ELEMENTS OF ARCHITECTURAL STRUCTURES:
FORM, BEHAVIOR, AND DESIGN
ARCH 614
DR. ANNE NICHOLS
SPRING 2013

lecture
twenty eight

# shells & structural systems



## Office Hours

Professor Anne Nichols (845-6540)

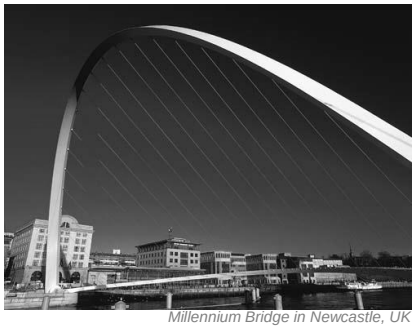
| | April 30 | May 1 | May 2 | May 5 | May 6 |
|---|---|---|---|---|---|
| 8 am | | | | | |
| 9 am | | | | | |
| 10 am | | | | | |
| 11 am | | | | | |
| 12 pm | | | | | |
| 1 pm | | | | | |
| 2 pm | | | | | |
| 3 pm | | | | | |
| 4 pm | | | | | |

*link to posted schedule*



## 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*

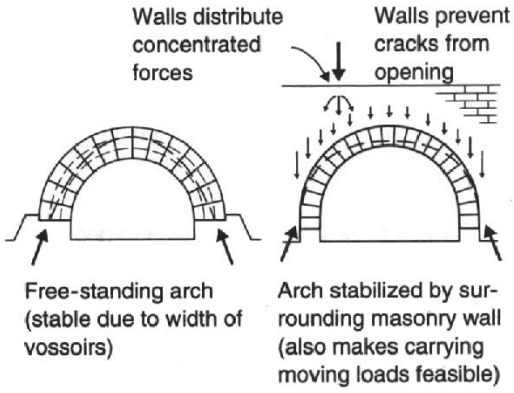


*Millennium Bridge in Newcastle, UK*



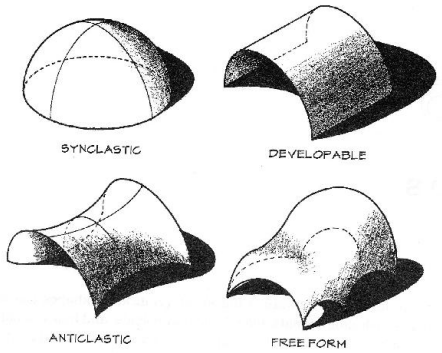
## Arches

- *behavior*
  - *stabilization*
  - *resist thrust*
- *compression only*



# Shell Types

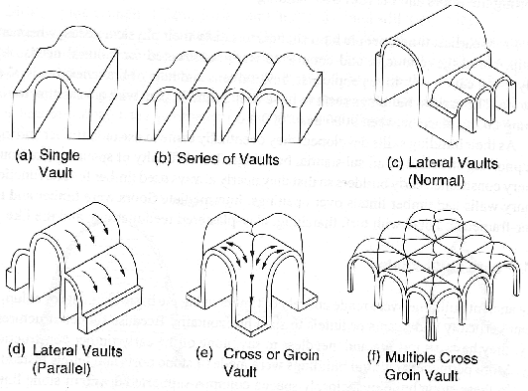
- *shape classifications*
  - *developable:*
    - *revolution (vault)*
  - *synclastic*
    - *doubly curved*
    - *same direction*
  - *anticlastic:*
    - *doubly curved*
    - *opposite curvature*
  - *free form*






