Description

- Mid-career residential and commercial inspectors and plan examiners will find this seminar useful as well as architects and engineers looking for a review of structural loads and their load paths.
- With a focus on connections, the course considers moment frame, braced frame and shear wall load paths in selecting a particular structural frame for a single story, low-rise or mid-rise building.

Objectives

By the end of this course, attendees will be able to:
1. Identify the general load path through a building built of light-frame construction, concrete shear walls or steel frames.
2. Determine applicable loads to be used in the design of a building given its location and climate.
3. Describe how to select the controlling or critical load combination.
4. Determine whether appropriate connections have been placed to transfer loads along the load path.
5. Differentiate between gravity and lateral load paths.
About me

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Pick up my business card

About you

- Plan review engineers
- Engineers and Architects
- Plans examiners
- Inspectors
- Special inspectors
- Manufacturers

Topics

1. Loads
   - Dead and Live
   - Environmental Loads
   - Load Combinations
2. Load Path
   - Gravity
   - Lateral
3. Structural Frame
   - Moment
   - Braced
   - Shear Walls
4. Structural Irregularities
   - Horizontal
   - Vertical
5. Mixed Framing Systems
Structural Loads and Load Paths

Loads

The effects of external loads acting on structural members include:

- Moment (bending)
- Shear
- Deflection (deformation)

Dead Loads

Dead load, $D$
The weight of the structure and any fixed service equipment.

- The weight of construction materials, such as walls, floors, roofs, ceilings, etc.
- The weight of service equipment, such as cranes, plumbing stacks and risers, heating, etc.
Dead Loads

<table>
<thead>
<tr>
<th>Roof Dead Load</th>
<th>Floor Dead Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Framing Members = 1.0psf</td>
<td>Framing Members = 2.0psf</td>
</tr>
<tr>
<td>1/2&quot; Sheathing = 1.5psf</td>
<td>1/2&quot; Sheathing = 2.5psf</td>
</tr>
<tr>
<td>2 Layers Asphalt Shingles = 3.0psf</td>
<td>2&quot; Lightweight Concrete = 16psf</td>
</tr>
<tr>
<td>12&quot; Insulation = 3.0psf</td>
<td>Carpet &amp; Pad = 1.0psf</td>
</tr>
<tr>
<td>1/2&quot; Gypsum = 2.8psf</td>
<td>1/2&quot; Gypsum = 2.8psf</td>
</tr>
<tr>
<td>Lights/Misc = 1.2psf</td>
<td>Lights/Misc = 1.2psf</td>
</tr>
<tr>
<td>Total Roof DL = 15.0psf</td>
<td>Total Floor DL = 26.0psf</td>
</tr>
</tbody>
</table>

Live Loads

Live load includes two loads, $L$ and $L_r$.

Occupancy live load, $L$. Produced by the use and occupancy of the building or other structure (does not include construction loads, dead loads or environmental loads—wind, snow, rain, earthquake or flood).
- Uniform live loads (Table 1607.1)
- Concentrated loads (Table 1607.1)
- Live load reduction (Section 1607.10)

Live loads are prescribed in Table 1607.1—read ALL footnotes!
### Table 1607.1 Minimum Live Loads

<table>
<thead>
<tr>
<th>OCCUPANCY OR USE</th>
<th>UNIFORM (psf)</th>
<th>CONCENTRATED (lbs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Apartments (see residential)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>2. Access floor systems</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Office use</td>
<td>50</td>
<td>2,000</td>
</tr>
<tr>
<td>Computer use</td>
<td>100</td>
<td>2,000</td>
</tr>
<tr>
<td>3. Armories and drill rooms</td>
<td>150</td>
<td>--</td>
</tr>
<tr>
<td>4. Assembly areas</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Fixed seats (fastened to floor)</td>
<td>60</td>
<td>--</td>
</tr>
<tr>
<td>Follow spot, projections and control rooms</td>
<td>50</td>
<td>--</td>
</tr>
<tr>
<td>Lobbies</td>
<td>100</td>
<td>--</td>
</tr>
<tr>
<td>Movable seats</td>
<td>100</td>
<td>--</td>
</tr>
<tr>
<td>Stage floors</td>
<td>150</td>
<td>--</td>
</tr>
<tr>
<td>Platforms (assembly)</td>
<td>100</td>
<td>--</td>
</tr>
<tr>
<td>Other assembly areas</td>
<td>100</td>
<td>--</td>
</tr>
<tr>
<td>5. Balconies and decks</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>6. Corridors</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>First floor</td>
<td>100</td>
<td>--</td>
</tr>
<tr>
<td>Other floors</td>
<td>Same as occupancy served</td>
<td>--</td>
</tr>
<tr>
<td>9. Dining rooms and restaurants</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>11. Elevator machine room grating (on area of 2 inches by 2 inches)</td>
<td>100</td>
<td>--</td>
</tr>
<tr>
<td>12. Finish light floor plate construction (on area of 1 inch by 1 inch)</td>
<td>--</td>
<td>200</td>
</tr>
<tr>
<td>14. Garages (passenger vehicles only)</td>
<td>40</td>
<td>Note a</td>
</tr>
<tr>
<td>Trucks and buses</td>
<td>See Section 1607.7</td>
<td></td>
</tr>
</tbody>
</table>

