

# ARCHITECTURAL STRUCTURES: FORM, BEHAVIOR, AND DESIGN

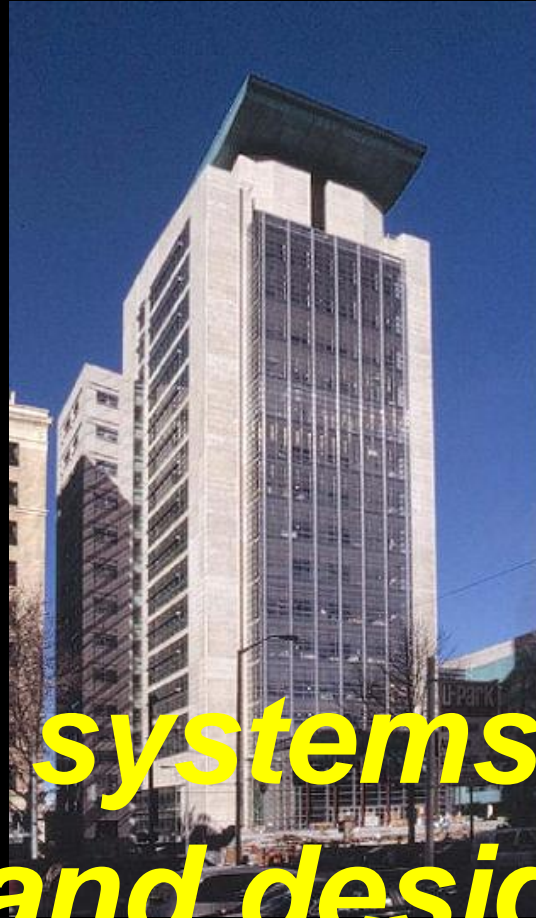
ARCH 331

DR. ANNE NICHOLS

FALL 2013

lecture  
**two**

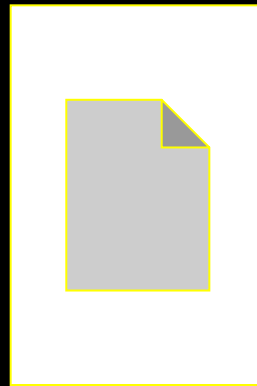
## structural systems, planning and design



AISC teaching aids: Courtesy of John Hooper, MKA Seattle

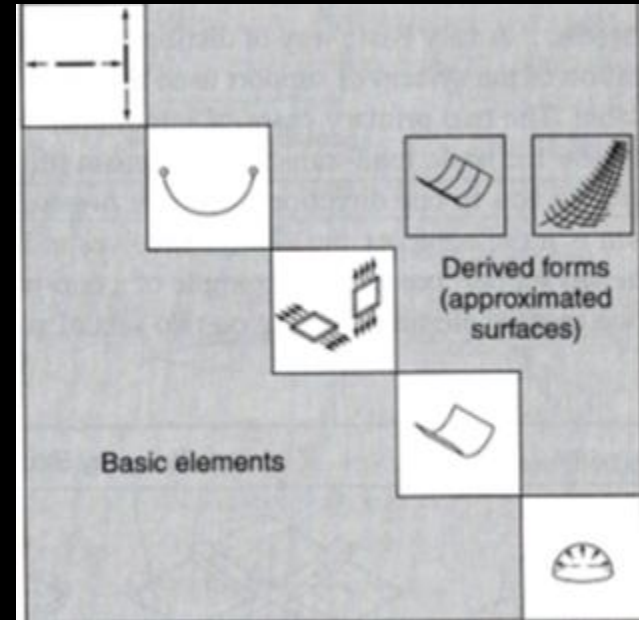
# *Project*

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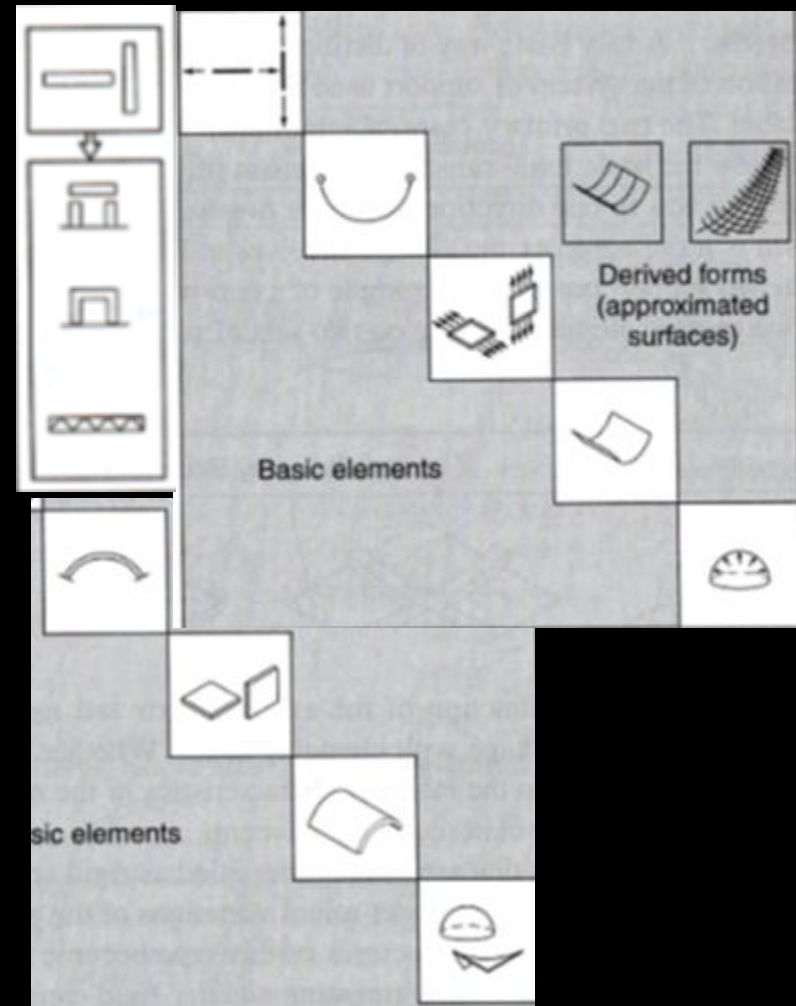
# Structural Organization

