 304.8 mm.

- a. For structural roofing and siding made of formed metal sheets, the total load deflection shall not exceed *l*/60. For secondary roof structural members supporting formed metal roofing, the live load deflection shall not exceed *l*/150. For secondary wall members supporting formed metal siding, the design wind load deflection shall not exceed *l*/90. For roofs, this exception only applies when the metal sheets have no roof covering.
- b. Flexible, folding and portable partitions are not governed by the provisions of this section. The deflection criterion for interior partitions is based on the horizontal load defined in Section 1607.14.
- c. See Section 2403 for glass supports.
- 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 0.5*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 AWC NDS provisions for long-term loading.
- e. The above deflections do not ensure against ponding. Roofs that do not have sufficient slope or camber to ensure adequate drainage shall be investigated for ponding. See Section 1611 for rain and ponding requirements and Section 1503.4 for roof drainage requirements.
- f. The wind load is permitted to be taken as 0.42 times the "component and cladding" loads for the purpose of determining deflection limits herein. Where members support glass in accordance with Section 2403 using the deflection limit therein, the wind load shall be no less than 0.6 times the "component and cladding" loads for the purpose of determining deflection.
- g. For steel structural members, the dead load shall be taken as zero.
- h. For aluminum structural members or aluminum panels used in skylights and sloped glazing framing, roofs or walls of sunroom additions or patio covers not supporting edge of glass or aluminum sandwich panels, the total load deflection shall not exceed *l*/60. For continuous aluminum structural members supporting edge of glass, the total load deflection shall not exceed *l*/175 for each glass lite or *l*/60 for the entire length of the member, whichever is more stringent. For aluminum sandwich panels used in roofs or walls of sunroom additions or patio covers, the total load deflection shall not exceed *l*/120.
- i. For cantilever members, *l* shall be taken as twice the length of the cantilever.

"Wind load
0.42 C&C
for
deflection"

Drift of Walls and Frames

115 mph, Exposure C, Ht= 80 ft, Risk Category II, Zone 4

ASCE 7-10 x 0.42

$$\rho = p_{\text{table}}(\text{EAF})(\text{RF})K_{\text{zt}} = (0.97)(37.5\text{psf}) = 36.4 \text{ psf}$$

$$W = .42 \times 36.4 = 15.3 \text{ psf}$$

Serviceability Maps:

$$10\text{-year: } 36.4 \text{ psf } (76/115)^2 = 15.9 \text{ psf}$$

$$25\text{-year: } 36.4 \text{ psf } (84/115)^2 = 19.4 \text{ psf}$$

$$50\text{-year: } 36.4 \text{ psf } (90/115)^2 = 22.3 \text{ psf}$$

$$100\text{-year: } 36.4 \text{ psf } (96/115)^2 = 25.4 \text{ psf}$$

TABLE 1604.3
DEFLECTION LIMITS^{a, b, c, d, e, f, g, h, i}

CONSTRUCTION	L	S or W ^f	D + L ^{g, h}
Roof members ^a			
Supporting plaster or stucco ceiling	f/360	f/360	f/240
Supporting nonplaster ceiling	f/240	f/240	f/180
Not supporting ceiling	f/180	f/180	f/120
Floor members	f/360	—	f/240
Exterior walls and interior partitions:			
With plaster or stucco finishes	—	f/360	—
With other brittle finishes	—	f/240	—
With flexible finishes	—	f/120	—
Farm buildings ^g	—	—	f/180
Greenhouses	—	—	f/120

For SI: 1 foot = 304.8 mm.

- For structural roofing and siding made of formed metal sheets, the total load deflection shall not exceed f/60. For secondary roof structural members supporting formed metal roofing, the live load deflection shall not exceed f/150. For secondary wall members supporting formed metal siding, the design wind load deflection shall not exceed f/50. For roofs, this exception only applies when the metal sheets have no roof covering.
- Interior partitions not exceeding 8 feet in height and flexible, folding and portable partitions are not governed by the provisions of this section. The deflection criterion for interior partitions is based on the horizontal load defined in Section 1607.14.
- See Section 2403 for glass supports.
- For wood structural members having a moisture content of less than 16 percent at time of installation and used under dry conditions, the deflection resulting from $L + 0.5D$ is permitted to be substituted for the deflection resulting from $L + D$.
- The above deflections do not ensure against ponding. Roofs that do not have sufficient slope or camber to assure adequate drainage shall be investigated for ponding. See Section 1611 for rain and ponding requirements and Section 1603.4 for roof drainage requirements.
- The wind load is permitted to be taken as 0.42 times the "component and cladding" loads for the purpose of determining deflection limits herein.
- For steel structural members, the dead load shall be taken as zero.
- For aluminum structural members or aluminum panels used in skylights and sloped glazing framing, roofs or walls of sunroom additions or patio covers, not supporting edge of glass, the total load deflection shall not exceed f/175 for each glass lite or f/60 for the entire length of the member, whichever is more stringent. For aluminum sandwich panels used in roofs or walls of sunroom additions or patio covers, the total load deflection shall not exceed f/120.
- For cantilever members, f shall be taken as twice the length of the cantilever.



Deflection Limits: Drift

- Drift limits in common usage for building are on the order of **1/600 to 1/400** of the building or story height.
- An absolute limit on *story drift* may also be needed due to reduce damage (nonstructural partitions, cladding, and glazing) which may occur if the story drift exceeds **3/8 in.**

Deflection Limits: Drift

- Density reduction for wind?

27.3.2 Velocity Pressure

Velocity pressure, q_z , evaluated at height z shall be calculated by the following equation:

$$q_z = 0.00256K_cK_dK_eK_gV^2 \text{ (lb/ft}^2\text{)} \quad (27.3-1)$$

The numerical constant of 0.00256 should be used except where sufficient weather data are available to justify a different value of this constant for a specific design application. The mass density of air will vary as a function of altitude, latitude, temperature, weather, and season. Average and extreme values of air density are given in Table C27.3-2.

- Use of $I = 1.0$ for components and cladding deflections even when building $I > 1.0$
→ Deflection limits are generally not a life safety issue.

Deflection Limits: Drift

- Members supporting anchored veneer
→ L/600 (BIA TEK note 28B).

Do not reduce to 0.42W based on BIA recommendations.