---

### Table 1607.1 Minimum Live Loads cont.

<table>
<thead>
<tr>
<th>OCCUPANCY OR USE</th>
<th>UNIFORM (psf)</th>
<th>CONCENTRATED (lbs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15. Handrails, guards and grab bars</td>
<td>See Section 1607.8</td>
<td></td>
</tr>
<tr>
<td>16. Libraries</td>
<td>See Section 1607.6</td>
<td></td>
</tr>
<tr>
<td>Contours above first floor</td>
<td>80</td>
<td>1,000</td>
</tr>
<tr>
<td>Reading rooms</td>
<td>60</td>
<td>1,000</td>
</tr>
<tr>
<td>Stack rooms</td>
<td>150</td>
<td>1,000</td>
</tr>
<tr>
<td>20. Manufacturing</td>
<td>300</td>
<td>1,000</td>
</tr>
<tr>
<td>Heavy</td>
<td>250</td>
<td>1,000</td>
</tr>
<tr>
<td>Light</td>
<td>125</td>
<td>1,000</td>
</tr>
</tbody>
</table>

- Live load reduction is only permitted in accordance with Section 1607.11.1.2 or Item 1 of Section 1607.11.2.
- Live load reduction is only permitted in accordance with Section 1607.11.1.3 or Item 2 of Section 1607.11.2.
### Table 1607.1
**Minimum Live Loads**

<table>
<thead>
<tr>
<th>OCCUPANCY OR USE</th>
<th>UNIFORM (psf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24. Recreational uses:</td>
<td></td>
</tr>
<tr>
<td>Bowling alleys, poolrooms and similar uses</td>
<td>75m</td>
</tr>
<tr>
<td>Dance halls and ballrooms</td>
<td>100m</td>
</tr>
<tr>
<td>Gymnasiums</td>
<td>100m</td>
</tr>
<tr>
<td>Ice skating rink</td>
<td>250m</td>
</tr>
<tr>
<td>Reviewing stands, grandstands and bleachers</td>
<td>100&lt;sup&gt;n&lt;/sup&gt;</td>
</tr>
<tr>
<td>Roller skating rink</td>
<td>100&lt;sup&gt;n&lt;/sup&gt;</td>
</tr>
<tr>
<td>Stadiums and arenas with fixed seats (fastened to floor)</td>
<td>60&lt;sup&gt;n&lt;/sup&gt;</td>
</tr>
<tr>
<td>c. Design in accordance with ICC 300. m. Live load reduction is not permitted.</td>
<td></td>
</tr>
</tbody>
</table>

### Table 1607.1
**Minimum Live Loads**

<table>
<thead>
<tr>
<th>OCCUPANCY OR USE</th>
<th>UNIFORM (psf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25. Residential</td>
<td></td>
</tr>
<tr>
<td>One- and two-family dwellings</td>
<td>10</td>
</tr>
<tr>
<td>Uninhabitable attics without storage&lt;sup&gt;1&lt;/sup&gt;</td>
<td>20</td>
</tr>
<tr>
<td>Uninhabitable attics with storage&lt;sup&gt;1&lt;/sup&gt;</td>
<td>30</td>
</tr>
<tr>
<td>Habitable attics and sleeping areas&lt;sup&gt;2&lt;/sup&gt;</td>
<td>20</td>
</tr>
<tr>
<td>Canopies, including marquees</td>
<td>40</td>
</tr>
<tr>
<td>All other areas</td>
<td>40</td>
</tr>
<tr>
<td>Hotels and multifamily dwellings</td>
<td>40</td>
</tr>
<tr>
<td>Private rooms and corridors serving them</td>
<td>100</td>
</tr>
</tbody>
</table>