- *classifications*
  - *geometry*
    - *line-forming*
    - *surface-forming*
  - *stiffness*
    - *rigid*
    - *flexible*
  - *one-way or two-way*
    - *spatial organization and load transfer*
  - *materials*

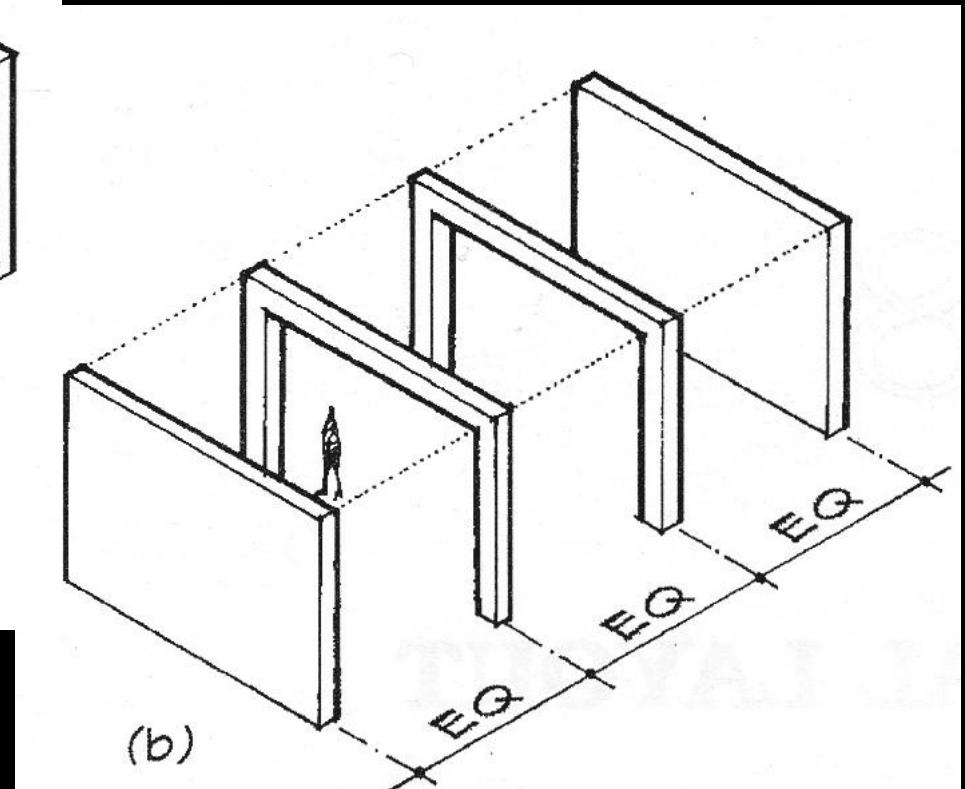
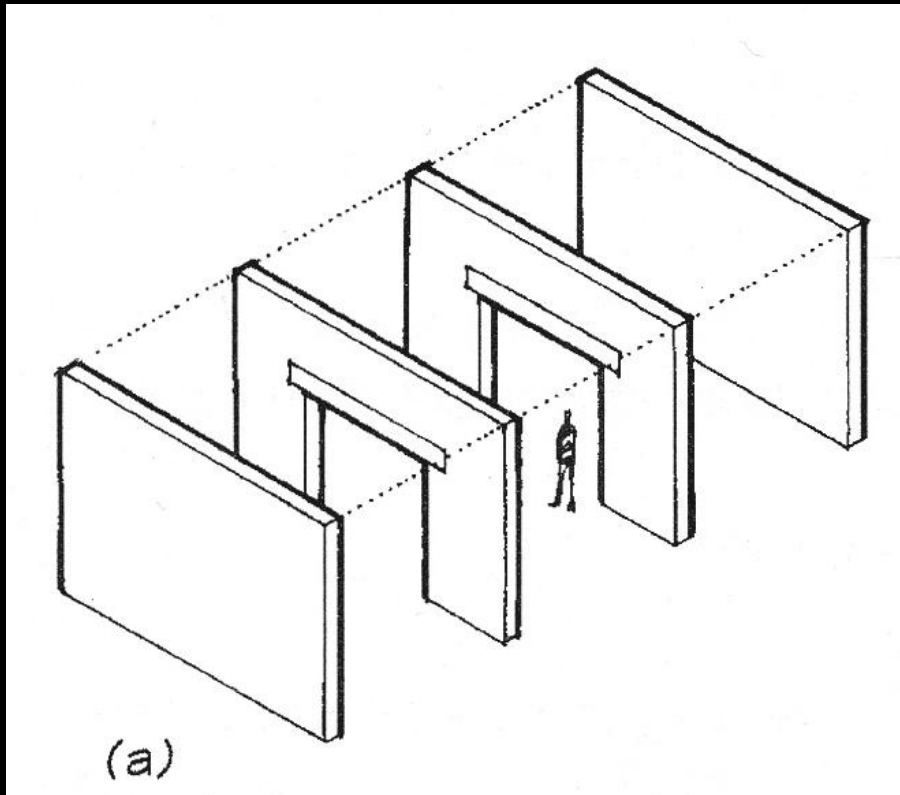