- Members supporting Portland cement or Gypsum Stucco
→ L/600
- Members supporting adhered veneer, synthetic (flexible) stucco/EFIS, gyp board and tile
→ L/360.
- Members supporting metal wall panels
→ L/180



Deflection Limits: Drift

Wind Serviceability Resources:

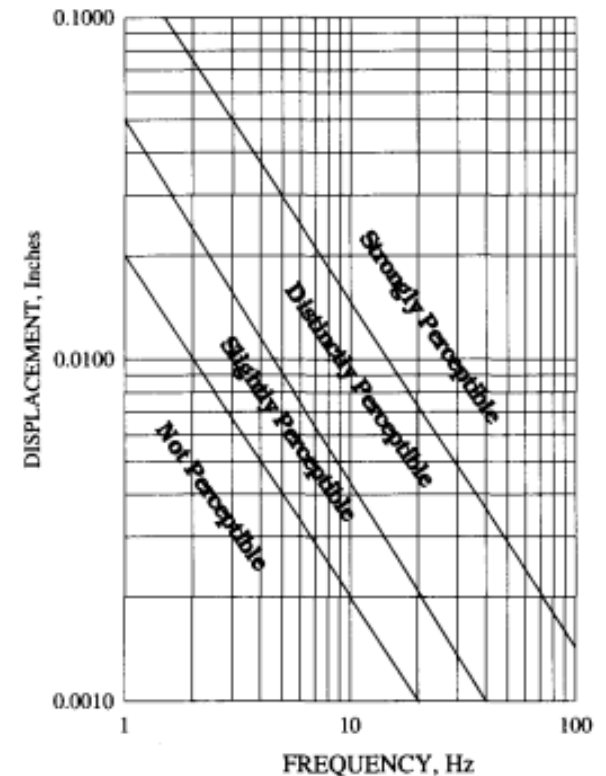
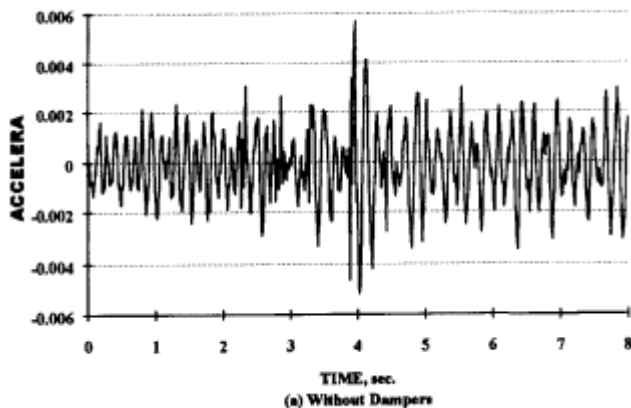
ASCE Task Committee on Drift Control of Steel Building Structures. (1988). “Wind drift design of steel-framed buildings: State-of-the-art report.” J. Struct. Engrg., 114(9), 2085–2108.

Griffis, L. G. (1993). “Serviceability limit states under wind load.” Engineering J., 30(1), 1–16.

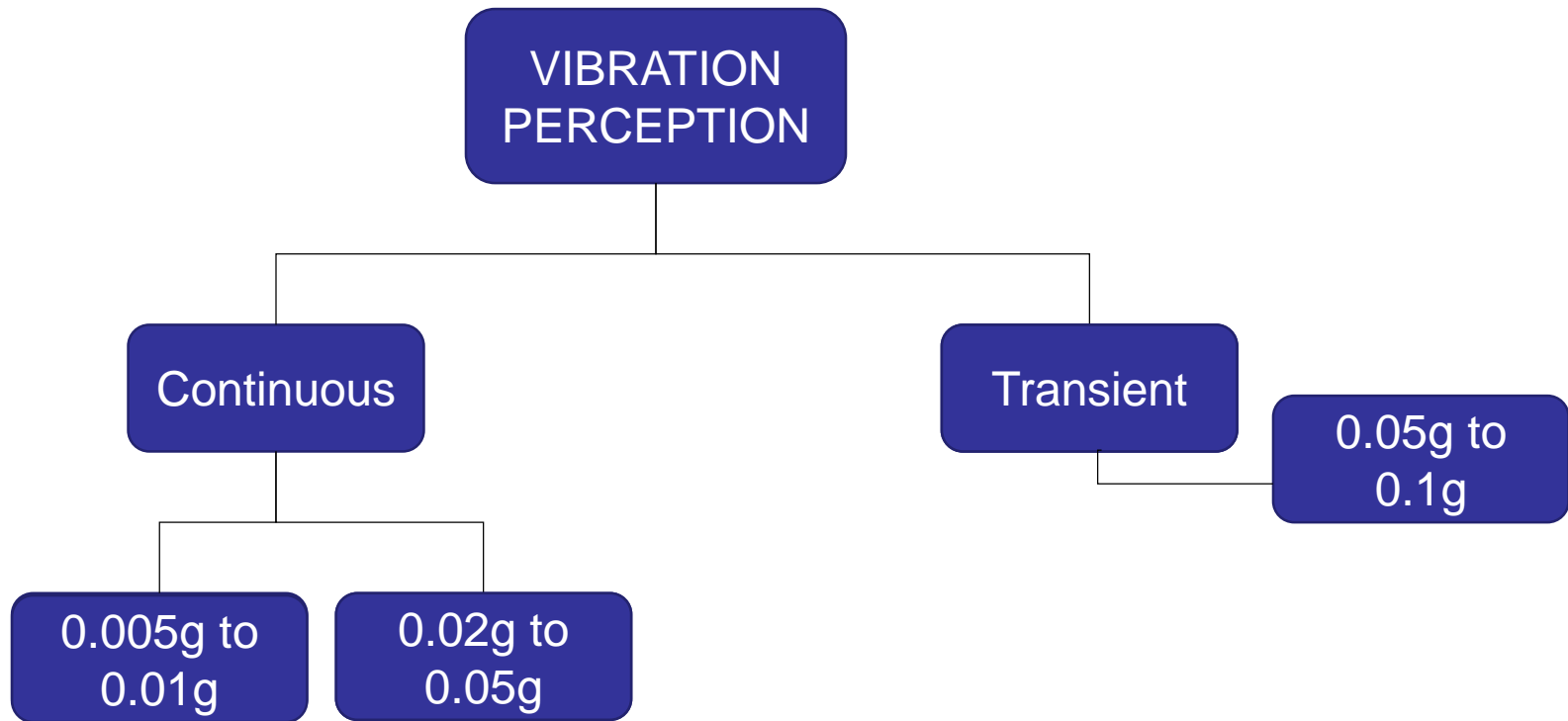
Tallin, A. G., and Ellingwood, B. (1984). “Serviceability limit states: Wind induced vibrations.” J. Struct. Engrg., 110(10), 2424–2437.

Vibration

- In recent years vibration complaints have increased.
- Traditional static deflection checks do not cover vibration concerns.



Vibration



Vibration

- Human activity imparts dynamic forces at frequencies of 2-6 Hz.
- If the fundamental frequency of the floor matches this range resonance may occur.
- The natural frequency of structure should be at least 2x the frequency of excitation.



→ Tune the system away from this range.