### Table 1607.1
**Minimum Live Loads**

<table>
<thead>
<tr>
<th>OCCUPANCY OR USE</th>
<th>UNIFORM (psf)</th>
<th>CONCENTRATED (psf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>26. Roofs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All roof surfaces subject to maintenance workers</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>Awnings and canopies</td>
<td>5&lt;sup&gt;–&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Fabric construction supported by a skeleton structure</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>All other construction</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Ordinary flat, pitched, and curved roofs (that are not occupiable)</td>
<td>2000</td>
<td></td>
</tr>
<tr>
<td>Where primary roof members are exposed to a work floor at single panel point of lower chord of roof trusses or any point along primary structural members supporting roofs:</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>Over manufacturing, storage warehouses, and repair garages</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All other primary roof members</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Occupable roofs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roof gardens</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Assembly areas</td>
<td>100&lt;sup&gt;n&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>All other similar areas</td>
<td>Note&lt;sup&gt;1&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
</table>

*Areas of occupable roofs, other than roof gardens and assembly areas, shall be designed for appropriate loads as approved by the building official. Unoccupied landscaped areas of roof shall be designed in accordance with Section 1607.12.3.*
Table 1607.1  
Minimum Live Loads

<table>
<thead>
<tr>
<th>OCCUPANCY OR USE</th>
<th>UNIFORM (psf)</th>
<th>CONCENTRATED (psf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30. Stairs and exits</td>
<td></td>
<td></td>
</tr>
<tr>
<td>One- and two-family dwellings</td>
<td>40</td>
<td>300</td>
</tr>
<tr>
<td>All other</td>
<td>100</td>
<td>300</td>
</tr>
<tr>
<td>31. Storage warehouses (shall be designed for heavier loads if required for anticipated storage)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heavy</td>
<td>250</td>
<td>--</td>
</tr>
<tr>
<td>Light</td>
<td>125</td>
<td>--</td>
</tr>
</tbody>
</table>

f. The minimum concentrated load on stair treads shall be applied on an area of 2 inches by 2 inches. This load need not be assumed to act concurrently with the uniform load.

Live Loads

Other types of roof live load:
- Greenhouses.
- Special-purpose roofs.
- Landscaped roofs.

Environmental Loads
Snow Loads

- Gravity Load
- Placed on roof of a structure
- Depends upon geographic location, roof geometry, roof covering and whether a heated building?

Building in Cedar Rapids, IA

- Flat roof, partially exposed; exposure category B, heated structure; RC II
- $p_g = 25$ psf
- $p_f = 0.7C_eC_tI_s p_g$
- $C_e = 1.0$ ASCE 7 Table 7.3-1
- $C_t = 1.0$ ASCE 7 Table 7.3-2
- $I_s = 1.0$ ASCE 7 Table 1.5-2
- $p_f = 0.7C_eC_tI_s p_g = 0.7 \times 1.0 \times 1.0 \times 25$ psf
- $= 17.5$ psf

Flood Loads

Flood Hazard Area
1. An area within a flood plain with a 1% chance of flooding in a year
2. An area designated as a flood hazard area.
Flood Loads

General
- Applies to new structures in FEMA designated flood areas.

Establishment of flood hazard areas
- From FEMA “FIRM” maps.

In riverine flood hazard areas where DFE is specified but floodways have not been designated,
- The applicant provides a floodway analysis
- Demonstrating that the proposed work will not increase the DFE more than 1 foot at any point within the jurisdiction of the applicable governing authority

Building in Cedar Rapids, IA
- Not in an area susceptible to flooding
Soil Loads

Backfilled soil creates gravity load on footing

Backfilled soil presses laterally against basement walls

Slab resists lateral movement and overturning

Soil bearing capacity below foundation – resists gravity loads and overturning

Soil Lateral Loads

Foundation and retaining walls designed to resist lateral soil loads.
Also must support weight of building without settlement (gravity load).