# Structural Components

- *bearing walls*
- *columns*
- *beams*
- *flat plates*
- *trusses*
- *arches*
- *shells*
- *cables*



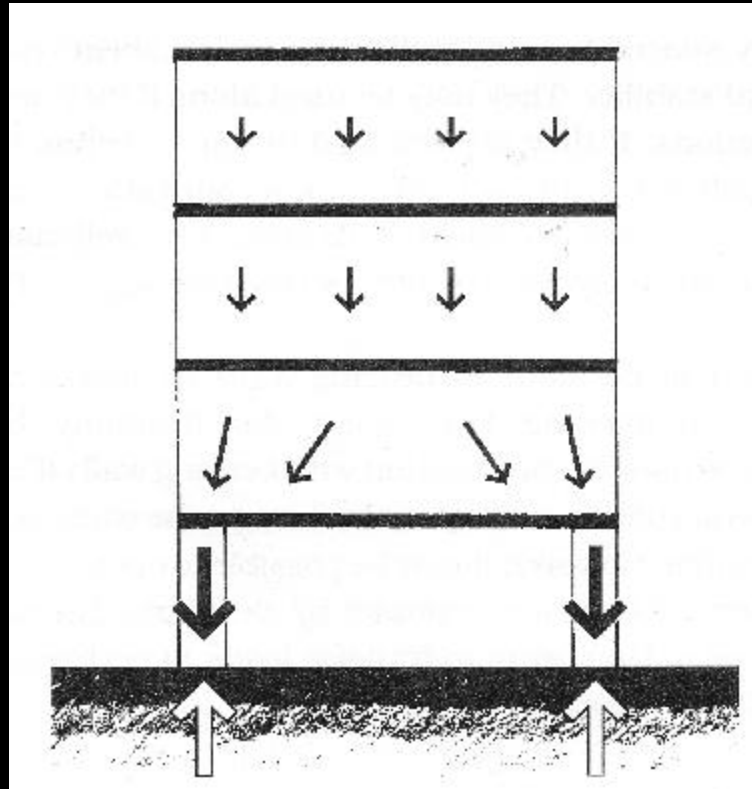
# Bearing Walls



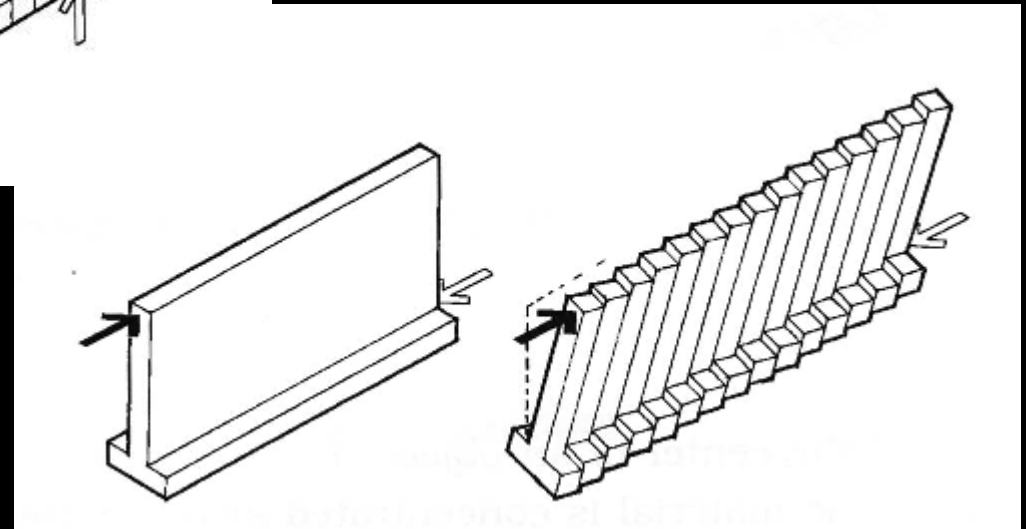