Table 5.2
Estimated Loading During Rhythmic Events

Activity	Forcing Frequency f , Hz	Weight of Participants* w_p		Dynamic Coefficient α	Dynamic Load α/w_p	
		kPa	psf		kPa	psf
Dancing: First Harmonic	1.5-3	0.6	12.5	0.5	0.3	6.2
Lively concert or sports event: First Harmonic	1.5-3	1.5	31.0	0.25	0.4	7.8
Second Harmonic	3-5	1.5	31.0	0.05	0.075	1.6
Jumping exercises: First Harmonic	2-2.75	0.2	4.2	1.5	0.3	6.3
Second Harmonic	4-5.5	0.2	4.2	0.6	0.12	2.5
Third Harmonic	6-8.25	0.2	4.2	0.1	0.020	0.42

* Based on maximum density of participants on the occupied area of the floor for commonly encountered conditions. For special events the density of participants can be greater.

Vibration

Increase Stiffness: Minimize vibrations by controlling the deflection (independent of span).

Fundamental frequency $f_o = \frac{\pi}{2l^2} \sqrt{\frac{EI}{\rho}}$ $f_o = \frac{\pi}{2l^2} \sqrt{\frac{EI}{w/g}}$

Deflection $\delta = \frac{5wl^4}{384EI}$

$$EI = \frac{5wl^4}{384\delta}$$

$$f_o = \frac{\pi}{2l^2} \sqrt{\frac{5wl^4}{384\delta} \frac{1}{w/g}} = \frac{18}{\sqrt{\delta}}$$



Limit the deflection to an absolute value rather than a fraction of the span (L/X)

Vibration

- Human activity: Assume 4 Hz
- Floor system to be 2 times excitation frequency
- Prefer a floor system with a frequency greater than 8 Hz.

$$f_o = \frac{18}{\sqrt{\delta}} = 8$$

→ The static deflection due to uniform load must be limited to about **0.20 in.** if the frequency of the floor system is to be kept above 8 Hz.

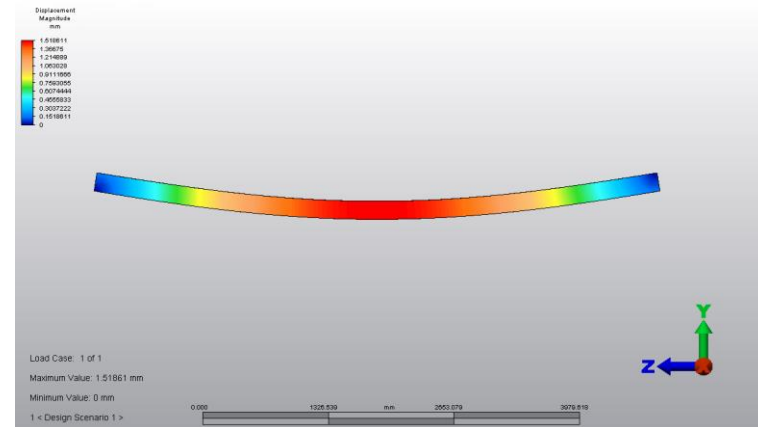
Vibration

Vibration References:

- Allen, D. E. (1990a). "Floor vibrations from aerobics." *Can. J. Civ. Engrg.*, 19(4), 771–779.
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- Allen, D. E., and Murray, T. M. (1993). "Design criterion for vibrations due to walking." *Engineering J.*, 30(4), 117–129.
- Allen, D. E., and Rainer, J. H. (1976). "Vibration criteria for long-span floors." *Can. J. Civ. Engrg.*, 3(2), 165–173.
- Allen, D. E., Rainer, J. H., and Pernica, G. (1985). "Vibration criteria for assembly occupancies." *Can. J. Civ. Engrg.*, 12(3), 617–623.
- American National Standards Institute (ANSI). (1983). *Guide to the evaluation of human exposure to vibration in buildings, ANSI S3.29-1983*, American National Standards Institute, New York.
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- Ellingwood, B., and Tallin, A. (1984). "Structural serviceability: Floor vibrations." *J. Struct. Engrg.*, 110(2), 401–418.
- Murray, T. (1991). "Building floor vibrations." *Engineering J.*, 28(3), 102–109.
- Ohlsson, S. (1988). "Ten years of floor vibration research—A review of aspects and some results." *Proceedings, Symposium on Serviceability of Buildings*, National Research Council of Canada, Ottawa, 435–450.

Long Term Deflection

- Under sustained loads, structural members may experience time-dependent deformations due to *creep*.
- Use a multiplier on immediate deflections.
 - Provided in material standards (1.5 to 2.0.)
 - Use load combination $D + 0.5L$



Expansion and Contraction

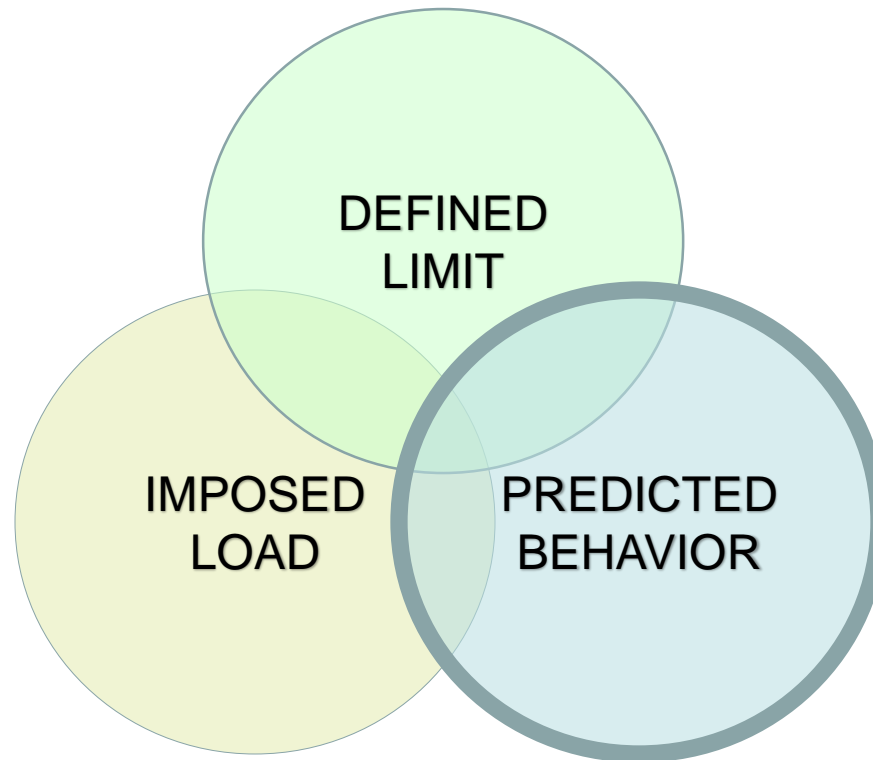
- Designs should consider dimensional changes due to expansion or contraction.
- Provide for such effects through relief joints or controlling crack widths.
- Restraint of thermal, shrinkage, prestressing.



