**Design**

- factors out of the designer’s control
  - loads
  - occurrence
- factors within the designer’s control
  - choice of material
  - “cost” of failure (F.S., probability, location)
  - economic design method
  - analysis method

**Design Methods**

- different approaches to meeting strength/safety requirements
  - allowable stress design (elastic)
  - ultimate strength design
  - limit state design
  - plastic design
  - load and resistance factor design
- assume a behavior at failure or other threshold and include a margin of safety

**Load Types**

- $D =$ dead load
- $L =$ live load
- $L_r =$ live roof load
- $W =$ wind load
- $S =$ snow load
- $E =$ earthquake load
- $R =$ rainwater load or ice water load
- $T =$ effect of material & temperature
- $H =$ hydraulic loads from soil (F from fluids)
Dead Loads

- fixed elements
  - structure itself
  - internal partitions
  - hung ceilings
  - all internal and external finishes
  - HVAC ductwork and equipment
  - permanently mounted equipment
- \( F = mg \) (GRAVITY)

Weight of Materials

- for a volume
  - \( W = \gamma V \) where \( \gamma \) is weight/volume
- for an extruded area with height of \( t \)
  - \( W = \gamma A \)

Concentrated Loads

Distributed Loads

- for an area
  - \( w = \gamma A \)
**Dynamic Loads**
- time, velocity, acceleration
- kinetics
  - forces causing motion
    \[ W = m \cdot g \]
  - work
  - conservation of energy

**Load Locations**
- centric
- eccentric
- bending or flexural load
- torsional load
- combined loading

**Load Paths**
- tributary areas
- transfer

**Live Loads**
- occupancy
- movable furniture and equipment
- construction / roof traffic – \( L_r \)
- minimum values
- reduction allowed as area increases
Wind Load

- wind speed
- gusting
- terrain
- windward, leeward, up and down!
- drag
- rocking
- harmonic
- torsion

Seismic Load

- earthquake acceleration
  - $F = ma$
  - movement of ground (3D)
  - building mass responds
  - static models often used, $V$ is static shear
  - building period, $T \approx 0.1N$, determines $C$
  - building resistance - $R_W$
  - $Z$ (zone), $I$ (importance)
  - $V = \frac{ZICW}{R_W}$

Snow Load

- latitude
- solar exposure
- wind speed
- roof slope

Dynamic Response
Dynamic Response

- **period of vibration or frequency**
  - wave
  - sway/time period
- **damping**
  - reduction in sway
- **resonance**
  - amplification of sway

**Frequency and Period**

- **natural period of vibration**
  - avoid resonance
  - hard to predict seismic period
  - affected by soil
  - short period
    - high stiffness
  - long period
    - low stiffness

“*To ring the bell, the sexton must pull on the downswing of the bell in time with the natural frequency of the bell.*”

Water Load

- **rainwater** – clogged drains
- **ponding**
- **ice formation**

Thermal Load

- **stress due to strain**
- **restrained expansion or contraction**
- **temperature gradients**
- **composite construction**
Hydraulic Loads

- pressure by water in soil, \( H \)
- fluid pressure, \( F \)
  - normal to surface
- flood

Building Codes

- documentation
  - laws that deal with planning, design, construction, and use of buildings
  - regulate building construction for
  - fire, structural and health safety
  - cover all aspect of building design
  - references standards
    - acceptable minimum criteria
    - material & structural codes

<table>
<thead>
<tr>
<th>OCCUPANCY OR USE</th>
<th>UNIFORM (lb)</th>
<th>CONCENTRATED (lbs)</th>
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</thead>
<tbody>
<tr>
<td>1. All other non-residential</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>2. Assisted living facilities</td>
<td>50</td>
<td>1,000</td>
</tr>
<tr>
<td>3. Apartment buildings</td>
<td>150</td>
<td>—</td>
</tr>
<tr>
<td>4. Assembly areas and occupancies</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Prescribed Loads

- ASCE-7
  - live load (not roof) reductions allowed
- International Building Code
  - occupancy
  - wind: pressure to static load
  - seismic: shear load
    - function of mass and response to acceleration
  - fire resistance

![Figure 1.14 Earthquake loads on a structure.](Image)
Structural Codes

- prescribe loads and combinations
- prescribe design method
- prescribe stress and deflection limits
- backed by the profession
- may require design to meet performance standards
- related to material or function

Design Methods

- probability of loads and resistance
- material variability
- overload, fracture, fatigue, failure
- allowable stress design
  \[ f_{\text{actual}} = \frac{P}{A} \leq f_{\text{allowed}} = \frac{f_{\text{capacity}}}{F.S.} \]
- limit state design
  - design loads & capacities

Structural Codes

- Design Codes
  - Wood
    - NDS
  - Steel
    - AISC
  - Concrete
    - ACI
    - AASHTO
  - Masonry
    - MSJC

Allowable Stress Design

- historical method
- a.k.a. working stress, strength design
- stresses stay in ELASTIC range

Figure 5.20 Stress-strain diagram for various materials.
ASD Load Combinations

- D
- D + L
- D + 0.75(L_r or S or R)
- D + 0.75L + 0.75(L_r or S or R)
- D + (0.6W or 0.7E)
  - D + 0.75L + 0.75(0.6W) + 0.75(L_r or S or R)
  - D + 0.75L + 0.75(0.7E) + 0.75S
- 0.6D + 0.6W
- 0.6D + 0.7E

Limit State Design

- a.k.a. strength design
- stresses go to limit (strain outside elastic range)
- loads may be factored
- resistance or capacity reduced by a factor
- based on material behavior
- “state of the art”

LRFD Load Combinations

- 1.4D
- 1.2D + 1.6L + 0.5(L_r or S or R)
- 1.2D + 1.6(L_r or S or R) + (L or 0.5W)
- 1.2D + 1.0W + L + 0.5(L_r or S or R)
- 1.2D + 1.0E + L + 0.2S
- 0.9D + 1.0W
- 0.9D + 1.0E
  - F has same factor as D in 1-5 and 7
  - H adds with 1.6 and resists with 0.9 (permanent)
Deflection Limits

- based on service condition, severity

<table>
<thead>
<tr>
<th>Use</th>
<th>LL only</th>
<th>DL+LL</th>
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<tr>
<td>Roof beams:</td>
<td></td>
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<tr>
<td>Industrial</td>
<td>L/180</td>
<td>L/120</td>
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<tr>
<td>Commercial</td>
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<tr>
<td>plaster ceiling</td>
<td>L/240</td>
<td>L/180</td>
</tr>
<tr>
<td>no plaster</td>
<td>L/360</td>
<td>L/240</td>
</tr>
<tr>
<td>Floor beams:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ordinary Usage</td>
<td>L/360</td>
<td>L/240</td>
</tr>
<tr>
<td>Roof or floor (damageable elements)</td>
<td>L/480</td>
<td></td>
</tr>
</tbody>
</table>

Load Conditions

- loads, patterns & combinations
  - usually uniformly distributed gravity loads
  - worst case for largest moments...
  - wind direction can increase moments