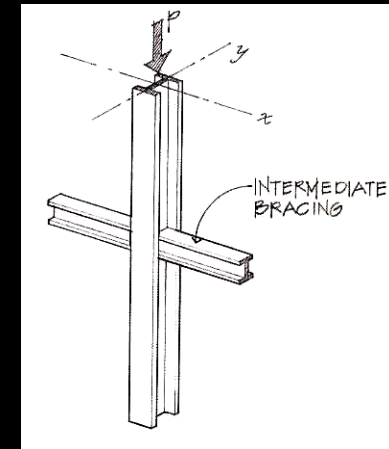
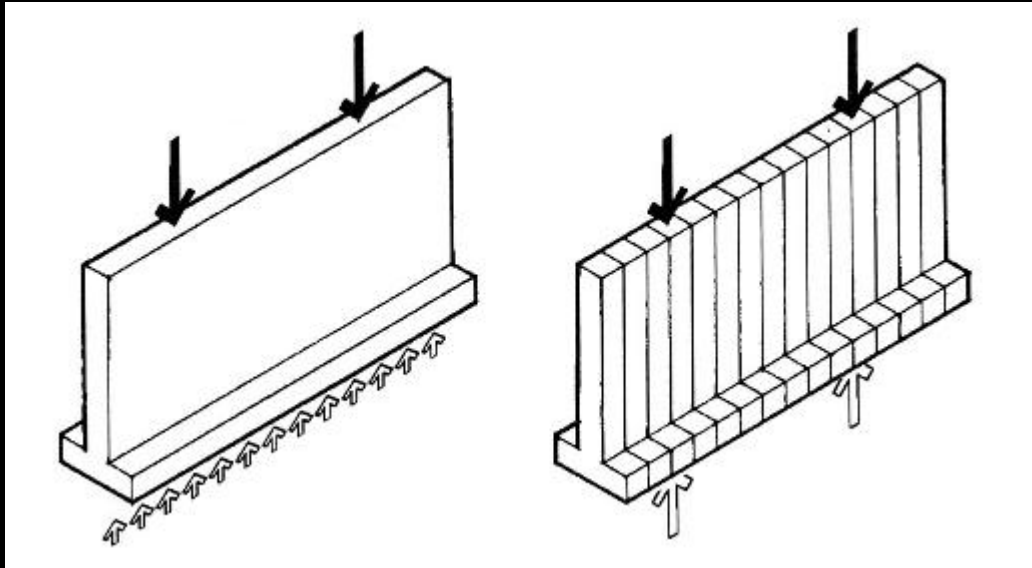
# Bearing Walls

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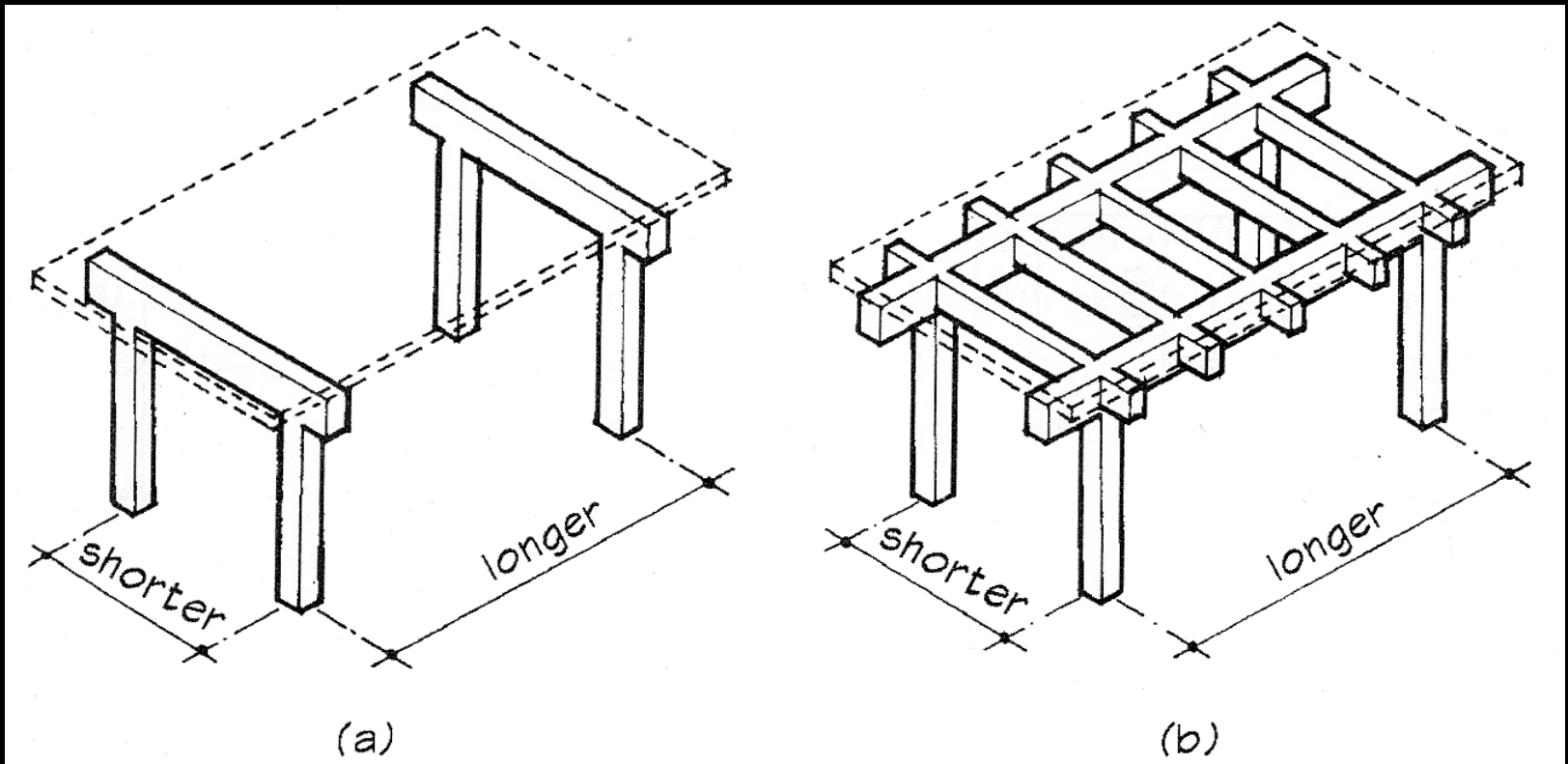
- *behavior as “deep beams”*