Durability

- Buildings may deteriorate in certain service environments.
- May be visible upon inspection (weathering, corrosion, staining) or may be undetectable visually.
- Designer should provide a specific amount of damage tolerance in design or specify adequate protection system or planned maintenance.





Concrete: Immediate Deflections

Two Options (One-Way, Non-Prestressed):

- 1) Minimum thickness from table
- 2) Calculate deflections per equations.

$$I_e = \left(\frac{M_{cr}}{M_a}\right)^3 I_g + \left[1 - \left(\frac{M_{cr}}{M_a}\right)^3\right] I_{cr} \quad (9-8)$$

where

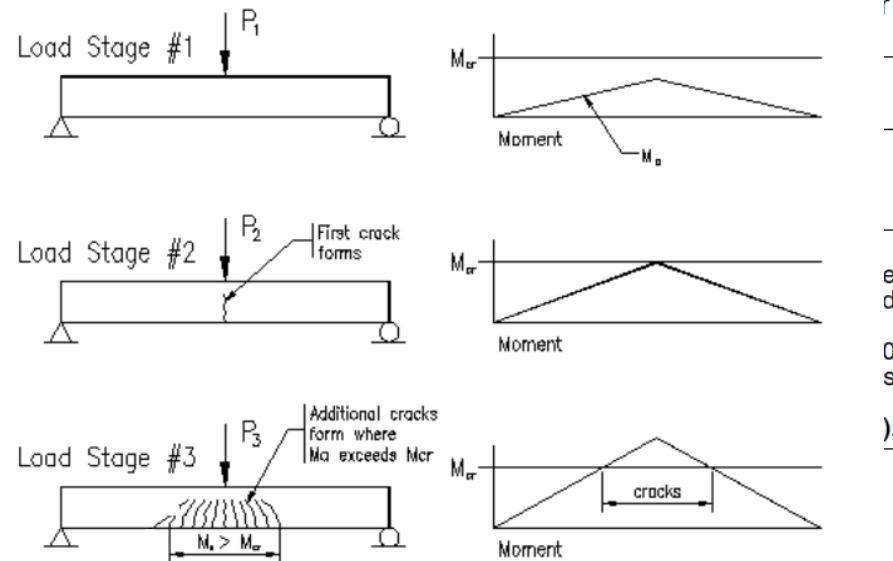
$$M_{cr} = \frac{f_r I_g}{y_t} \quad (9-9)$$

and

$$f_r = 7.5 \lambda \sqrt{f'_c} \quad (9-10)$$

TABLE 9.5(a) — MINIMUM THICKNESS OF NONPRESTRESSED BEAMS OR ONE-WAY SLABS UNLESS DEFLECTIONS ARE CALCULATED

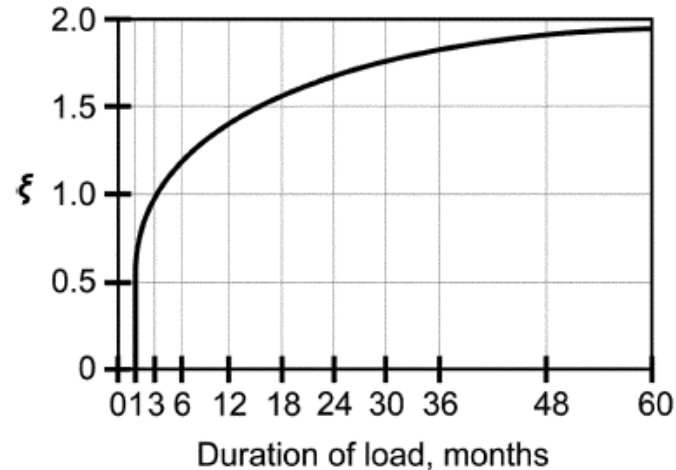
	Minimum thickness, h			
	Simply supported	One end continuous	Both ends continuous	Cantilever



Concrete: Creep and Shrinkage

- Time Effects: Creep and shrinkage

$$\lambda_{\Delta} = \frac{\xi}{1 + 50\rho'}$$



Concrete: Lateral Drift

- Section 10.10.4: Elastic second order analysis related to drift
 - Problem: “EI” for strength design (assume cracked sections)
 - Very conservative for wind drift

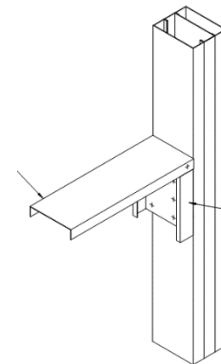
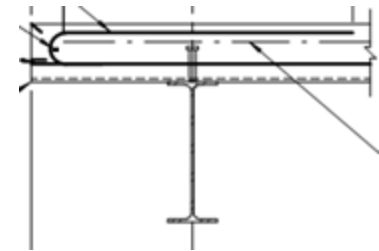
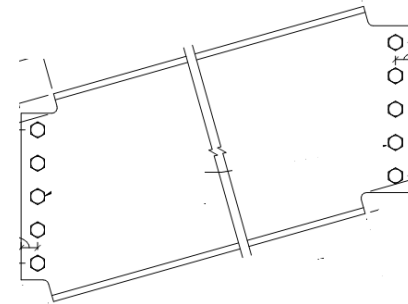
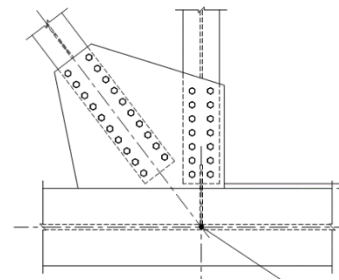
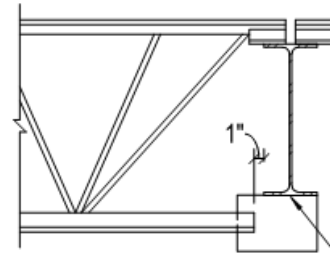
10.10.4.1 — It shall be permitted to use the following properties for the members in the structure:

(a) Modulus of elasticity.....	E_c from 8.5.1
(b) Moments of inertia, I	
Compression members:	
Columns	$0.70I_g$
Walls—Uncracked	$0.70I_g$
—Cracked.....	$0.35I_g$
Flexural members:	
Beams	$0.35I_g$
Flat plates and flat slabs.....	$0.25I_g$
(c) Area.....	$1.0A_g$

- Unless a more accurate estimate of the degree of cracking at service load level is available, it is satisfactory to use $I = 1.43I_{cr}$

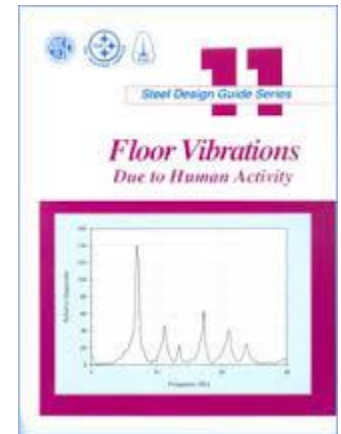
Steel

- Rolled structural steel
- Open-web joists
- Composite steel
- Fabricated trusses
- Cold-formed steel