Building in Cedar Rapids, IA
- Soils are a poorly graded sand-clay mix (SC)
- Design lateral soil load
  - Soil type SC: 85 psf per ft ASCE Table 3.2-1
  - The water table is 20 feet below grade.
Rain Loads

- Consider ponding instability from progressive deflection
- Flat roofs

Figure 1611.1
100-year, 1-hour Rainfall (in.)
Western United States

Figure 1611.1
100-year, 1-hour Rain
Eastern United States
Rain Loads

Building in Cedar Rapids, IA

- Rain load (100-year, 1-hour rainfall) = 3.25 inches
- Water weight is 62.4 lb/ft³
- Multiple water weight by 3.25 in/12 in per ft

\[
\text{Rain load} \times \frac{3.25 \text{ in}}{12 \text{ in}/\text{ft}} = 16.9 \text{ psf}
\]

Atmospheric Ice Loads

- Atmospheric ice loads are due to freezing rain, snow, and in-cloud icing.

ICE-SENSITIVE STRUCTURE. A structure for which the effect of an atmospheric ice load governs the design of a structure or portion thereof. This includes, but is not limited to, lattice structures, guyed masts, overhead lines, light suspension and cable-stayed bridges, aerial cable systems (e.g., for ski lifts or logging operations), amusement rides, open catwalks and platforms, flagpoles and signs.
Atmospheric Ice

Building in Cedar Rapids, IA
- Not susceptible to icing

Wind Loads

What creates wind loads?
Either gusts or steady fast flowing air, common examples include:
- Tornadoes
- Hurricanes
- Thunderstorms
- Microbursts
- Downdrafts
- Funnelling effects through river gorges and valleys
- Speed-up at the top of hills
**Tornadoes**

- A narrow, violently rotating column of air extending from the base of a thunderstorm to the ground.
- Hard to see a tornado unless it forms a condensation funnel of water droplets, dust and debris.

<table>
<thead>
<tr>
<th>Fujita Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>F number</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

**Hurricanes**

*Hurricanes = Typhoons = Cyclones*

- Tropical cyclones are powered by heat from the sea.
- They are products of a warm tropical ocean and a warm, moist atmosphere.
- Wind and flood damage possible.
- Additionally, remnants of hurricanes strike the Pacific Coast and move across the country as large storms.

**Thunderstorms**

- A rain shower during which you hear thunder.
- A thunderstorm is classified as "severe" when it contains any of these:
  - Hail one inch or greater
  - Winds gusting in excess of 50 knots
  - Tornado
  - Strong (up to 120 mph) straight-line winds associated with thunderstorms knock down trees, power lines and damage roof and wall cladding.
Microbursts and Downdrafts

Downdraft
- Small-scale column of air that rapidly sinks toward the ground.

Downburst
- A strong downdraft with dimensions larger than 2.5 miles with an outward burst of damaging winds on or near the ground.

Microburst
- Small concentrated downburst that produces an outward burst of damaging winds at the surface.
- Microbursts are generally small (< 2.5 miles wide) and short-lived, lasting only 5-10 minutes.
- Maximum wind speeds up to 168 mph.
- Wet or dry.

Gorges, Valleys and Hills (Funnelling effects)

Winds funnel through valleys, river gorges and up hills. This means the upper half of hills facing the winds and the length of valleys oriented to the wind can have significantly higher wind speeds than surrounding flat areas.

IBC Wind Speed Map – RC II

Figure 1609.3(1) Basic Design Wind Speeds, $V$, For RC II Buildings
Exposure Category

<table>
<thead>
<tr>
<th>Exposure category</th>
<th>Section 1609.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Based on surface roughness categories B, C, and D.</td>
<td></td>
</tr>
<tr>
<td>Depends on the proximity of the building to the surface roughness categories.</td>
<td></td>
</tr>
<tr>
<td>Exposure B = Urban; Suburban</td>
<td></td>
</tr>
<tr>
<td>Exposure C = Open areas</td>
<td></td>
</tr>
<tr>
<td>Exposure D = Adjacent to a large body of water</td>
<td></td>
</tr>
</tbody>
</table>

Wind Loads

- Design wind speed – from Figure 1609.3(1) and ASCE 7 Hazard Tool: 109 mph
- Enclosed building, Exposure Category C, flat roof
- Use Envelope Method, Part II (simplified method)
  \[ p_{30} = \lambda K z t p_{30} \]
  \[ V = 109 \text{ mph} \rightarrow p_{30} \]
  \[ K = 1.0 \text{ (no abrupt hills or ridges)} \]
  \[ \lambda = 1.59, \text{ building 55 ft tall} \quad (\text{ASCE 7 Figure 28.5-1}) \]
  \[ p_{30} = \text{see table on next slide} \]

