Three design codes, building codes
Structural Requirements

• serviceability
  – strength
  – deflections

• efficiency
  – economy of materials

• construction

• cost

• other
Structure Requirements

• strength & equilibrium
  – safety
  – stresses not greater than strength
  – adequate foundation

Figure 1.16 Equilibrium and Stability?—sculpture by Richard Byer. Photo by author.
Structure Requirements

- stability & stiffness
  - stability of components
  - minimum deflection and vibration
  - adequate foundation

Figure 1.15  Stability and the strength of a structure—the collapse of a portion of the UW Husky stadium during construction (1987) due to a lack of adequate bracing to ensure stability. Photo by author.
Structure Requirements

- economy and construction
  - minimum material
  - standard sized members
  - simple connections and details
  - maintenance
  - fabrication/erection
Design Procedure

• planning
• preliminary structural configuration
• determination of loads
• preliminary member selection
• analysis
• evaluation
• design revision
• final design
Design Procedure

- planning to establish
  - function of structure
  - criteria for optimum design
  - code jurisdiction

- preliminary structural configuration
  - arrangement of elements within form
  - columns
  - beams
  - joists
  - trusses
Design Procedure

• determination of loads
  – structure weight
  – moving loads
  – severe, rare loads

• preliminary member selection
  – based on configuration, determine loads on individual elements
  – determine internal forces & stresses
  – choose section to satisfy primary strength requirement

{ building codes }
Design Procedure

• analysis
  – actual structure weight
  – with other loads
  – based on structural system / modeling
    • elements – columns, beams...
    • connections
    • systems – frames, trusses
  – deflections and deformations
    • different load combination?
    • pattern loading
Design Procedure

• evaluation
  – measure results against criteria
    • strength?
    • deflections?
    • economy?

• revise design
  – any criteria NOT met
  – change member sizes, material, arrangement
Design Procedure

• final design
  – analyze revised design
  – evaluate and meets requirements
  – draw structural plan
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

<table>
<thead>
<tr>
<th>OCCUPANCY OR USE</th>
<th>UNIFORM (psf)</th>
<th>CONCENTRATED (lbs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Apartments (see residential)</td>
<td>---</td>
<td>---</td>
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<tr>
<td>2. Access floor systems</td>
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<td></td>
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<tr>
<td>Office use</td>
<td>50</td>
<td>2,000</td>
</tr>
<tr>
<td>Computer use</td>
<td>100</td>
<td>2,000</td>
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<tr>
<td>3. Armories and drill rooms</td>
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<td>---</td>
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<tr>
<td>4. Assembly areas and theaters</td>
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<tr>
<td>Fixed seats (fastened to floor)</td>
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<tr>
<td>Lobbies</td>
<td>100</td>
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<td>Movable seats</td>
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<tr>
<td>Stages and platforms</td>
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<tr>
<td>Follow spot, projections and control rooms</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Catwalks</td>
<td>40</td>
<td></td>
</tr>
</tbody>
</table>
Building Codes

• adoptable codes
  – Southern Building Code Congress International (SBCCI)
  – Building Officials & Code Administrators International (BOCA)
  – International Conference of Building Officials (ICBO - UBC)
  – International Building Code (IBC)
    • attempt to get one unified code in 2000
**Code Reduction of Live Loads**

- for (ordinary) live loads
  - factored area supported $\geq 400$ 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/ft$^2$
  - live load reduction of 20% on columns

- for (ordinary) roofs: $L_r = L_o R_1 R_2$
  - $12$ lb/ft$^2 \leq L_r \leq 20$ lb/ft$^2$
Standards

- criteria for quality
  - American National Standards Institute (ANSI)
  - American Society of Testing and Materials (ASTM)

- materials
  - Brick Industry Association (BIA)
  - Portland Cement Association (PCA)
  - National Concrete Masonry Association (NCMA)
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
Structural Codes

- American Concrete Institute (ACI)
- American Institute of Steel Construction (AISC)
- Precast/Prestressed Concrete Institute (PCI)
- Post Tensioning Institute (PTI)
- Structural Joist Institute (SJI)
- National Design Specifications (NDS)
  – American Wood Council
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
Design Methods

- structures and connections see
  - shear
  - bending
  - bearing
  - axial stress
    - compression
    - tension
  - torsion
Design Methods

- materials have a critical stress value where they could break or yield
  - ultimate stress
  - yield stress
  - compressive stress
  - fatigue strength
  - (creep & temperature)

acceptance vs. failure
Design Methods

- material behavior

Figure 5.22 Stress-strain diagram for mild steel (A36) with key points highlighted.
Design Methods

• allowable stress design
  – elastic range
  – factor of safety (F.S.)

\[ f_{\text{actual}} = \frac{P}{A} \leq f_{\text{allowed}} = \frac{f_{\text{capacity}}}{F.S.} \]

– probability of loads and resistance
– material variability
– overload, fracture, fatigue, failure
Design Methods

• **load and resistance factor design (LRFD)**
  – beyond allowable stress
• materials aren’t uniform 100% of the time
  – ultimate strength or capacity to failure may be different and some strengths hard to test for
• **RISK & UNCERTAINTY**

\[ f_u = \frac{P_u}{A} \]
Design Methods

• loads on structures are
  – not constant
  – can be more influential on failure
  – happen more or less often
  – UNCERTAINTY

\[ \gamma_D P_D + \gamma_L P_L \leq \phi P_n \]

\(\phi\) - Resistance factor

\(\gamma\) - Load factor for (D)ead & (L)ive load
Loads

- gravity acts on mass \( (F=m^*g) \)
- force of mass
  - acts at a point
    - ie. joist on beam
  - acts along a “line”
    - ie. floor on a beam
  - acts over an area
    - ie. people, books, snow on roof or floor
Load Tracing

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

Horizontal spanning system

Lateral support system

Vertical support system

Decking carries roof loads by bending.

Decking reactions become forces on beams (which carry loads by bending).

Beam reactions become forces on trusses.

Truss reactions cause compressive forces to develop in columns.

Columns are in compression.

Column reactions become forces on foundations (which distribute the forces into the earth).

tributary area
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

(a) FBD—decking.

Joist Loads (PLF)

(c) FBD—beams.

(b) FBD—joists.

Beam Loads (Pounds)

(d) FBD—girder.
Load Paths

• wall systems
Load Paths

- openings & pilasters

Figure 4.15 Arching over wall openings.
Figure 4.16 Stud wall with a window opening.
Figure 4.17 Pilasters supporting concentrated beam loads.
Load Paths

- foundations

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

- deep foundations
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)
ASD Load Combinations

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