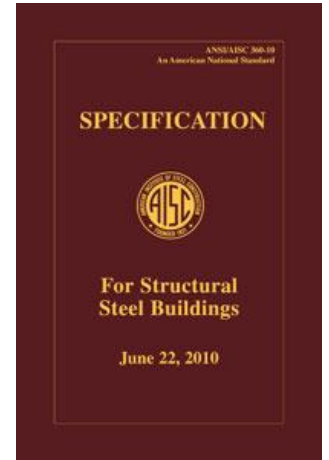


Steel: Non-Composite

- Deflection
- Vibration
- No significant time effects
- Assumed to act elastically at service level

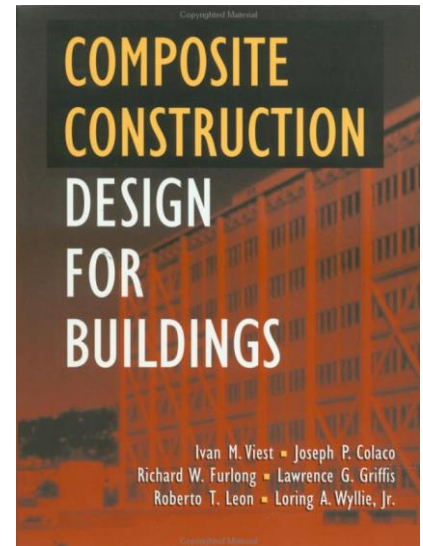


Steel: Composite



- Similar to non-composite design
 - Camber: Counteract deflections due to self-weight of structure
- AISC 360 Section L.3: “additional deflections due to shrinkage and creep of the concrete should be considered.”
- AISC 360 Commentary L3.2: “in the US shrinkage and creep of the concrete flange is generally not considered.”

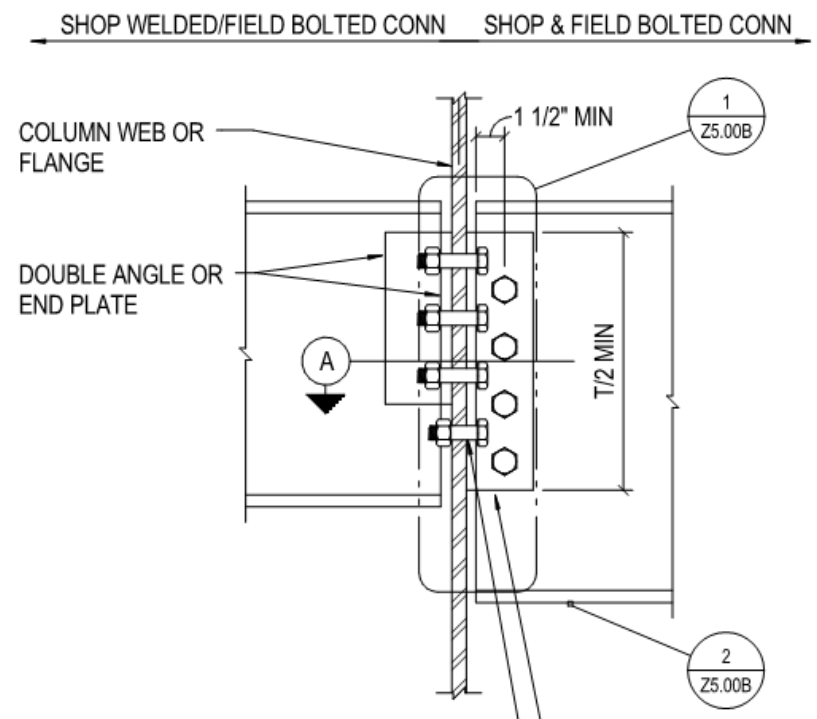
Steel: Composite



- Long-term deflection due to shrinkage significant? → $L/1200$ to $L/1000$.
- Simplified method of predicting additional deflection due to beam shrinkage by modeling shrinkage strain as a compressive force in the slab.
- Suggestion: Long-term deflections due to creep/shrinkage are usually small and can be ignored.
 - Consideration for long spans, high sustained loads, high composite action.

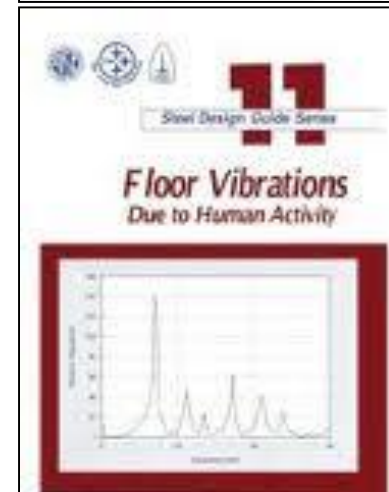
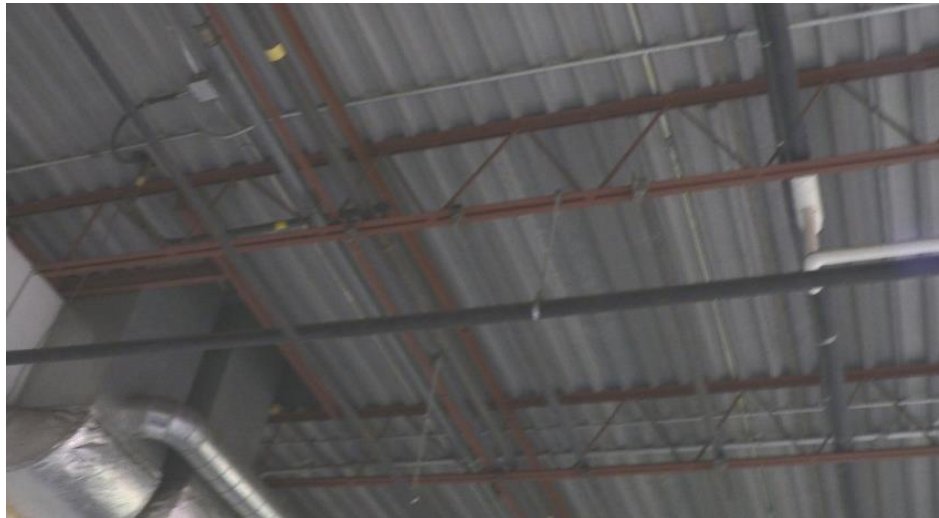
Steel: “Pinned” Connections

- At ultimate levels, bolted connections behave as pinned.
- At service levels, bolted connections in WF framing provides restraint to reduce deflections up to 80% of a pin-connection.