# Vaults

- *"wide" arch*

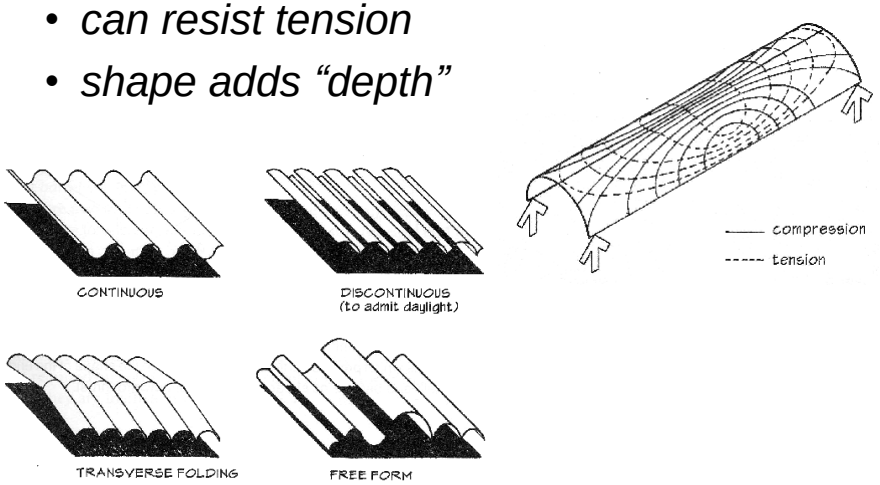



*http:// nisee.berkeley.edu/godden*



# Vaulted Shells

- *can resist tension*
- *shape adds "depth"*

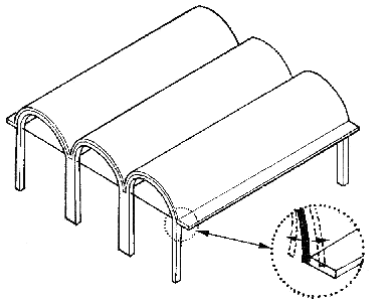


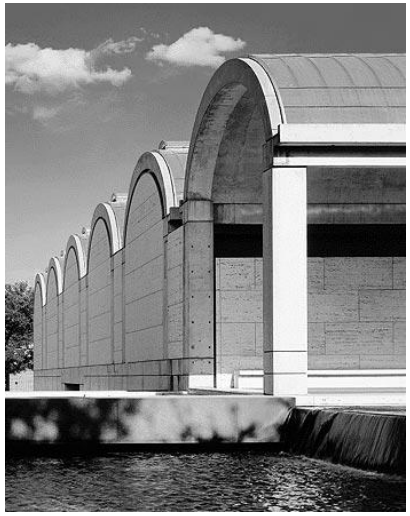



# Kimball Museum, Kahn 1972

## Kimball Museum, Kahn 1972

- *outer shell edges*

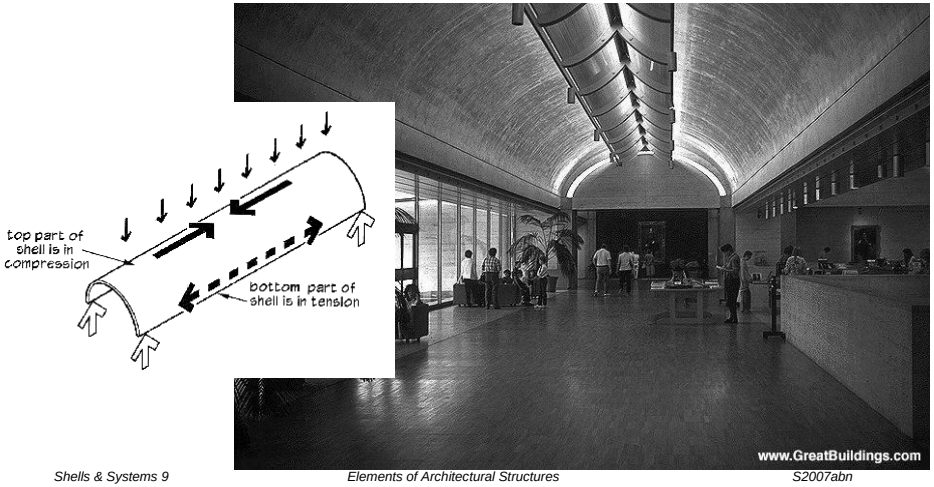






## Kimball Museum, Kahn 1972

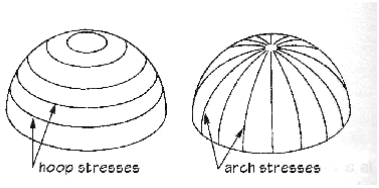
- *skylights at peak*

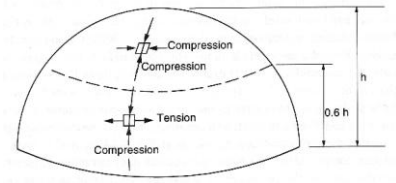


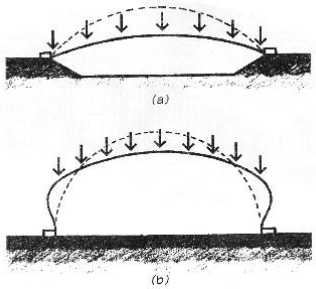



