ARCHITECTURAL STRUCTURES: FORM, BEHAVIOR, AND DESIGN
ARCH 331
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lecture
fourteen

system assemblies & load tracing
Structural Loads

- gravity acts on mass \((F=m\times g)\)
- 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
Concentrated Loads
Distributed Loads
Equivalent Force Systems

- replace forces by resultant
- place resultant where $M = 0$
- using calculus and area centroids

$$W = \int_{0}^{L} w(x) \, dx = \int dA_{\text{loading}} = A_{\text{loading}}$$

\[ W = \int_{0}^{L} w(x) \, dx \]

\[ = \int dA_{\text{loading}} \]

\[ = A_{\text{loading}} \]
# Area Centroids

- **Table 7.1 – pg. 242**

## Centroids of Common Shapes of Areas and Lines

<table>
<thead>
<tr>
<th>Shape</th>
<th>$\bar{x}$</th>
<th>$\bar{y}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triangular area</td>
<td>$\frac{b}{3}$</td>
<td>$\frac{h}{3}$</td>
</tr>
<tr>
<td></td>
<td>right triangle only</td>
<td></td>
</tr>
<tr>
<td>Quarter-circular area</td>
<td>$\frac{4r}{3\pi}$</td>
<td>$\frac{4r}{3\pi}$</td>
</tr>
<tr>
<td>Semicircular area</td>
<td>0</td>
<td>$\frac{4r}{3\pi}$</td>
</tr>
<tr>
<td>Semiparabolic area</td>
<td>$\frac{3a}{8}$</td>
<td>$\frac{3h}{5}$</td>
</tr>
<tr>
<td>Parabolic area</td>
<td>0</td>
<td>$\frac{3h}{5}$</td>
</tr>
</tbody>
</table>
Equivalent Load Areas

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

\[
\begin{align*}
\text{Area:} & \quad w \cdot x = W \\
\text{Load per unit length:} & \quad \frac{w \cdot x}{2} = \frac{W}{2} \\
\text{Total load:} & \quad \begin{cases} w \text{ at } x/2, W/2 \text{ at } 2x/3, W/2 \text{ at } x/3 \end{cases}
\end{align*}
\]
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
Load Tracing

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

Figs. 1.1a, 1.1b Structural loading diagram of an architectural condition
Load Tracing

- Horizontal spanning system
- Vertical support system
- Tributary area

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).
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 Tracing

Patcenter
Rogers 1986

Figure 3.5: Patcenter, load path diagram.

primary stays suspend secondary stays which support roof
main masts transfer vertical loads to columns and foundations
vertical ties resist wind uplift only

www.columbia.edu
Load Tracing

Alamillo Bridge
Calatrava 1992

Figure 3.12: Alamillo bridge, load path diagram.

diagonal stays support roadbed and generate inward thrust
weight of sloped pylon resists thrust due to cable stays
roadbed transmits horizontal thrust to pylon

http://en.structurae.de
Load Paths

• floors and framing

(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

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
Load Paths

• deep foundations
Spans

- **direction**
- **depth**

(a) Long, lightly loaded joists bearing on shorter beams create a more uniform structural depth. Space can be conserved if the joists and beams are flush framed.

(b) Short joists loading relatively long beams yield shallow joists and deep beams. The individual structural bays are more clearly expressed.

(c) Loads can be reduced on selected beams by introducing intermediate beams.

(d) The span capability of the decking material controls the spacing of the joists, while beam spacing is controlled by the allowable joist span.
Levels

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

one:
Levels

- **two:**

- **three:**
Irregular Configurations

• tracing still $\frac{1}{2}$ each side
Slabs

• edge support

![Diagram of edge support in slabs]

Figure 2-16: Supporting beams' contributing areas for reinforced concrete floor system.

• linear and uniform distribution

![Diagram of linear and uniform distribution in beams]

Figure 2-17: Trapezoidal distributed load for Beam AB of Fig. 2-16.
Girders and Transfer

- openings
  - no load & no half way
- girder actions at beam supports

Figure 5.54 (a) Isometric view of partial steel framing arrangement. (b) Partial floor framing—office structure.
Sloped Beams

- stairs & roofs
- projected live load
- dead load over length

- perpendicular load to beam:
  \[ W_{\perp} = W \cdot \cos \alpha \]

- equivalent distributed load:
  \[ W_{\text{adj.}} = \frac{W}{\cos \alpha} \]
Framing Diagrams

- beam lines and “dots”
- breaks & ends

Spanning direction of decking or reinforcement
__________________________ Concrete lines

= = = = = = = Unexposed concrete or masonry wall lines

__________________________ Reinforcement

__________________________ Center lines

__________________________ Dimension lines

Concrete beam framing into column which extends through floor
Concrete beam framing into column which stops at floor

Load Tracing 27  Architectural Structures  S2014abn
Lecture 14  ARCH 331
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, \( q \)
Retaining Wall Equilibrium

- **sliding** - overcome friction?
- **overturning at toe (o)** - overcome mass?

\[
SF = \frac{M_{\text{resist}}}{M_{\text{overturning}}} \geq 1.5 - 2
\]

\[
SF = \frac{F_{\text{horizontal-resist}}}{F_{\text{sliding}}} \geq 1.25 - 2
\]
Pressure Distribution

- want resultant of load from pressure inside the middle third of base (kern)
- triangular stress block with $p_{\text{max}}$
- $x = 1/3 \times \text{width of stress}$
- equivalent force location:

\[
W \cdot x = \frac{p_{\text{max}} 3x}{2} \cdot \frac{x}{3}
\]

\[
p_{\text{max}} = \frac{2W}{3x} = \frac{2W}{a}
\]

when $a$ is fully stressed

Figure 3.88   Tension possible at the heel.
Wind Pressure

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

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