# Columns & Walls

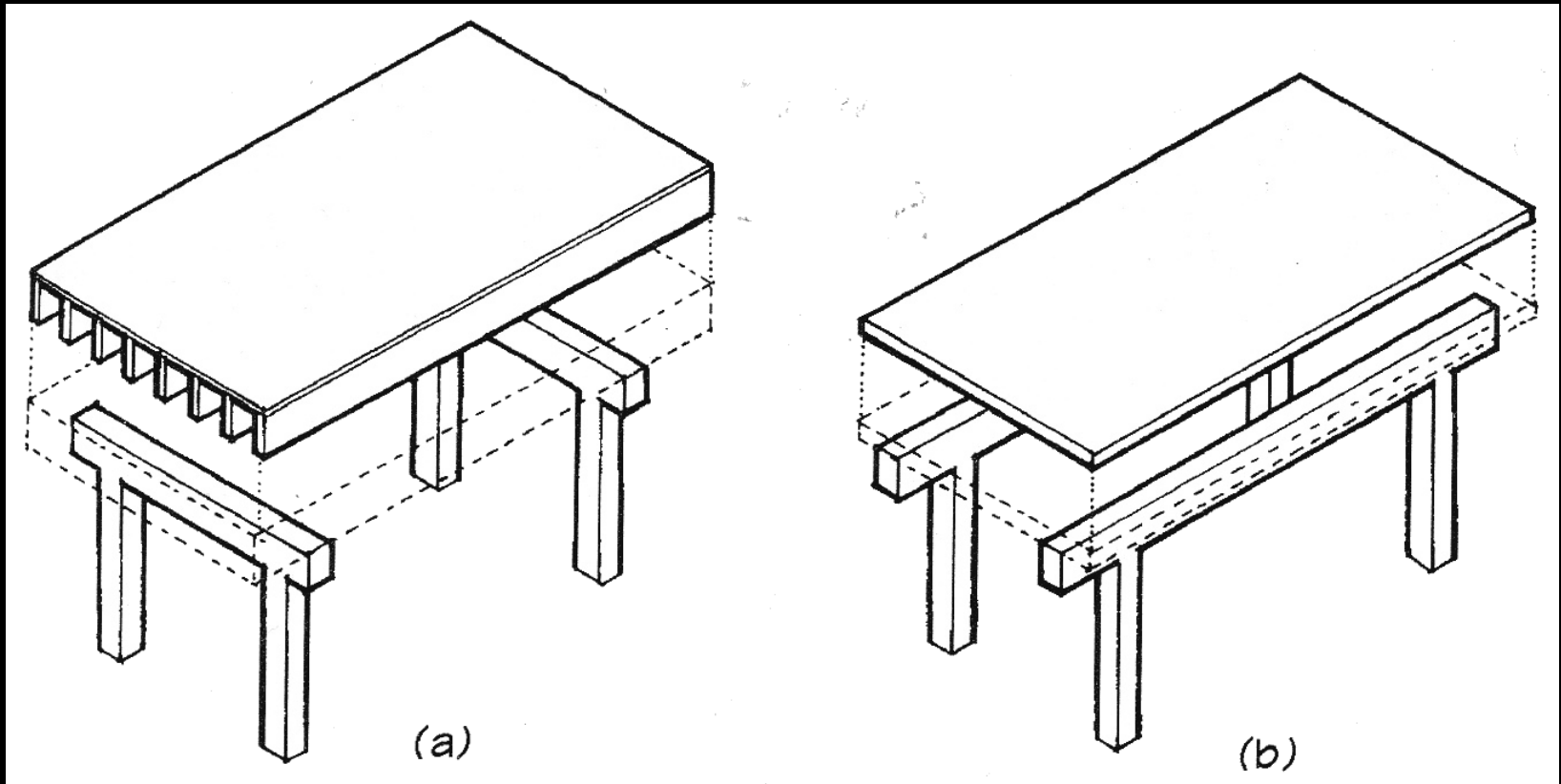


# Beams & Plates

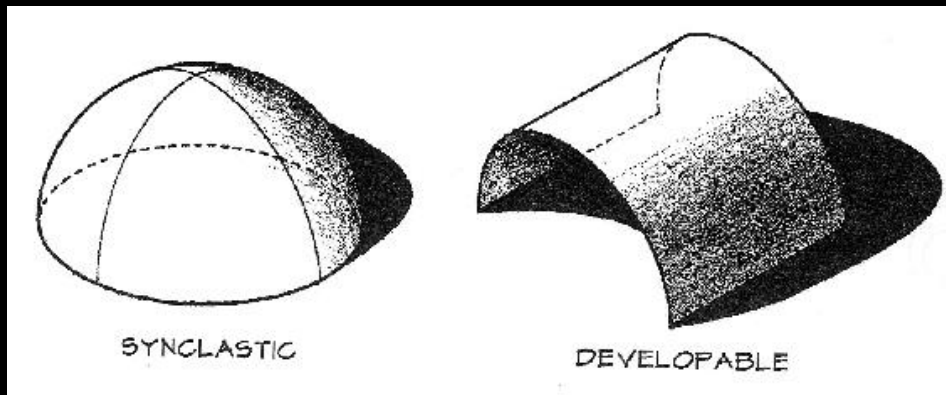
