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

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)
Dead Loads

- fixed elements
  - structure itself
  - internal partitions
  - hung ceilings
  - all internal and external finishes
  - HVAC ductwork and equipment
  - permanently mounted equipment
- $F = mg$ (GRAVITY)

Weight of Materials

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

Concentrated Loads

Distributed Loads

- for an area
  - $w = \gamma A$
**Dynamic Loads**
- time, velocity, acceleration
- kinetics
  - forces causing motion \( W = m \cdot g \)
  - work
  - conservation of energy

**Load Locations**
- centric
- eccentric
- bending of flexural load
- torsional load
- combined loading

**Load Paths**
- tributary areas
- transfer

**Live Loads**
- occupancy
- movable furniture and equipment
- construction / roof traffic – \( L_r \)
- minimum values
- reduction allowed as area increases
Wind Load
- wind speed
- gusting
- terrain
- windward, leeward, up and down!
- drag
- rocking
- harmonic
- torsion

Snow Load
- latitude
- solar exposure
- wind speed
- roof slope

Seismic Load
- earthquake acceleration
  - $F = ma$
  - movement of ground (3D)
  - building mass responds
  - static models often used, $V$ is static shear
  - building period, $T \approx 0.1N$, determines C
  - building resistance $- R_W$
  - Z (zone), I (importance factor)

Dynamic Response
- Lateral ground motions associated with earthquakes cause inertial forces to develop that are dependent on the weight of the structure. Sliding failures can occur.
- The lateral ground motions can also cause a sculpture to overturn. The magnitude of the overturning effect depends on the weight of the sculpture and its height above the ground.
- Back and forth ground motions can cause different parts of the sculpture to move in different directions. Overturning or cracking of elements can consequently occur.
Dynamic Response

• period of vibration or frequency
  – wave
  – sway/time period
• damping
  – reduction in sway
• resonance
  – amplification of sway

Frequency and Period

• natural period of vibration
  – avoid resonance
  – hard to predict seismic period
  – affected by soil
  – short period
    • high stiffness
  – long period
    • low stiffness

“To ring the bell, the sexton must pull on the downswing of the bell in time with the natural frequency of the bell.”

Water Load

• rainwater – clogged drains
• ponding
• ice formation

Thermal Load

• stress due to strain
• restrained expansion or contraction
• temperature gradients
• composite construction
Hydraulic Loads

- pressure by water in soil, H
- fluid pressure, F
  - normal to surface
- flood

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

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
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
  \[ \frac{f_{\text{actual}}}{A} \leq f_{\text{allowed}} = \frac{f_{\text{capacity}}}{F.S.} \]
• limit state design
  – design loads & capacities

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

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

- $D$
- $D + L$
- $D + 0.75(L_r \text{ or } S \text{ or } R)$
- $D + 0.75L + 0.75(L_r \text{ or } S \text{ or } R)$
- $D + (0.6W \text{ or } 0.7E)$
  - $D + 0.75L + 0.75(0.6W) + 0.75(L_r \text{ or } S \text{ or } R)$
  - $D + 0.75L + 0.75(0.7E) + 0.75S$
- $0.6D + 0.6W$
- $0.6D + 0.7E$

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”

LRFD Load Combinations

- $1.4D$
- $1.2D + 1.6L + 0.5(L_r \text{ or } S \text{ or } R)$
- $1.2D + 1.6(L_r \text{ or } S \text{ or } R) + (L \text{ or } 0.5W)$
- $1.2D + 1.0W + L + 0.5(L_r \text{ or } S \text{ or } R)$
- $1.2D + 1.0E + L + 0.2S$
- $0.9D + 1.0W$
- $0.9D + 1.0E$
  - $F$ has same factor as $D$ in 1-5 and 7
  - $H$ adds with 1.6 and resists with 0.9 (permanent)
**Deflection Limits**

- based on service condition, severity

<table>
<thead>
<tr>
<th>Use</th>
<th>LL only</th>
<th>DL+LL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof beams:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industrial</td>
<td>L/180</td>
<td>L/120</td>
</tr>
<tr>
<td>Commercial</td>
<td></td>
<td></td>
</tr>
<tr>
<td>plaster ceiling</td>
<td>L/240</td>
<td>L/180</td>
</tr>
<tr>
<td>no plaster</td>
<td>L/360</td>
<td>L/240</td>
</tr>
<tr>
<td>Floor beams:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ordinary Usage</td>
<td>L/360</td>
<td>L/240</td>
</tr>
<tr>
<td>Roof or floor (damageable elements)</td>
<td>L/480</td>
<td></td>
</tr>
</tbody>
</table>

**Load Conditions**

- loads, patterns & combinations
  - usually uniformly distributed gravity loads
  - worst case for largest moments...
  - wind direction can increase moments

