Elements of Architectural Structures: Form, Behavior, and Design

ARCH 614

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Lecture twelve

design methods, structural codes
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

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

Figure 1.13  Wind loads on a structure.
Weight of Materials

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

<table>
<thead>
<tr>
<th>LOAD SOURCES</th>
<th>153</th>
</tr>
</thead>
</table>

**TABLE 4.1 Weight of Building Construction**

<table>
<thead>
<tr>
<th></th>
<th>psf(^a)</th>
<th>kPa(^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Roofs</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-ply ready roofing (roll, composition)</td>
<td>1</td>
<td>0.05</td>
</tr>
<tr>
<td>3-ply felt and gravel</td>
<td>5.5</td>
<td>0.26</td>
</tr>
<tr>
<td>5-ply felt and gravel</td>
<td>6.5</td>
<td>0.31</td>
</tr>
<tr>
<td><strong>Shingles: Wood</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asphalt</td>
<td>2–3</td>
<td>0.10–0.15</td>
</tr>
<tr>
<td>Clay tile</td>
<td>9–12</td>
<td>0.43–0.58</td>
</tr>
<tr>
<td>Concrete tile</td>
<td>6–10</td>
<td>0.29–0.48</td>
</tr>
<tr>
<td>Slate, 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 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>
</tr>
<tr>
<td>2. Access floor systems</td>
<td></td>
<td></td>
</tr>
<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>
</tr>
<tr>
<td>3. Armories and drill rooms</td>
<td>150</td>
<td>---</td>
</tr>
<tr>
<td>4. Assembly areas and theaters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fixed seats (fastened to floor)</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Lobbies</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Movable seats</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Stages and platforms</td>
<td>125</td>
<td></td>
</tr>
<tr>
<td>Follow spot, projections and</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>control rooms</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Catwalks</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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
    • 0.5L₀ (one floor) or 0.4L₀ (more)
    \[
    L = L₀ \left( 0.25 + \frac{15}{\sqrt{K_{LL}A_T}} \right)
    \]

• for live loads > 100 lb/ft²
  – live load reduction of 20% on columns

• for (ordinary) roofs: \( L_r = L₀R₁R₂ \)
  – 12 lb/ft² ≤ Lᵣ ≤ 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
Structural Codes

• Design Codes
  – Wood
    • NDS
  – Steel
    • AISC
  – Concrete
    • ACI
    • AASHTO
  – Masonry
    • MSJC
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

Figure 5.20 Stress-strain diagram for various materials.
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

\[ \gamma_D R_D + \gamma_L R_L \leq \phi R_n \]

\( \phi \) - Resistance factor

\( \gamma \) - 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

Horizontal spanning 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.

(b) FBD—joists.

(c) FBD—beams.

(d) FBD—girder.
Load Paths

• wall systems

Figure 4.12 Uniform wall load from a slab.

Figure 4.13 Uniform wall load from rafters and joists.

Figure 4.14 Concentrated loads from widely spaced beams.
Load Paths

- openings & pilasters
Load Paths

- foundations

Figure 4.24  Spread footing.

Figure 4.25  Wall footing.

Figure 4.26  Mat or raft foundation.
Load Paths

- deep foundations