## Domes

- *arch of revolution*
- *compression*
- *some tension*



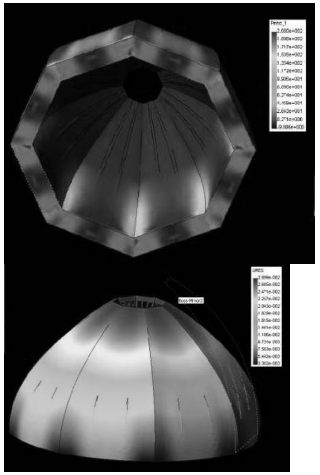






## Domes

- *stresses and displacements*

*© Harvard GSD*



## Annunciation Greek Orthodox Church

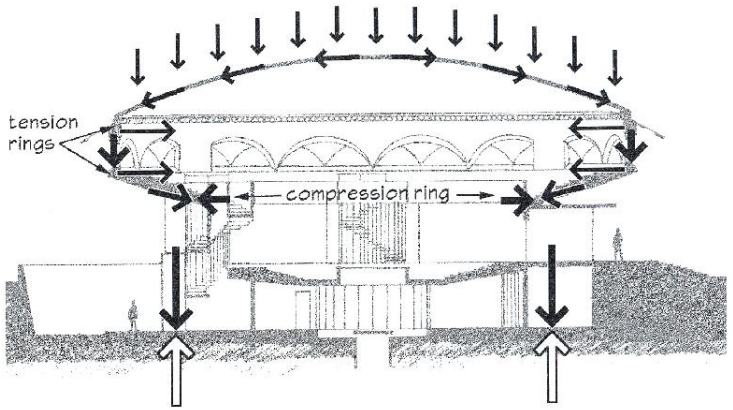
- Wright, 1956

http://www.bluffton.edu



## Annunciation Greek Orthodox Church

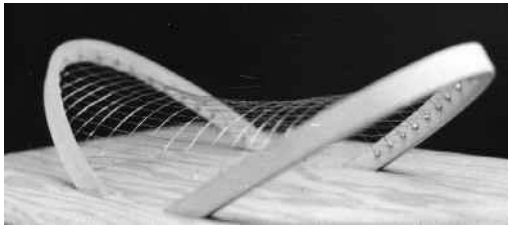
- Wright, 1956






## Anticlastic Shells

- saddle or “ruled” shapes
- surface generated with straight lines



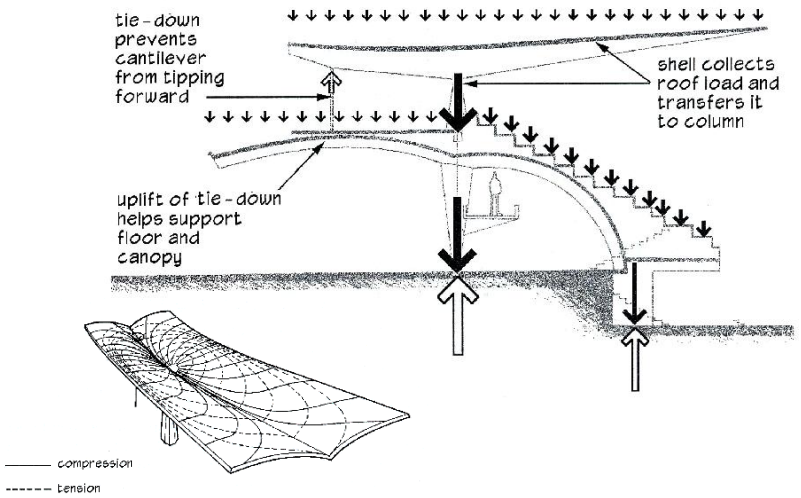
- tension follows “cable drape”
- compression follows “arch”