Wind Loads

- \[ p_{30} \rightarrow \text{from Figure 28.5-1} \]

<table>
<thead>
<tr>
<th>Wind Speed, V</th>
<th>Roof angle</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0</td>
<td>17.5</td>
<td>3.1</td>
<td>11.6</td>
<td>5.4</td>
<td>27</td>
<td>11.9</td>
<td>14.8</td>
<td>0.7</td>
</tr>
<tr>
<td>110</td>
<td>0</td>
<td>19.2</td>
<td>3.9</td>
<td>12.7</td>
<td>6.2</td>
<td>30.1</td>
<td>13.8</td>
<td>16.1</td>
<td>0.8</td>
</tr>
</tbody>
</table>

- \[ p_{30} = \lambda K z t p_{30} = 1.59 \times 1.0 \times \text{values in table} \]
- \[ p_{30} \rightarrow \text{from Table} \]

<table>
<thead>
<tr>
<th>Wind Speed, V</th>
<th>Roof angle</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0</td>
<td>28.9</td>
<td>10.8</td>
<td>13.9</td>
<td>6.3</td>
<td>32.9</td>
<td>15.1</td>
<td>17.9</td>
<td>0.9</td>
</tr>
<tr>
<td>110</td>
<td>0</td>
<td>31.6</td>
<td>12.5</td>
<td>15.1</td>
<td>7.1</td>
<td>35.9</td>
<td>16.7</td>
<td>19.7</td>
<td>1.0</td>
</tr>
</tbody>
</table>
Wind Loads

- (A) 30 psf
- (C) 12.5 psf
- (E) -22.7 psf
- (F) -12.9 psf
- (G) -15.7 psf
- (H) -10 psf

Earthquake Loads

The good stuff:
- Site Class A – “East coast hard rock”
- Site Class B – “West coast hard rock”
- Site Class C – Stiff rocky soil
- Site Class D – Good stiff soil (not rock)
**Earthquake Loads**

*Site class definitions*

The not-so-good stuff:
- Site Class E – Soft soil
- Site Class F – Bad soil, possible liquefaction

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**Seismic Ground Motion Map – S_5***

- MCE Ground Motion Response Accelerations - 0.2 sec Spectral Response Acceleration

---

**Seismic Ground Motion Map – S_1***

- MCE Ground Motion Response Accelerations - 1 sec Spectral Response Acceleration

---
Design Ground Motion

Design ground motion: $S_{DL} = \frac{2}{3} S_{ML}$

Soil factor:

$S_{DL} = \frac{2}{3} S_{ML} \quad F_s S_i$

$S_{DL} = F_s S_i$

Structural Loads and Load Paths
Earthquake Loads

- **Cedar Rapids, IA**
  - $S_0 = 0.095g$  
  - $S_1 = 0.095g$  
  - $S_{DS} = 0.073g$  
  - $S_{D1} = 0.088g$  

  - $S_{DS} = 0.073g$ → SDC A  
  - $S_{D1} = 0.088g$ → SDC B

- $V = C_sW$  
  - $W$ – weight of the building

$V = C_sW = 0.0243W$

---

Earthquake Loads

- $C_s = \frac{S_{DS}}{C_p} = 0.073g = 0.0243$

  - $R = 3$, Ordinary reinforced concrete moment frames

  - $C_s = 0.044S_{DS} = 0.044 \times 0.073 \times 1.0 = 0.0032 < 0.01$

  - $\text{Min } C_s = 0.01$  
    - OK

- $V = C_sW = 0.0243W$

---

Earthquake Loads

Determine $E_v$ and $E_h$

- $E_v = \rho Q_E$
- $E_h = 0.2S_{DS}D$

where

- $\rho = 1.0$ for SDC B
- $Q_E = V$

- $E_v = \rho Q_E = 1.0 \times 0.0243W = 0.0243W$
- $E_h = 0.2S_{DS}D = 0.2 \times 0.073g \times W = 0.0146W$
Load Combinations

**Vertical Gravity**
- Dead load
- Live (floor) load
- Roof live load
- Rain load
- Snow load

**Lateral**
- Soil pressure
- Wind pressure
- Earthquake ground motion
- Soil pushing against a foundation wall
- Wind blowing against a wall surface
- Inertial shear force caused by earthquake ground motion
Symbols

\( D \) = Dead load
\( L \) = Live load, except roof live load, including any permitted live load reduction
\( L_r \) = Roof live load including any permitted live load reduction
\( R \) = Rain load
\( S \) = Snow load
\( W \) = Load to wind pressure
\( E \) = Combined effect of horizontal and vertical earthquake induced forces

\( f_1 \): 1 for places of public assembly
\( f_1 \): 1 for live loads > 100 psf
\( f_1 \): 0.7 for roof configurations that don’t shed snow
\( f_1 \): 0.7 for roof configurations that don’t shed snow
\( f_1 \): 0.2 for other roof configurations

Note: Rain, snow, wind and earthquake loads are environmental loads.