Open-Web Joists

- Vibration: High stiffness to mass ratio
 - See SJI, AISC references
- Deflection
 - Connection flexibility: Pinned
 - Camber



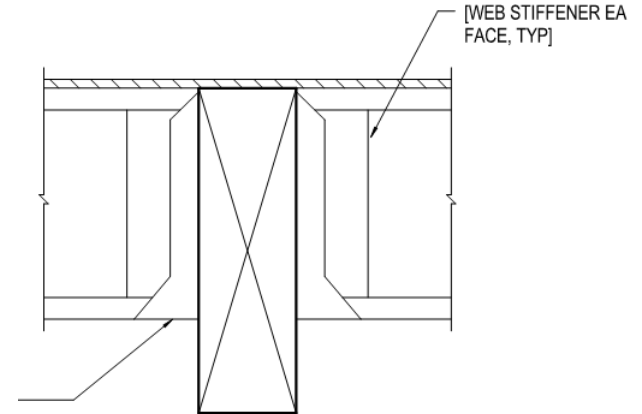
Open-Web Joists: Deflection: Camber

- Supplied with standard camber unless otherwise specified.
- Camber is related to the dead load deflections based on the capacity of the joist.
 - Uniform depth joists?
 - Heavy live loads?

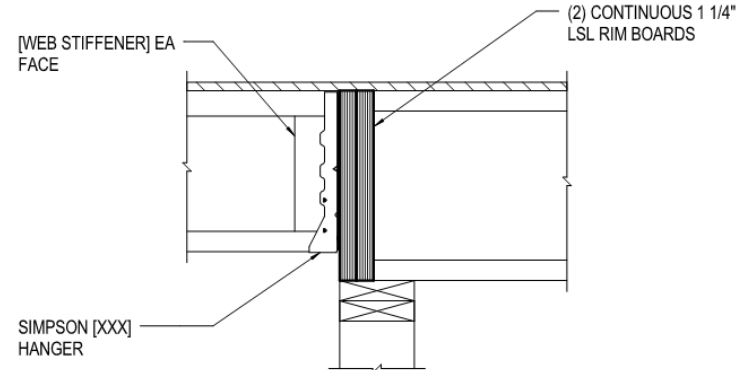


Wood

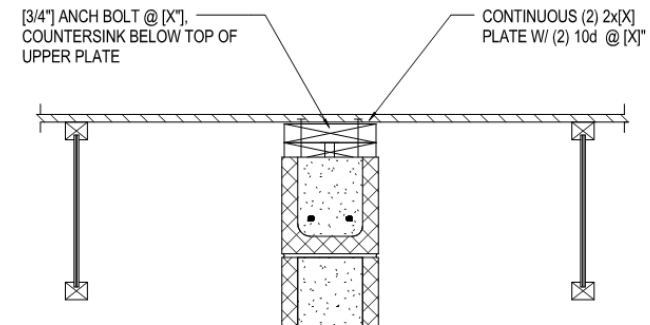
- Natural Wood



- Engineered Wood



- Compatibility of Wood with Other Systems



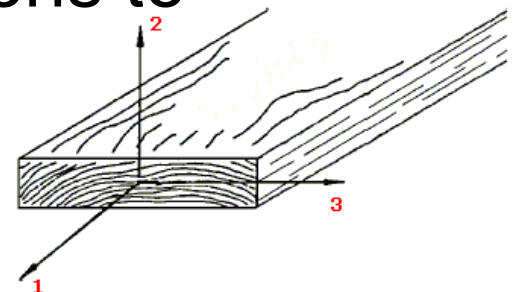
Natural Wood

- Wood is not isotropic and not stable over time
 - Shrinkage and creep depend on moisture content and drying of material
 - Typical creep about equal to initial deflection
 - NDS increase short term deflections to account for creep

$$\Delta_T = K_{cr} \Delta_{LT} + \Delta_{ST}$$

= 1.5 for seasoned lumber, structural glued laminated timber, prefabricated wood I-joists, or structural composite lumber used in dry service conditions as defined in 4.1.4, 5.1.5, 7.1.4, and 8.1.4, respectively.

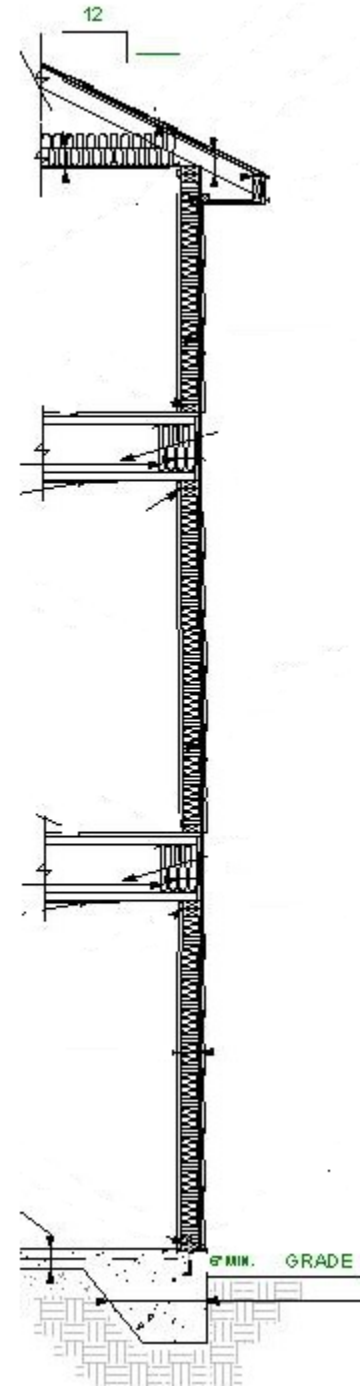
= 2.0 for unseasoned lumber or for seasoned lumber used in wet service conditions as defined in 4.1.4.



Natural Wood

- IBC 2304.3.3: Prescriptive requirements to limit differential shrinkage.

2304.3.3 Shrinkage. Wood walls and bearing partitions shall not support more than two floors and a roof unless an analysis satisfactory to the *building official* shows that shrinkage of the wood framing will not have adverse effects on the structure or any plumbing, electrical or mechanical systems, or other equipment installed therein due to excessive shrinkage or differential movements caused by shrinkage. The analysis shall also show that the roof drainage system and the foregoing systems or equipment will not be adversely affected or, as an alternate, such systems shall be designed to accommodate the differential shrinkage or movements.



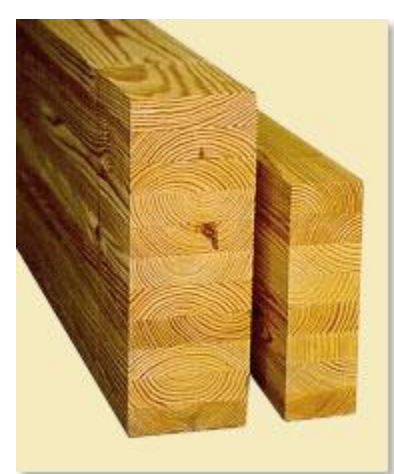
Natural Wood

- Wood Trusses: Time dependent effect- “set”.
 - Experience, engineering judgment



Engineered Wood

- Glulams, parallams, LVLs, plywood, I-joists, composite lumber, wood panels.