## Zarzuela Hippodrome, Torroja 1935

http://www.bluffton.edu

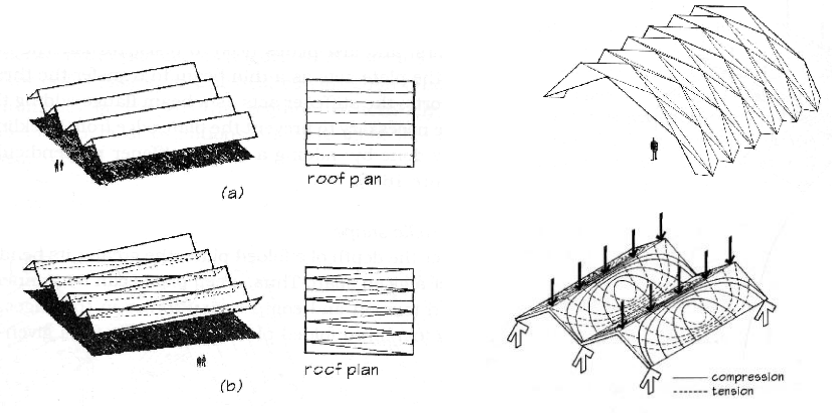
## Zarzuela Hippodrome, Torroja 1935






## Folded Plates

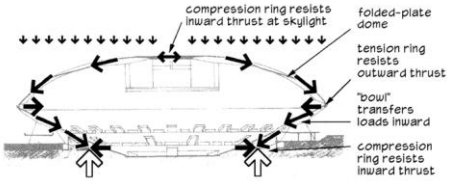
- *increased stiffness with folding*






## Illini Hall, Harrison & Abramovitz 1963

www.library.illinois.edu

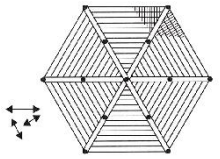



- *Assembly Hall, University of Illinois*
- *Harrison & Abramovitz 1963*
- *Edge-supported dome spanning 400 feet wound with 614 miles of one-fifth inch steel wire*

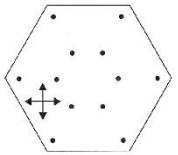


## Systems

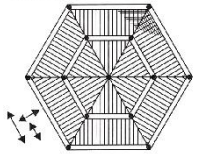
- *total of components*
- *behavior of whole*
- *classifications*
  - *one-way*
  - *two-way*
  - *tubes*
  - *braced*
  - *unbraced*



(a) One-way radial beam-and-column system for a hexagonal or circular configuration.



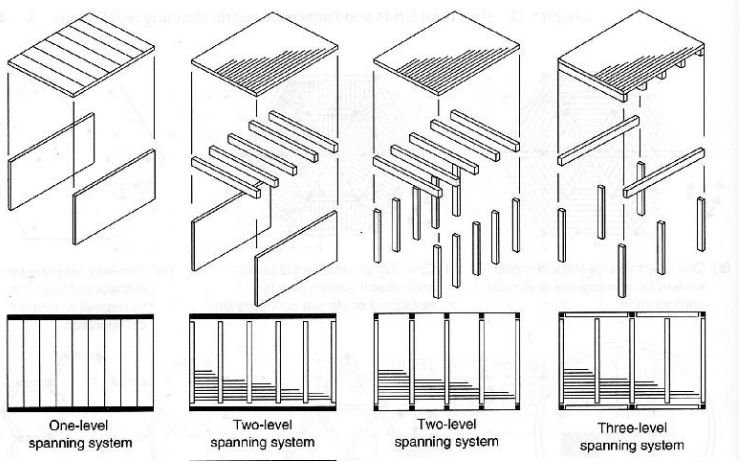
(c) Two-way flat-plate system (without beams) for a hexagonal or circular configuration.



