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

### 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
Code Reduction of Live Loads

• for (ordinary) live loads
  – factored area supported ≥ 400 ft²
  – 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: $L_r = L_o R_1 R_2$
    – $12 \text{ lb/ft}^2 \leq L_r \leq 20 \text{ lb/ft}^2$

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

![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”

ASCE-7 (2010)

$\gamma_D P_D + \gamma_L P_L \leq \phi P_u$

$\phi$ - Resistance factor
$\gamma$ - Load factor for (D)ead & (L)ive load

Limit State Design

- load and resistance factor design (LRFD)
  - loads:
    - not constant,
    - possibly more influential on failure
    - happen more or less often
  - UNCERTAINTY
    $\gamma_D P_D + \gamma_L P_L \leq \phi P_u$
**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.

Load Paths

- openings & pilasters

Load Paths

- foundations
Load Paths

• deep foundations