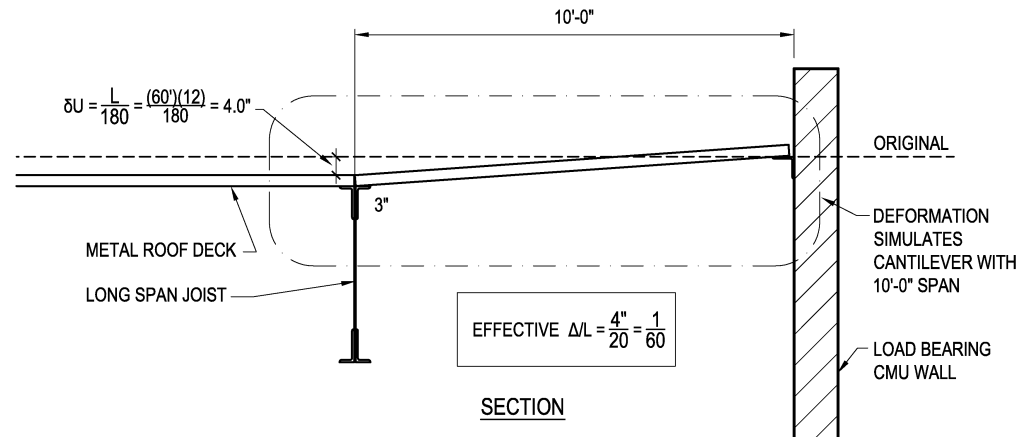
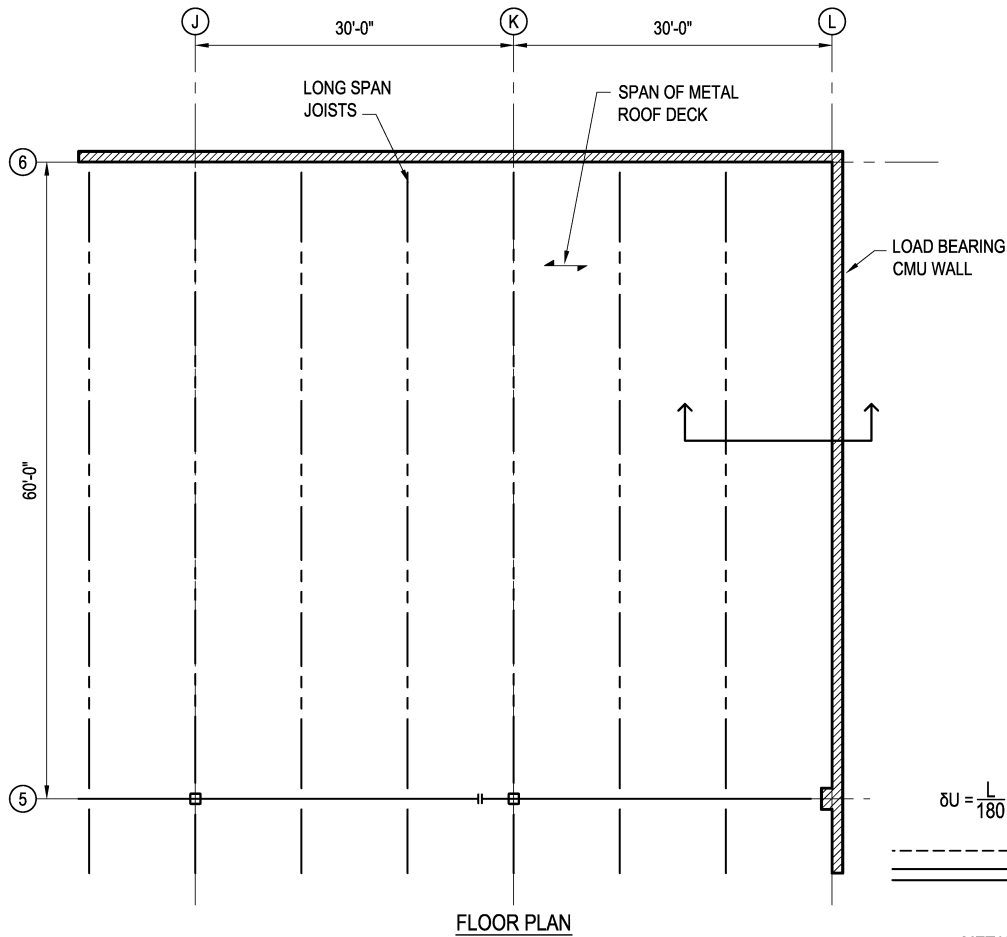
Serviceability design: See product data along with engineering judgment.