(b) One-way circumferential beam-and-column system plan for hexagonal or circular configuration.

# One-Way Systems

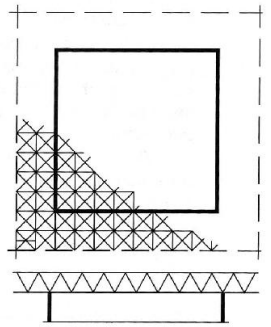
- *horizontal vs. vertical*






# Two-Way Systems

- *spanning system less obvious*
- *horizontal*
  - *plates*
  - *slabs*
  - *space frames*
- *vertical*
  - *columns*
  - *walls*

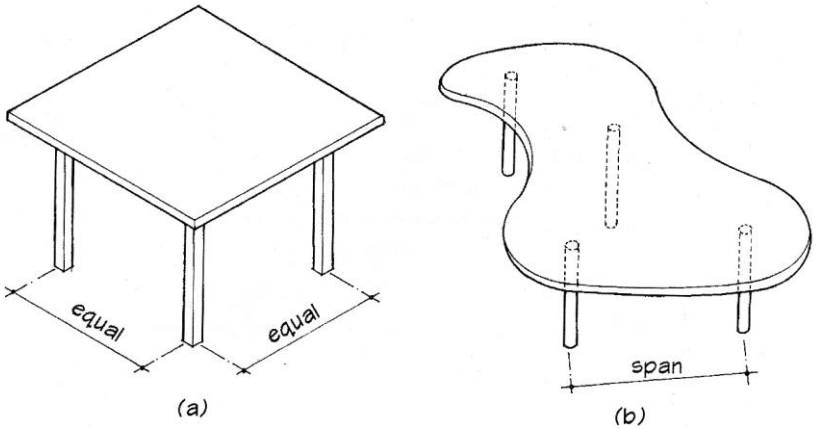


(i) Space-frame system on walls with cantilevers.