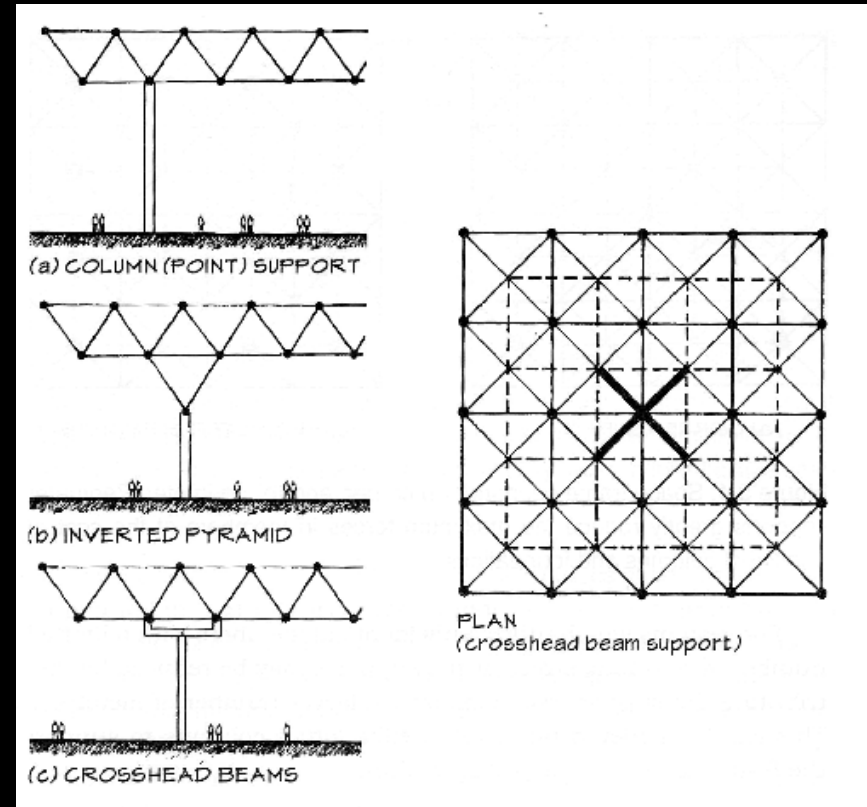
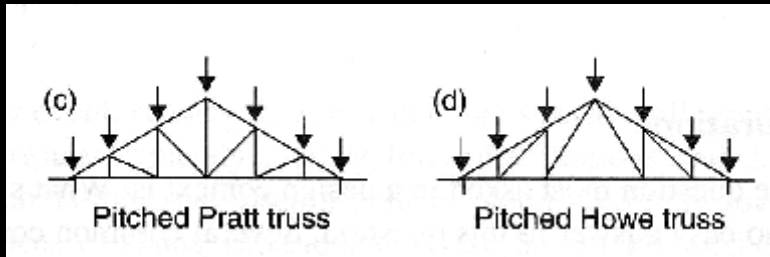