Load Combinations – LRFD/Strength Design

1.4\( D \)  ASCE 7 §2.3.1 Eq 1
1.2\( D \) + 1.6\( L \) + 0.5\( (L_r \) or \( S \) or \( R \))  §2.3.1 Eq 2
1.2\( D \) + 1.6\( L \) (or \( S \) or \( R \)) + \( f_1 \)\( L \) or 0.5\( W \)  §2.3.1 Eq 3
1.2\( D \) + 1.0\( W \) + \( f_1 \)\( L \) + 0.5\( (L_r \) or \( S \) or \( R \))  §2.3.1 Eq 4
0.9\( D \) + 1.0\( W \)  §2.3.1 Eq 5

Load Combinations – Allowable Strength Design

\( D \)  ASCE 7 §2.4.1 Eq 1
\( D \) + 0.6\( W \)  §2.4.1 Eq 5
\( D \) + 0.75\( L \) + 0.75(0.6\( W \)) + 0.75\( (L_r \) or \( S \) or \( R \))  §2.4.1 Eq 6
0.6\( D \) + 0.6\( W \)  §2.4.1 Eq 7
Load Combination – Example – Roof

- Snow load – 17.5 psf
- Rain load – 16.9 psf
- Roof live load – 20 psf
- Dead load (roof) – 15 psf
- Dead load (floor) – 26 psf
- Live load (residential) – 40 psf
- Wind load – 30 psf (wall) -22.7 psf (roof)
- Earthquake load – to be determined

Load Combination – Example – Roof

Worst case load combinations (SD):
1.2D + 1.6L + 0.5(L or S or R)
1.2D + 1.6(L or S or R) + (fL or 0.5W)
1.2D + 1.0W + fL + 0.5(L or S or R)

Dead + Live + Snow
1.2D + 1.6L + 0.5(L or S or R) = 1.2(15) + 1.6(40) + 0.5(17.5) = 91 psf
Load Combination – Example – Roof

- Dead load (roof) – 15 psf
- Live load (residential) – 40 psf
- Snow load – 34 psf
- Wind load – 32 psf

Dead + Snow + Live or Wind

Live load larger than wind load

\[ 1.2D + 1.6S + f_r L \]

\[ = 1.2(15) + 1.6(17.5) + 0.5(40) = 66 \text{ psf} \]

Load Combination – Example – Roof

- Dead load (roof) – 15 psf
- Live load (residential) – 40 psf
- Snow load – 34 psf
- Wind load – 32 psf

Dead + Wind + Live + Snow

\[ 1.2D + 1.0W + f_r L + 0.5(L, S \text{ or } R) \]

\[ = 1.2(15) + 1.0(30) + 0.5(40) + 0.5(17.5) = 77 \text{ psf} \]

Earthquake Loads

\[ E_h = \rho Q_e = 0.0243W = 19.44 \text{ kips} \]

\[ E_v = 0.2S_{DS}D = 0.0146W = 11.68 \text{ kips} \]

where \( W \) = 800,000 lbs or 800 kips → translated to an equivalent roof load for a roof of 70 ft x 300 ft

\[ 6. \quad 1.2D + E_v + 0.5E_h + L + 0.2S \quad \text{ASCE 7 §2.3.6 Eq 6} \]

\[ = 1.2(15) + 1.0(12) + 0.5(20) + 1.0(40) + 0.5(17.5) \times 89 \text{ psf} \]
Load Combination – Example – Roof

- Dead + Live + Snow = 91 psf
- Dead + Snow + Live = 66 psf
- Dead + Wind + Live + Snow = 77 psf
- Dead + EQ + Live + Snow = 89 psf

Load Path

Concentrated vs Uniform Loads
**Roof**

- Snow, rain and roof live loads rest on top of roof materials
- Rafters or trusses support the roof
- Ceiling joists and wall framing supports the rafters and trusses

**Columns**

- Columns resist gravity loads by compressing and transferring loads into the members below by compression.