# System Selection

- *evaluation of alternatives*

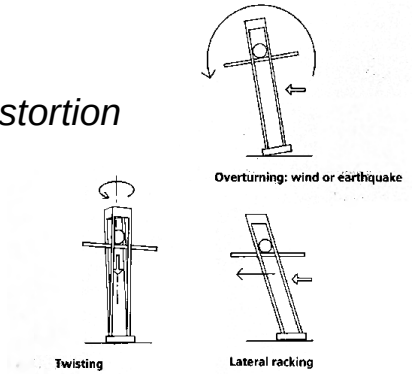





| DESIGN CRITERIA | Light-frame timber | Heavy-frame timber | Masonry bearing wall | Steel frame (hinge connections) | Steel frame (rigid connections) | Steel open-web joists | Steel space frame | Steel decking | Site-cast concrete: one-way slab | Site-cast concrete: two-way plate | Site-cast concrete: two-way slab | Site-cast concrete: one-way joists | Site-cast concrete: waffle slab | Precast concrete: solid slab | Precast concrete: hollow-core slab | Precast concrete: single tee | Precast concrete: double tee | RATIONALE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Exposed, fire-resiant construction | | ■ | ■ | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | Inherently fire-resistive construction |
| Irregular building form | ■ | | | ■ | | | | | ■ | ■ | ■ | | | | | | | Simple, site-fabricated systems |
| Irregular column placement | | | | | | | | | | ■ | ■ | | ■ | | | | | Systems without beams in roof or floors |
| Minimize floor thickness | | | | | | | | | ■ | ■ | | | | ■ | ■ | | | Precast-concrete systems without ribs |
| Allow for future renovations | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | ■ | | ■ | ■ | ■ | ■ | | Short-span, one-way, easily modified |
| Permit construction in poor weather | ■ | ■ | | ■ | ■ | ■ | ■ | ■ | | | | | | ■ | ■ | ■ | ■ | Quickly erected; avoid site-cast concrete |
| Minimize off-site fabrication time | ■ | | ■ | | | | | | ■ | ■ | ■ | ■ | ■ | | | | | Easily formed or built on site |
| Minimize on-site erection time | | ■ | | ■ | ■ | ■ | | ■ | | | | | | ■ | ■ | ■ | | Highly prefabricated; modular components |
| Minimize low-rise construction time | ■ | ■ | | ■ | ■ | ■ | | ■ | | | | | | ■ | ■ | ■ | | Lightweight, easily formed or prefabricated |
| Minimize medium-rise construction time | | | | ■ | ■ | ■ | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | Precast, site-cast concrete; steel frames |
| Minimize high-rise construction time | | | | ■ | ■ | ■ | | ■ | | | | | | | | | | Strong; prefabricated; lightweight |
| Minimize shear walls or diagonal bracing | | | ■ | | ■ | | | | ■ | ■ | ■ | | ■ | | | | | Capable of forming rigid joints |
| Minimize dead load on foundations | ■ | ■ | | ■ | ■ | ■ | ■ | ■ | | | | | | ■ | ■ | ■ | | Lightweight, short-span systems |
| Minimize damage due to foundation settlement | ■ | ■ | | ■ | | | | ■ | | | | | | ■ | ■ | ■ | | Systems without rigid joints |
| Minimize the number of separate trades on job | ■ | ■ | ■ | | | | | | | | | | | | | | | Multipurpose components |
| Provide concealed space for mech. services | ■ | | | | | ■ | ■ | | | | | | | | ■ | | | Systems that inherently provide voids |
| Minimize the number of supports | | | | | | | ■ | ■ | | | | | | | | | | Two-way, long-span systems |
| Long spans | | | | | | | ■ | ■ | | | | | | | | ■ | | Long-span systems |

## Structural Design Criteria

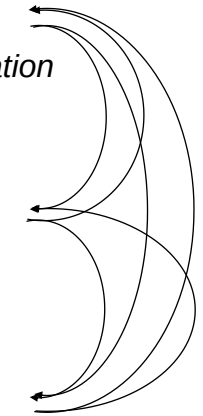
- components stay together
- structure acts as whole to be stable
  - resist sliding
  - resist overturning
  - resist twisting and distortion
- internal stability
  - interconnectedness
- strength & stiffness






## Structural Design Sequences

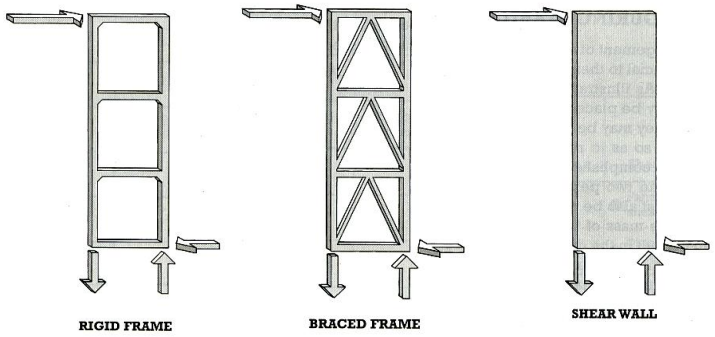
- first-order design
  - structural type and organization
  - design intent
  - contextual or programmatic
- second-order
  - structural strategies
  - material choice
  - structural systems
- third-order
  - member shaping & sizing