Compatibility of Wood and Other Systems

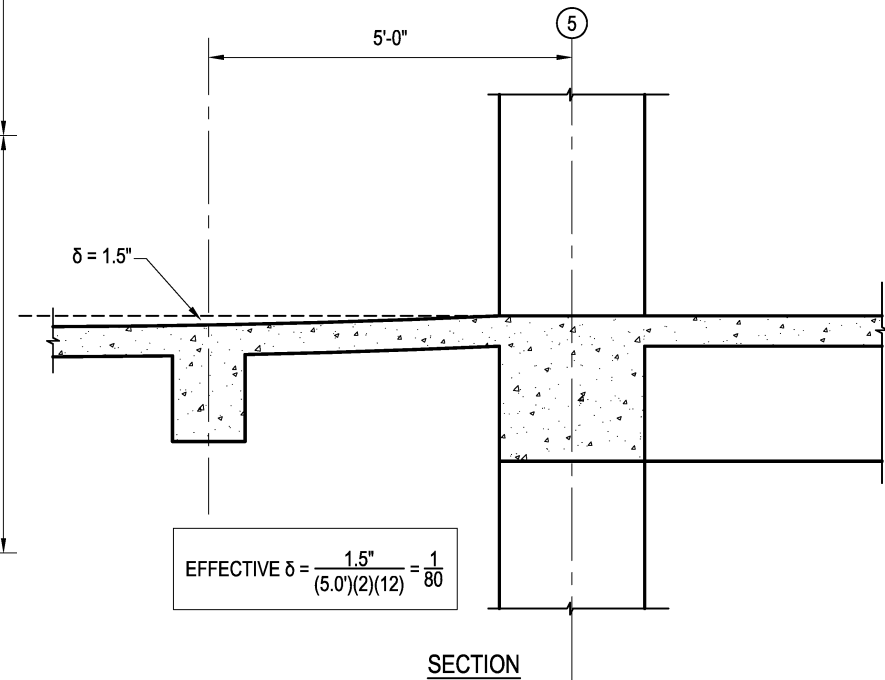
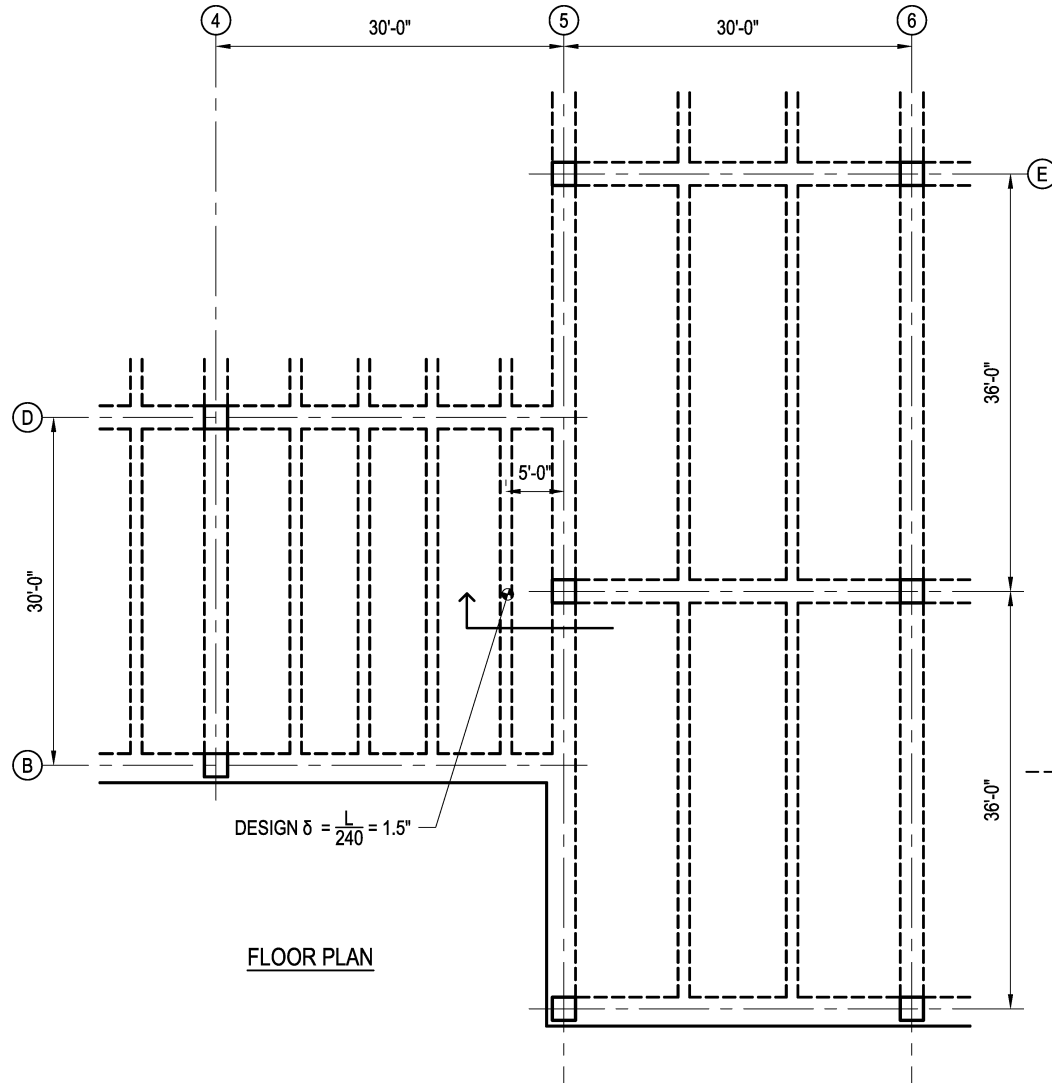
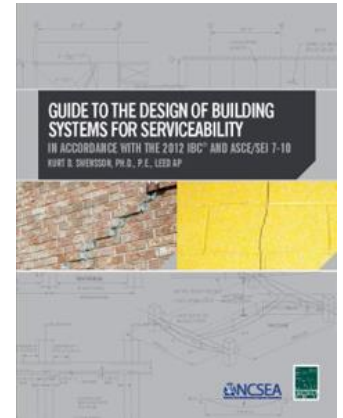
1. Wood floor/ roof in parallel with steel.
2. Load bearing wood walls adjacent to CMU/ concrete walls.
3. Load bearing wood walls adjacent to steel columns.
4. Adjacent wood walls of varying height due to basement walls.



Commonly Missed Serviceability Issues



Commonly Missed Serviceability Issues



Poll:

Should the building code include a more thorough treatment of serviceability?



- Yes
- No



“Why should the building code include a more thorough treatment of serviceability.”

1

2

3

4

“Why should the building code **NOT** include a more thorough treatment of serviceability.”

1

2

3

4

5

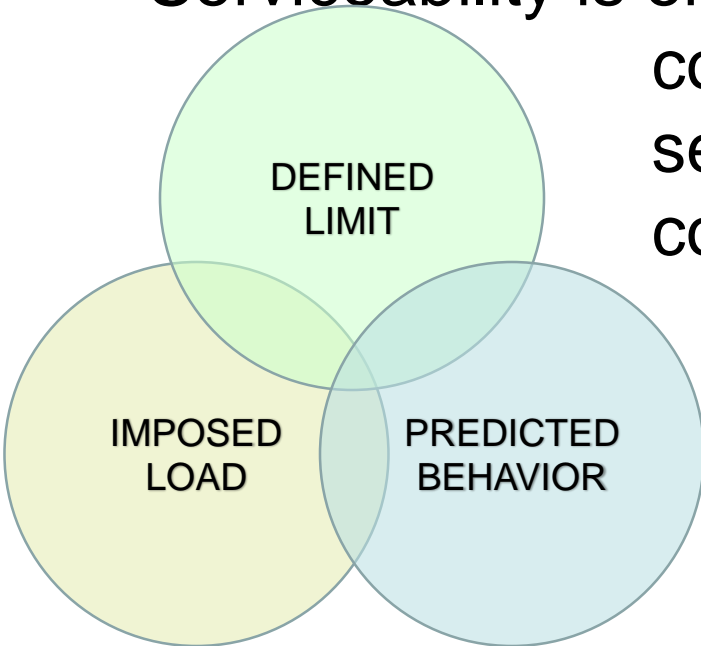
6



Questions?

Summary

- Serviceability considerations vary by building type, construction material, client, usage, analysis method.
 - Discuss early with client, PM/ PIC
- Many of the serviceability requirements are in material standards and/or design guides.
- Serviceability is only partially addressed in the building code, and the direction of serviceability requirements in the code is evolving.



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