**Walls**

- Walls transfer gravity loads down through framing by compression similar to columns
**Floor**
- Floor live and dead loads transfer to columns
- Loads then transfer to the foundation
- Then to supporting soils

**Metal Buildings**
1. Snow load on roof sheathing
2. Transfer to walls and roof purlins
3. Load travels to rigid frame and down to the foundation

**Lateral Load Path**
Structural Loads and Load Paths

Lateral Loads

1. Wind presses against roof and wall sheathing transferring force to roof purlins and wall framing
2. Wind forces transfer to the rigid frame
3. Load travels down rigid frame to the foundation

Lateral Load Path

Seismic or wind force
Resists wind or seismic forces in side walls

Roof

1. Winds push against walls and roof
   Roof and wall sheathing resist the movement
2. Loads travel down from the sheathing through the roof and wall framing to the foundation

Straps help tie together vertically stacked lumber
**Floor**

1. Winds push against walls
2. Floors and wall sheathing resist the lateral movement
3. Loads travel down the floor and wall framing to the foundation

**Beams**

- Lateral loads transfer from the horizontal motion of the beam to the column due to gravity

**Collectors**

1. Wind load pushes wall line laterally
2. Top plate drags load to shear walls
3. Shear walls resist lateral load as the load is transferred down the framing to the foundation
Connections

Create a load path from one member to another within the frame of the structure.

Foundation

Panel Connection to Slab-on-grade

Connecting All Stories
Incomplete Load Path

- See the workbook page 28 and 29.

Table P.1 Load Path Connections for Horizontal Volumes

<table>
<thead>
<tr>
<th>Load</th>
<th>Connection</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shear</td>
<td>Steel connections</td>
<td>No special</td>
</tr>
<tr>
<td>Lateral</td>
<td>Steel connections</td>
<td>No special</td>
</tr>
<tr>
<td>Diaphragm</td>
<td>Steel connections</td>
<td>No special</td>
</tr>
</tbody>
</table>

Structural Frame
Structural System Selection 12.2

Every building is assigned a response modification coefficient, $R$, overstrength factor, $\Omega_0$, and deflection amplification factor, $C_d$ based on the seismic force-resisting system incorporated in the building.

<table>
<thead>
<tr>
<th>Seismic Force-resisting System</th>
<th>$R$</th>
<th>$\Omega_0$</th>
<th>$C_d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bearing Wall Systems</td>
<td>1½ to 6½</td>
<td>2 to 3</td>
<td>1½ to 5</td>
</tr>
<tr>
<td>Building Frame Systems</td>
<td>1½ to 8</td>
<td>2 to 2½</td>
<td>1½ to 8</td>
</tr>
<tr>
<td>Moment-resisting Frame Systems</td>
<td>3 to 8</td>
<td>3</td>
<td>2½ to 5½</td>
</tr>
<tr>
<td>Dual Systems with Special Moment Frames</td>
<td>4 to 8</td>
<td>2½ to 3</td>
<td>3½ to 6½</td>
</tr>
<tr>
<td>Dual Systems with Intermediate Moment Frames</td>
<td>3½ to 6½</td>
<td>2½ to 3</td>
<td>2½ to 5</td>
</tr>
<tr>
<td>Concrete Shearwall-frame Interactive Systems</td>
<td>4½</td>
<td>2½</td>
<td>4</td>
</tr>
<tr>
<td>Cantilevered Column Systems</td>
<td>1 to 2½</td>
<td>1½ to 1½</td>
<td>1 to 2½</td>
</tr>
<tr>
<td>Steel Systems Not Detailed for Seismic</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

Moment Frames

- Resist loads through axial tension and compression of the members
- Resists loads through moment-resisting joints
  - Steel
  - Reinforced concrete
  - Wood
Deformation of LFRS

- The moment frame, typically made of columns and beams, has a complex deformed shape.

Moment Frames

- Structural Loads and Load Paths
Moment Frames

Resist lateral loads through axial tension and compression of the bracing members and are assumed to have pinned joints.
- Steel
- Reinforced concrete
- Stiffer than moment frames, less deflection

Braced Frame

Deformation of LFRS
- The braced frame, typically made of columns and beams, has a complex deformed shape.
Braced Frames

- Are vertical cantilevered diaphragms
- Resist lateral forces of shear in the diaphragm
- Resist compression and tension in the boundary members.
  - Wood or CFS studs
  - Reinforced concrete
  - Masonry

Shear Wall

- All lateral force resisting systems (LFRS) resist lateral loads. The walls resist loads by deflecting.
- A shear wall becomes trapezoidal in shape.