## Design Issues

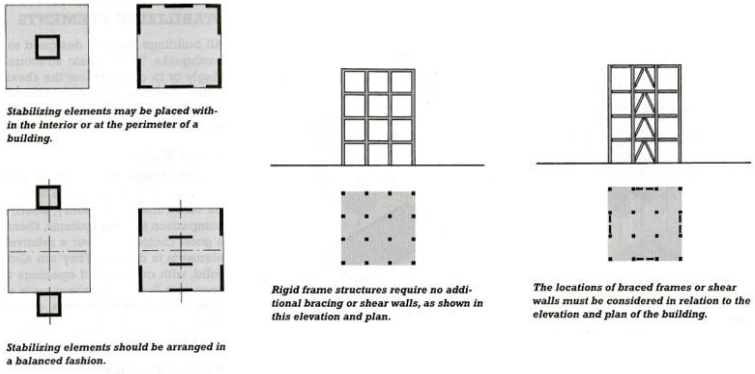
- lateral stability – all directions





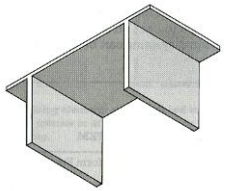

## Design Issues

- configuration

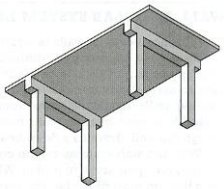


## Design Issues

- *vertical load resistance*



WALL AND SLAB SYSTEMS
*(shown from below)*



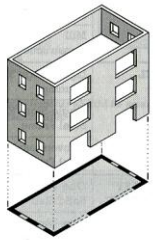
COLUMN AND BEAM SYSTEMS
*(shown from below)*

*walls* *columns*

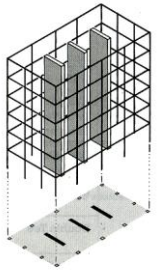


## Design Issues

- *lateral load resistance*



*Shear walls may be arranged in a box form to resist lateral forces from all directions.*

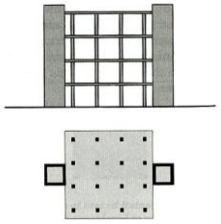


*When combined with other stabilizing mechanisms, shear walls may be arranged so as to resist forces in only one direction of a building.*

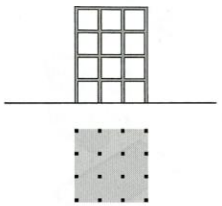


## Design Issues

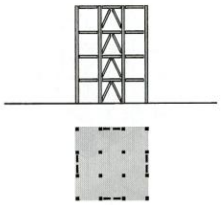
- *lateral load resistance*



*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 no additional bracing or shear walls, as shown in this elevation and plan.*

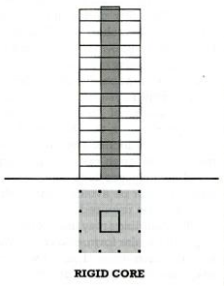


*The locations of braced frames or shear walls must be considered in relation to the elevation and plan of the building.*

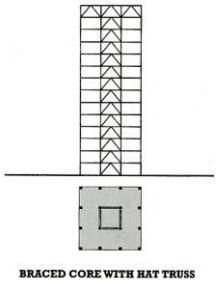


## Design Issues

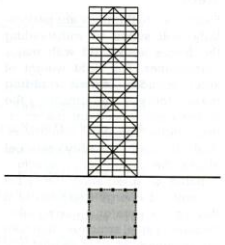
- *multi-story*
  - *cores, tubes, braced frames*



RIGID CORE



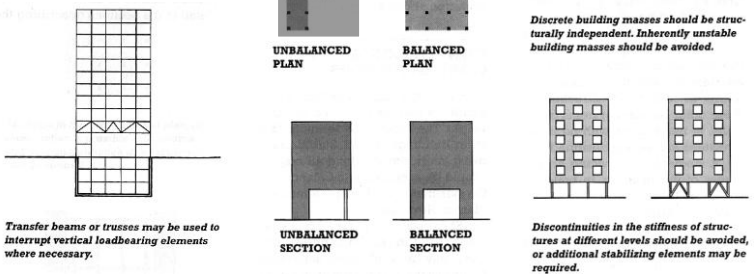
BRACED CORE WITH HAT TRUSS



BRACED FRAME TUBE

## 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*



## Final Exam Material

- *my list (continued):*
  - *systems*
    - *levels*
    - *design considerations*
  - *design specifics*
    - *steel (ASD & LRFD)*
    - *concrete*
    - *wood*
    - *masonry*