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

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)
### Weight of Materials

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

<table>
<thead>
<tr>
<th>Material</th>
<th>Weight/volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>3% Ply roofing (roll, composition)</td>
<td>0.05</td>
</tr>
<tr>
<td>3% felt and gravel</td>
<td>0.26</td>
</tr>
<tr>
<td>6% felt and gravel</td>
<td>0.31</td>
</tr>
<tr>
<td>Asphalt</td>
<td>0.10</td>
</tr>
<tr>
<td>Clay tile</td>
<td>0.43 - 0.58</td>
</tr>
<tr>
<td>Concrete tile</td>
<td>0.29 - 0.48</td>
</tr>
<tr>
<td>Slate, 3 in.</td>
<td>10</td>
</tr>
</tbody>
</table>

### 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

### 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 L14** Earthquake loads on a structure.
**Code Reduction of Live Loads**

- for (ordinary) live loads
  - factored area supported \( \geq 400 \text{ ft}^2 \)
  - reduction can’t exceed
    - \( 0.5L_o \) (one floor) or \( 0.4L_o \) (more)
    \[
    L = L_o \left( 0.25 + \frac{15}{\sqrt{K_{LL} A_T}} \right)
    \]
- for live loads > 100 lb/ft²
  - live load reduction of 20% on columns
- for (ordinary) roofs: \( L_r = L_o R_1 R_2 \)
  - 12 lb/ft² \( \leq L_r \leq 20 \text{ lb/ft}^2 \)

**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
Allowable Stress Design

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

ASD Load Combinations

- \( D \)
- \( D + L \)
- \( D + (L_r \text{ or } S \text{ or } R) \)
- \( D + 0.75L + 0.75(L_r \text{ or } S \text{ or } R) \)
- \( D + (0.6W \text{ or } 0.7E) \)
- \( D + 0.75L + 0.75(0.6W \text{ or } 0.7E) + (0.75L_r \text{ or } S \text{ or } R) \)
- \( 0.6D + (0.6W \text{ or } 0.7E) \)

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”

Limit State Design

- load and resistance factor design (LRFD)
  - loads:
    - not constant,
    - possibly more influential on failure
    - happen more or less often
  - UNCERTAINTY
    \[ \gamma_D P_D + \gamma_L P_L \leq \phi P_u \]
    \[ \phi - \text{Resistance factor} \]
    \[ \gamma - \text{Load factor for (D)ead & (L)ive load} \]
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)

Load Tracing

- **how loads are transferred**
  - usually starts at top
  - distributed by supports as actions
  - distributed by tributary areas

Load Tracing

- **tributary load**
  - think of water flow
  - "concentrates" load of area into center

\[ w = \left( \frac{\text{load}}{\text{area}} \right) \times (\text{tributary width}) \]
Load Paths

• wall systems

• openings & pilasters

• foundations
Load Paths

- deep foundations