Deformation of LFRS
Irregular Buildings 12.3

The “trigger” for considering structural irregularities is the assigned Seismic Design Category of the building.

Seismic Design Category B
- Horizontal irregularity Types 1, 4 and 5
- Vertical irregularity Types 4 and 5

Seismic Design Category C
- Horizontal irregularity Types 1, 4 and 5
- Vertical irregularity Types 4 and 5

Seismic Design Categories D, E or F
- All structural irregularities must be considered.

Horizontal Structural Irregularities

Note: Structures that have horizontal structural irregularity Type 1, 4 or 5 are to be analyzed using a 3-D representation. See ASCE 7, Section 12.7.3 - Structural Modeling.

Torsional Irregularity – H1

- Maximum story drift, including accidental torsion, at one end of the structure is 20% greater than the average of story drifts at the ends of the structure.

\[ \frac{\Delta_{\text{max}}}{\Delta_{\text{ave}}} > 1.2 \]
Torsional Irregularity – H1

Extreme Irregularity
- $\frac{\Delta_{\text{max}}}{\Delta_{\text{ave}}} > 1.4$
- Prohibited in SDC E-F

Torsional Irregularity
- Caused by a difference in the location of the center of mass and the center of resistance

Reentrant Corner – H2
- Wall offset more than 15% of length of wall line
  - $\frac{X}{X} > 0.15$
  - $\frac{Y}{Y} > 0.15$
**Reentrant Corner**

**Diaphragm Discontinuity – H3**
- Occurs when stiffness decreases by 50% story to story
- Large opening in diaphragm exists

\[ A_{open} > 0.5XY \]

**Diaphragm Irregularity**
- Openings must be at least 25% of the total diaphragm area.
- Or diaphragm stiffness is significantly reduced story to story
Out-of-plane offset – H4

- Lateral loads must run along a horizontal diaphragm to reach a lower LFRS
- Must strengthen floors

Nonparallel Systems – H5

- Nonparallel systems intensify forces allowing more damage during an event.
Soft Story – Stiffness – V1a
- $K_i < 0.7 K_{i+1}$
  OR
- $K_i < 0.8/3 (K_{i+1} + K_{i+2} + K_{i+3})$
  AND
- $\frac{\delta_{x1}}{h_1} > 1.30\frac{\delta_{x2} - \delta_{x1}}{h_2}$

Extreme Soft Story – Stiffness – V1b
- $K_i < 0.6 K_{i+1}$
  OR
- $K_i < 0.7/3 (K_{i+1} + K_{i+2} + K_{i+3})$
  AND
- $\frac{\delta_{x1}}{h_1} > 1.30\frac{\delta_{x2} - \delta_{x1}}{h_2}$

Softy Story – Stiffness Irregularity
- Two criteria!
- That the story stiffness is significant lower in a lower story and the story drift ratio is 30% greater than the story above
- Extreme soft story prohibited in SDC E-F
### Weight (Mass) – V2

- 50% increase from story to story
- \( M_i > 1.5M_{i+1} \)
- or
- \( M_i > 1.5M_{i-1} \)

### Mass Irregularity

- Heavy object or changing construction can increase mass at a given story
- Examples - large swimming pool or mechanical equipment on upper floors, airport control tower

### Geometric – V3

- The length of the LFRS is 30% greater than the length of the LFRS in the story above or below.
- \( L_i > 1.3L_{i+1} \)
Geometric Irregularity

In-plane Discontinuity – V4
- Offset of the vertical LFRS
  - offset > $L_{\text{below}}$
  - offset > $L_{\text{above}}$

In-plane Discontinuity
- Causes larger overturning demand on the supporting floor, beams and columns
### Lateral Strength – Weak Story – V5
- Lower story weaker than story directly above
- \( Str_i < 0.8 Str_{i+1} \)
- 100-80 = 20% weaker

### Lateral Strength – Extreme Weak Story – V5
- Lower story much weaker than story directly above
- \( Str_i < 0.65 Str_{i+1} \)
- 100-65 = 35% weaker

### Weak Story
- Weak Story prohibited in SDC E-F
- Extreme Weak Story prohibited in SDC D-F
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