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

• $D = \text{dead load}$
• $L = \text{live load}$
• $L_r = \text{live roof load}$
• $W = \text{wind load}$
• $S = \text{snow load}$
• $E = \text{earthquake load}$
• $R = \text{rainwater load or ice water load}$
• $T = \text{effect of material & temperature}$
• $H = \text{hydraulic loads from soil (F from fluids)}$
Weight of Materials

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

<table>
<thead>
<tr>
<th>Material</th>
<th>( \text{lb}^3 )</th>
<th>( \text{kPa}^3 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sapwood (sawn, compression)</td>
<td>1</td>
<td>0.05</td>
</tr>
<tr>
<td>Sawn and planed wood</td>
<td>5.5</td>
<td>0.26</td>
</tr>
<tr>
<td>Sawn and planed 1/8 in</td>
<td>6.5</td>
<td>0.36</td>
</tr>
<tr>
<td>Glued 1/8 in</td>
<td>2</td>
<td>0.10</td>
</tr>
<tr>
<td>Asphalt</td>
<td>2–3</td>
<td>0.10–0.15</td>
</tr>
<tr>
<td>Clay brick</td>
<td>9–12</td>
<td>0.45–0.58</td>
</tr>
<tr>
<td>Concrete</td>
<td>0.7–1.0</td>
<td>0.48</td>
</tr>
<tr>
<td>Stucco, 3 in.</td>
<td>10</td>
<td>0.48</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 aspects 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

Figure 1.14 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 \( \leq L_r \leq 20 \) lb/ft²

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

![Stress-strain diagram for various materials.](image)

**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
    - $\gamma_D P_D + \gamma_L P_L \leq \phi P_u$
    - $\phi$ - Resistance factor
    - $\gamma$ - Load factor for (D)ead & (L)ive load
LRFD Load Combinations

ASCE-7 (2010)

- 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

(a) FBD—decking.
(b) FBD—joists.
(c) FBD—beams.
(d) FBD—girder.

• openings & pilasters

Figure 4.15 Arching over wall openings.
Figure 4.16 Solid wall with a window opening.
Figure 4.17 Pilasters supporting concentrated loads.

• foundations

Figure 4.24 Spread footing.
Figure 4.25 Wall footing.
Figure 4.26 Mat or raft foundation.

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Load Paths

- deep foundations

Figure 4.27  Pile foundations.
Figure 4.28  Pile cap on one pile group.
Figure 4.29  Grade beam supporting a bearing wall.