**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)

**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
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
- $W = \gamma A$ for an extruded area with height of $t$

Concentrated Loads

- for an area
  - $w = \gamma A$

Distributed Loads

Table 5.1 Selected building material weights.

<table>
<thead>
<tr>
<th>Assembly</th>
<th>$\gamma_{m}$</th>
<th>$\gamma_{w}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor</td>
<td>0.31</td>
<td>0.31</td>
</tr>
<tr>
<td>Concrete slab</td>
<td>0.56/6 in.</td>
<td>0.56/6 in.</td>
</tr>
<tr>
<td>Steel decking</td>
<td>1.00-1.16</td>
<td>1.00-1.16</td>
</tr>
<tr>
<td>Wood joints</td>
<td>0.10-0.15</td>
<td>0.10-0.15</td>
</tr>
<tr>
<td>Ceramic tile</td>
<td>0.15/0.08</td>
<td>0.15/0.08</td>
</tr>
<tr>
<td>Lightweight concrete</td>
<td>0.20/0.13</td>
<td>0.20/0.13</td>
</tr>
<tr>
<td>Timber decking</td>
<td>0.20/0.13</td>
<td>0.20/0.13</td>
</tr>
</tbody>
</table>
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

Snow Load

• latitude
• solar exposure
• wind speed
• roof slope

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)

Dynamic Response

Lateral ground motions associated with earthquakes cause inertial forces to develop that are dependent on the weight of the structure. Sliding failures can occur.

The lateral ground motions can also cause a sculpture to overturn. The magnitude of the overturning effect depends on the weight of the sculpture and its height above the ground.

Back and forth ground motions can cause different parts of the sculpture to move in different directions. Overturning or cracking of elements can consequently occur.
**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

“Methods & Codes 17
Lecture 13
Foundations Structures
ARCH 331
F2008abn

Methods & Codes 18
Lecture 13
Foundations Structures
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Methods & Codes 19
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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

Building Codes

- occupancy
- construction types
- structural chapters
  - loads, tests, foundations
- structural materials, assemblies
  - roofs
  - concrete
  - masonry
  - steel

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
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

<table>
<thead>
<tr>
<th>Combination</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D$</td>
<td></td>
</tr>
<tr>
<td>$D + L$</td>
<td></td>
</tr>
<tr>
<td>$D + 0.75(L_r \text{ or } S \text{ or } R)$</td>
<td></td>
</tr>
<tr>
<td>$D + 0.75L + 0.75(L_r \text{ or } S \text{ or } R)$</td>
<td></td>
</tr>
<tr>
<td>$D + (0.6W \text{ or } 0.7E)$</td>
<td></td>
</tr>
<tr>
<td>$- D + 0.75L + 0.75(0.6W) + 0.75(L_r \text{ or } S \text{ or } R)$</td>
<td></td>
</tr>
<tr>
<td>$- D + 0.75L + 0.75(0.7E) + 0.75S$</td>
<td></td>
</tr>
<tr>
<td>$0.6D + 0.6W$</td>
<td></td>
</tr>
<tr>
<td>$0.6D + 0.7E$</td>
<td></td>
</tr>
</tbody>
</table>

### 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

<table>
<thead>
<tr>
<th>Combination</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1.4D$</td>
<td></td>
</tr>
<tr>
<td>$1.2D + 1.6L + 0.5(L_r \text{ or } S \text{ or } R)$</td>
<td></td>
</tr>
<tr>
<td>$1.2D + 1.6(L_r \text{ or } S \text{ or } R) + (L \text{ or } 0.5W)$</td>
<td></td>
</tr>
<tr>
<td>$1.2D + 1.0W + L + 0.5(L_r \text{ or } S \text{ or } R)$</td>
<td></td>
</tr>
<tr>
<td>$1.2D + 1.0E + L + 0.2S$</td>
<td></td>
</tr>
<tr>
<td>$0.9D + 1.0W$</td>
<td></td>
</tr>
<tr>
<td>$0.9D + 1.0E$</td>
<td></td>
</tr>
<tr>
<td>$\cdot F \text{ has same factor as } D \text{ in 1-5 and 7}$</td>
<td></td>
</tr>
<tr>
<td>$\cdot H \text{ adds with } 1.6 \text{ and resists with } 0.9 \text{ (permanent)}$</td>
<td></td>
</tr>
</tbody>
</table>
Deflection Limits

• based on service condition, severity

<table>
<thead>
<tr>
<th>Use</th>
<th>LL only</th>
<th>DL+LL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof beams:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industrial</td>
<td>L/180</td>
<td>L/120</td>
</tr>
<tr>
<td>Commercial</td>
<td></td>
<td></td>
</tr>
<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