**Structural Loads**

- gravity acts on mass \( F = m \cdot g \)
- 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

**Equivalent Force Systems**

- replace forces by resultant
- place resultant where \( M = 0 \)
- using calculus and area centroids

\[
W = \int_0^L w(x) \, dx = \int dA_{\text{loading}} = A_{\text{loading}}
\]
Area Centroids

- **Table 6.1 – pg. 304**

<table>
<thead>
<tr>
<th>Shape</th>
<th>x</th>
<th>y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triangular area</td>
<td>( \frac{b}{3} )</td>
<td>( \frac{h}{3} )</td>
</tr>
<tr>
<td>Quarter-circular area</td>
<td>( 4r )</td>
<td>( 3r )</td>
</tr>
<tr>
<td>Semicircular area</td>
<td>0</td>
<td>( 4r )</td>
</tr>
<tr>
<td>Semi-parabolic area</td>
<td>( \frac{3a}{8} )</td>
<td>( \frac{3a}{5} )</td>
</tr>
<tr>
<td>Parabolic area</td>
<td>0</td>
<td>( \frac{3b}{5} )</td>
</tr>
</tbody>
</table>

Equivalent Load Areas

- area is width x “height” of load
- \( w \) is load per unit length
- \( W \) is total load

\[
\begin{align*}
\text{w} \cdot x &= W \\
\text{w} \cdot \frac{x}{2} &= \frac{W}{2}
\end{align*}
\]

Distributed Area Loads

- \( w \) is also load per unit area

Load Tracing

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

- **Snow or Roof LL for Non-Snow Areas**
- **Use and Occupancy**
- **Self-Weight of Structure**
- **Ground Reaction**

*figure 2.7 Area-distributed load (pressure) on floor decking.*
Load Tracing

• areas see distributed area load
• beams or trusses see distributed line loads
• “collectors” see forces
  – columns
  – supports

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

• floors and framing

(a) FBD—decking.

(b) FBD—joists.

(c) FBD—beams.

(d) FBD—girder.

Load Paths

• wall systems

Load Paths

• openings & pilasters
Load Paths

- foundations

- deep foundations

Spans

- direction
- depth

Levels

- determine span at top level
- find half way to next element
- *include self weight
- look for “collectors”
- repeat
- one:

Load Tracing

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Lecture 14
Foundations Structures
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F2008abn

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ARCH 331
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Lecture 14
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Lecture 14
Foundations Structures
ARCH 331
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Levels

- two:

- three:

Irregular Configurations

- tracing still ½ each side

Slabs

- edge support

- linear and uniform distribution

Girders and Transfer

- openings
  - no load & no half way

- girder actions at beam supports
Sloped Beams
- stairs & roofs
- projected live load
- dead load over length

perpendicular load to beam:
\[ w_\perp = w \cdot \cos \alpha \]
equivalent distributed load:
\[ w_{adj.} = \frac{w}{\cos \alpha} \]

Framing Diagrams
- beam lines and “dots”
- breaks & ends

Retaining Walls
- purpose
  - retain soil or other material
- basic parts
  - wall & base
  - additional parts
    - counterfort
    - buttress
    - key

Retaining Wall Types
- “gravity” wall
  - usually unreinforced
  - economical & simple
- cantilever retaining wall
  - common
Retaining Wall Loads

- **gravity**
  \[ W = \gamma \times V \]
- **fluid pressure**
  \[ p = \omega' \times h \]
  \[ P = \frac{1}{2} p h \text{ at } h/3 \]
- **friction**
  \[ F = \mu \times N \]
- **soil bearing pressure, }q}**

**Pressure Distribution**

- want resultant of load from pressure inside the middle third of base (kern)

  - triangular stress block with }p_{max}\)
  \[ x = \frac{1}{3} x \text{ width of stress} \]
  - equivalent force location:
  \[ W \cdot x = \frac{p_{max}}{2} \frac{3x}{3} \frac{x}{2} \]
  \[ p_{max} = \frac{2W}{3x} = \frac{2W}{a} \text{ when } a \text{ is fully stressed} \]

Retaining Wall Equilibrium

- **sliding - overcome friction?**
  \[ SF = \frac{M_{\text{resist}}}{M_{\text{overturning}}} \geq 1.5 - 2 \]

- **overturning at toe (o) - overcome mass?**
  \[ SF = \frac{F_{\text{horizontal-resist}}}{F_{\text{sliding}}} \geq 1.25 - 2 \]

Wind Pressure

- **distributed load**
  - “collected” into V
- **lateral loads**
  - must be resisted
Bracing Configurations

Figure 4.54 Various shortwall arrangements—some stable, others unstable.