Arch & Shell Systems

- curved, thin surface or 2D structures
- see very little bending stresses
- design for
  - axial stresses
  - shear stresses
- efficient because of uniformly distributed loads

Arches

- behavior
  - stabilization
  - resist thrust
- compression only

Millennium Bridge in Newcastle, UK

Office Hours

Professor Anne Nichols (345-6546)

link to posted schedule

Shells & Systems 3
Lecture 28
Elements of Architectural Structures
ARCH 614

S2007abn

Shells & Systems 2
Lecture 28
Elements of Architectural Structures
ARCH 614

S2008abn

Shells & Systems 1
Lecture 28
Elements of Architectural Structures
ARCH 614

S2007abn
Shell Types

- shape classifications
  - developable:
    - revolution (vault)
  - synclastic
    - doubly curved
    - same direction
  - anticlastic:
    - doubly curved
    - opposite curvature
  - free form

Vaults

- “wide” arch

Vaulted Shells

- can resist tension
- shape adds “depth”

Kimball Museum, Kahn 1972
**Kimball Museum, Kahn 1972**

- outer shell edges

- skylights at peak

**Domes**

- arch of revolution
- compression
- some tension

**Domes**

- stresses and displacements

© Harvard GSD
Annunciation Greek Orthodox Church

- Wright, 1956

![Annunciation Greek Orthodox Church](http://www.bluffton.edu)

Anticlastic Shells

- saddle or “ruled” shapes
- surface generated with straight lines
- tension follows “cable drape”
- compression follows “arch”

Zarzuela Hippodrome, Torroja 1935

![Zarzuela Hippodrome, Torroja 1935](http://www.bluffton.edu)
Zarzuela Hippodrome, Torroja 1935

Folded Plates
- increased stiffness with folding

Illini Hall, Harrison & Abramovitz 1963
- Assembly Hall, University of Illinois
- Harrison & Abramovitz 1963
- Edge-supported dome spanning 400 feet wound with 614 miles of one-fifth inch steel wire

Systems
- total of components
- behavior of whole
- classifications
  - one-way
  - two-way
  - tubes
  - braced
  - unbraced
One-Way Systems
• horizontal vs. vertical

Two-Way Systems
• spanning system less obvious
• horizontal
  – plates
  – slabs
  – space frames
• vertical
  – columns
  – walls

System Selection
• evaluation of alternatives
Structural Design Criteria

- Components stay together
- Structure acts as whole to be stable
  - Resist sliding
  - Resist overturning
  - Resist twisting and distortion
- Internal stability
  - Interconnectedness
- Strength & stiffness

Structural Design Sequences

- First-order design
  - Structural type and organization
  - Design intent
  - Contextual or programmatic
- Second-order
  - Structural strategies
  - Material choice
  - Structural systems
- Third-order
  - Member shaping & sizing

Design Issues

- Lateral stability – all directions

Design Issues

- Configuration
Design Issues

• vertical load resistance

![Walls and Slab Systems](image1)

![Columns and Beam Systems](image2)

- walls
- columns

Design Issues

• lateral load resistance

- Shear walls may be arranged in a two-form to resist lateral forces from all directions.
- When combined with other stabilizing mechanisms, shear walls may be arranged so as to resist forces in any one direction of a building.

Design Issues

• lateral load resistance

- Shear walls are commonly used with column and slab systems. In this elevation and plan, the shear walls are shown incorporated into a pair of vertical cores.
- Rigid frame structures require an additional connection so shear walls, as shown in this elevation and plan.
- The location of braced frames or shear walls must be considered in relation to the elevation and plan of the building.

Design Issues

• multi-story
  - cores, tubes, braced frames
Design Issues

- multi-story
  - avoid discontinuities
    - vertically
    - horizontally

Final Exam Material

- my list:
  - equilibrium - $\Sigma F$ & $\Sigma M$
    - supports, trusses, cables, beams, pinned frames, rigid frames
  - materials
    - strain & stress ($E$), temperature, constraints
  - beams
    - distributed loads, tributary width, V&M, stresses, design, section properties ($I$ & $S$), pitch, deflection

Final Exam Material

- my list (continued):
  - columns
    - stresses, design, section properties ($I$ & $r$)
  - frames
    - $P$, $V$ & $M$, $P-\Delta$, effective length with joint stiffness, connection design, tension member design
  - foundations
    - types
    - sizing & structural design
    - overturning and sliding

- systems
  - levels
  - design considerations
  - design specifics
    - steel (ASD & LRFD)
    - concrete
    - wood
    - masonry