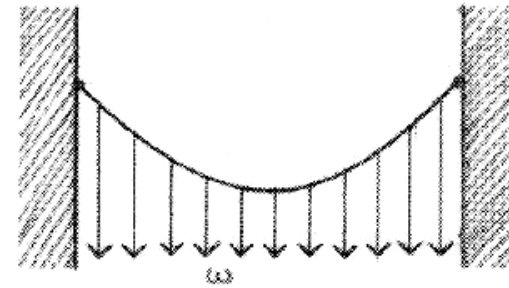
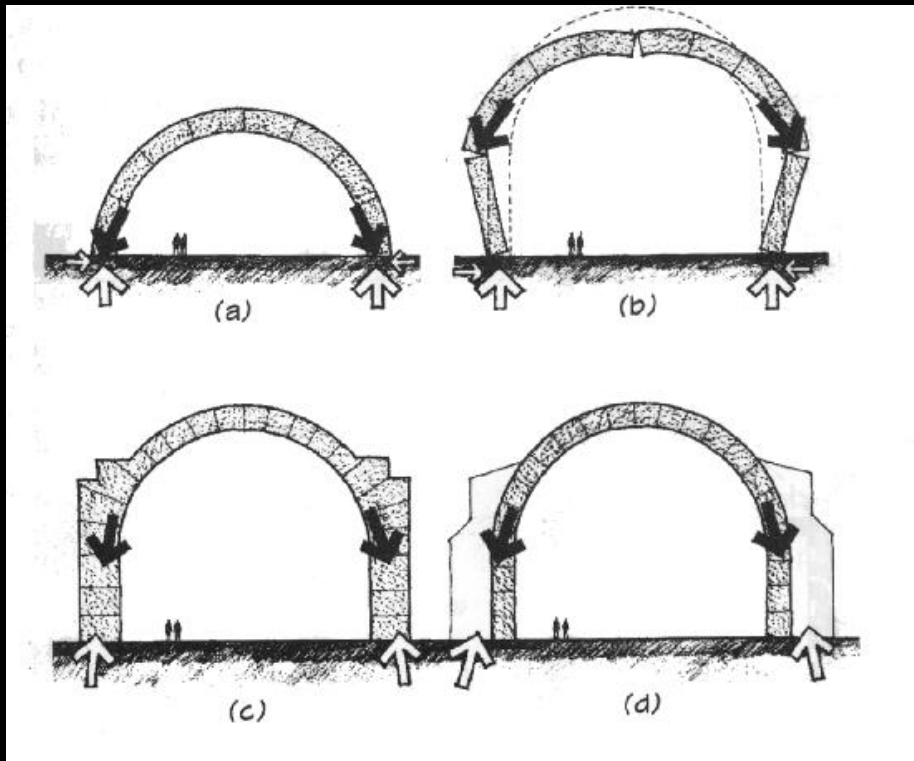
# Beams & Plates



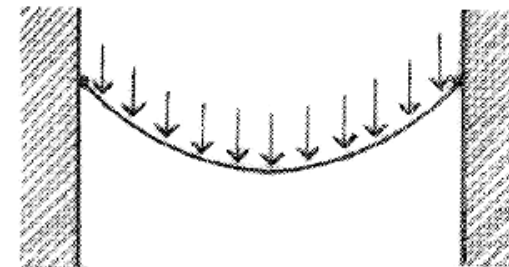
# Trusses and Shells



# Arches and Cables



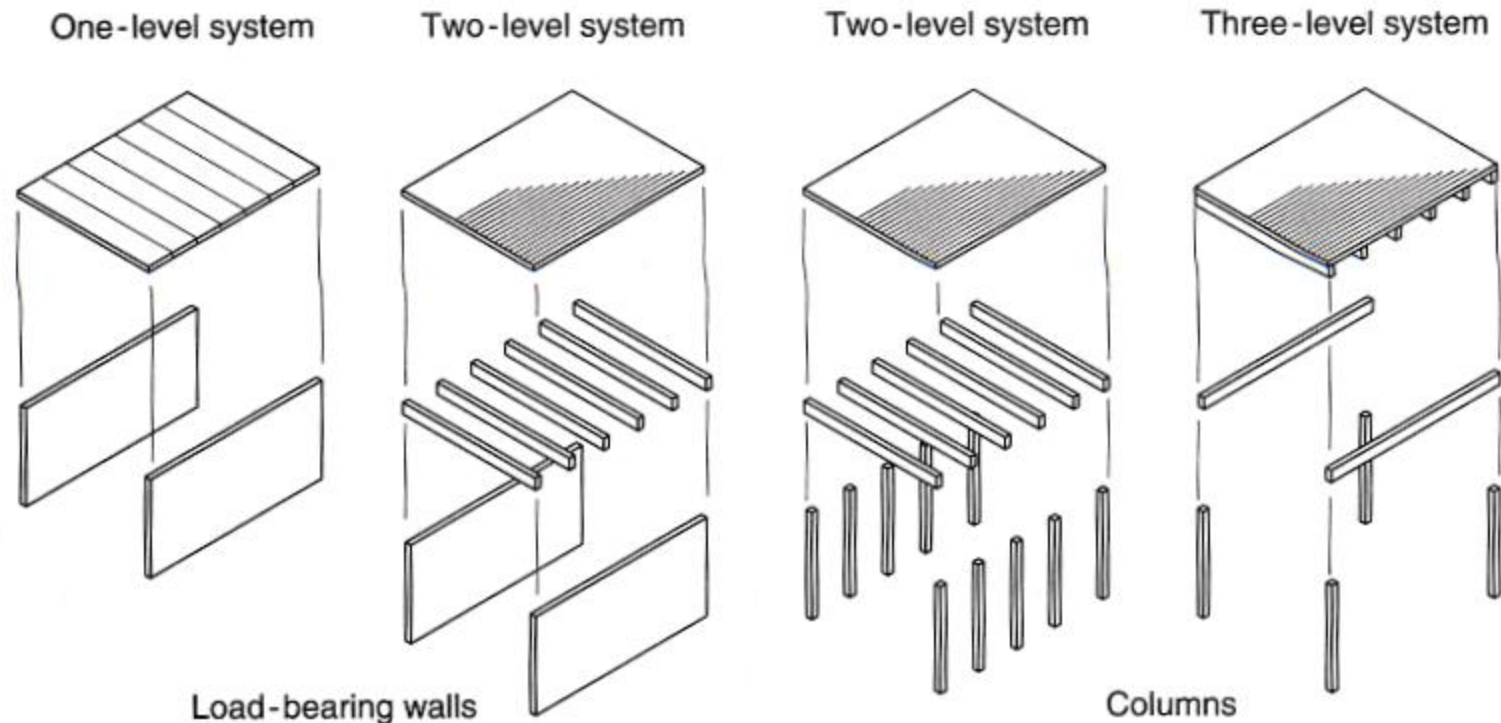
(c) Uniform loads (horizontally)—parabola.



