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

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

• 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 ON USE</th>
<th>UNIFORM</th>
<th>CONCENTRATED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Apartments (not residential)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Areas for systems</td>
<td>50</td>
<td>2,000</td>
</tr>
<tr>
<td>3. Administrative</td>
<td>100</td>
<td>2,000</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 (UBO)
  – International Building Code (IBC)
    • attempt to get one unified code in 2000

Code Reduction of Live Loads

• for (ordinary) live loads
  – factored area supported \( \geq 400 \text{ ft}^2 \)
  – reduction can’t exceed
    • \( 0.5L_o \) (one floor) or \( 0.4L_o \) (more)
    \[
    L = L_o \left( 0.25 + \frac{15}{\sqrt{K_{1L}A_T}} \right)
    \]
• 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\(^2\) \( \leq L_r \leq 20 \text{ lb/ft}^2 \)

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

**Design**
- factors out of the designer’s control
  - loads
  - occurrence
- factors within the designer’s control
  - “cost” of failure (F.S., probability, location)
  - economic design method
  - analysis method

**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)
  - National Forest Products Association

**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)

Design Methods

- material behavior

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**
  \[ f_u = \frac{P_u}{A} \]

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

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

Design Methods

• **Loads on structures are**
  – not constant
  – can be more influential on failure
  – happen more or less often
  – **Uncertainty**

Load Tracing

• **How loads are transferred**
  – usually starts at top
  – distributed by supports as actions
  – distributed by tributary areas

Loads

• **Gravity acts on mass** (\( F = m \times g \))
• **Force of mass**
  – acts at a point
    • *i.e.* joist on beam
  – acts along a “line”
    • *i.e.* floor on a beam
  – acts over an area
    • *i.e.* 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

• 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
Load Paths

• openings & pilasters

Figure 4.15 Arched over wall openings.
Figure 4.36 Load wall with a window opening.
Figure 4.17 Pilasters supporting concentrated 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

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

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

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

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### LRFD Load Combinations

<table>
<thead>
<tr>
<th>Combination</th>
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</thead>
<tbody>
<tr>
<td>( 1.4D )</td>
</tr>
<tr>
<td>( 1.2D + 1.6L + 0.5(L_r \text{ or } S \text{ or } R) )</td>
</tr>
<tr>
<td>( 1.2D + 1.6(L_r \text{ or } S \text{ or } R) + (L \text{ or } 0.5W) )</td>
</tr>
<tr>
<td>( 1.2D + 1.0W + L + 0.5(L_r \text{ or } S \text{ or } R) )</td>
</tr>
<tr>
<td>( 1.2D + 1.0E + L + 0.2S )</td>
</tr>
<tr>
<td>( 0.9D + 1.0W )</td>
</tr>
<tr>
<td>( 0.9D + 1.0E )</td>
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</tbody>
</table>

**Note:**
- \( 0.9D + 1.0E \) F has the same factor as D in 1-5 and 7
- \( H \) adds with 1.6 and resists with 0.9 (permanent)

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