(d) Uniform loads (along the cable length)—catenary.

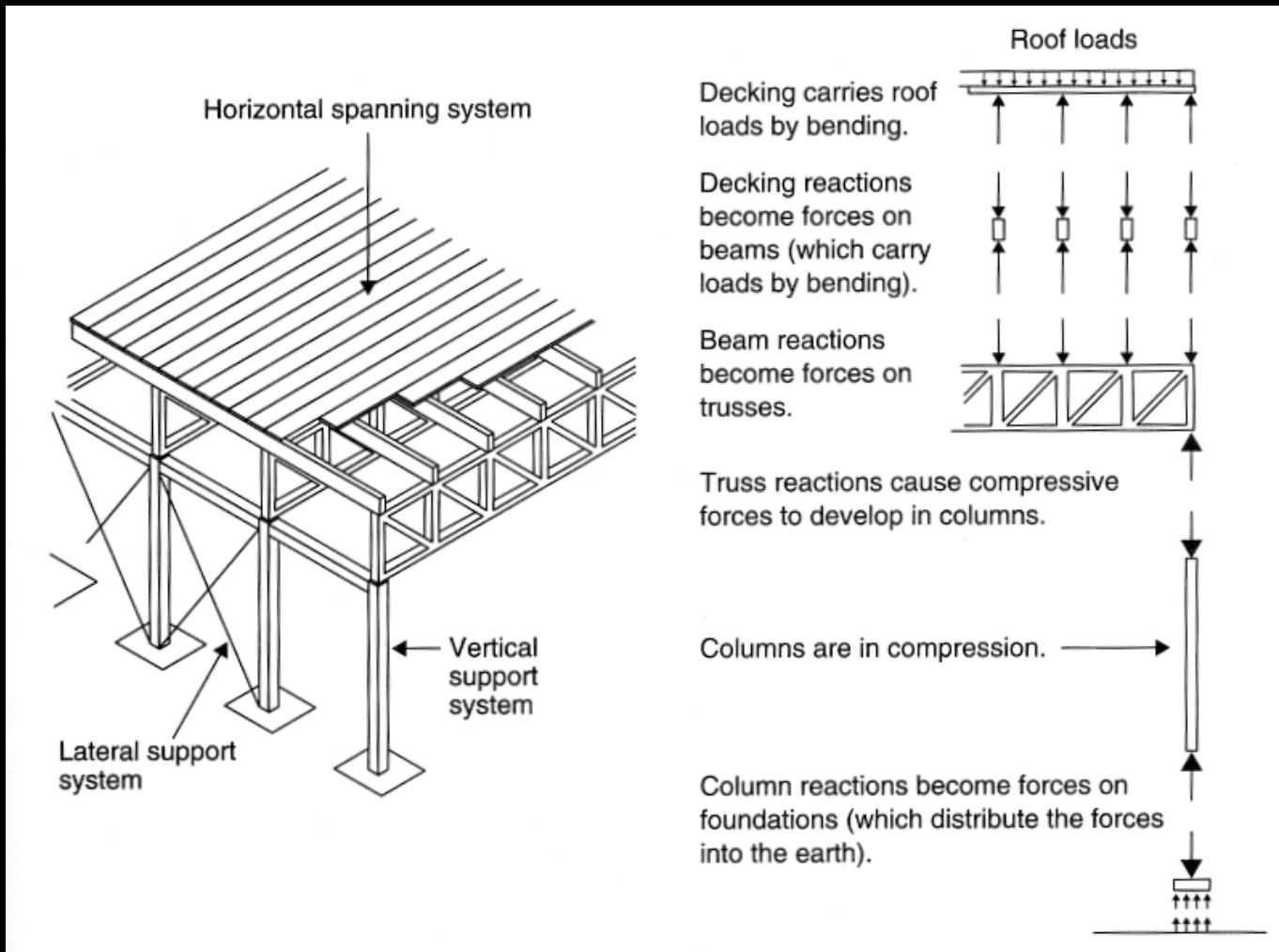
# Building Framing

- *Components or Assemblages*



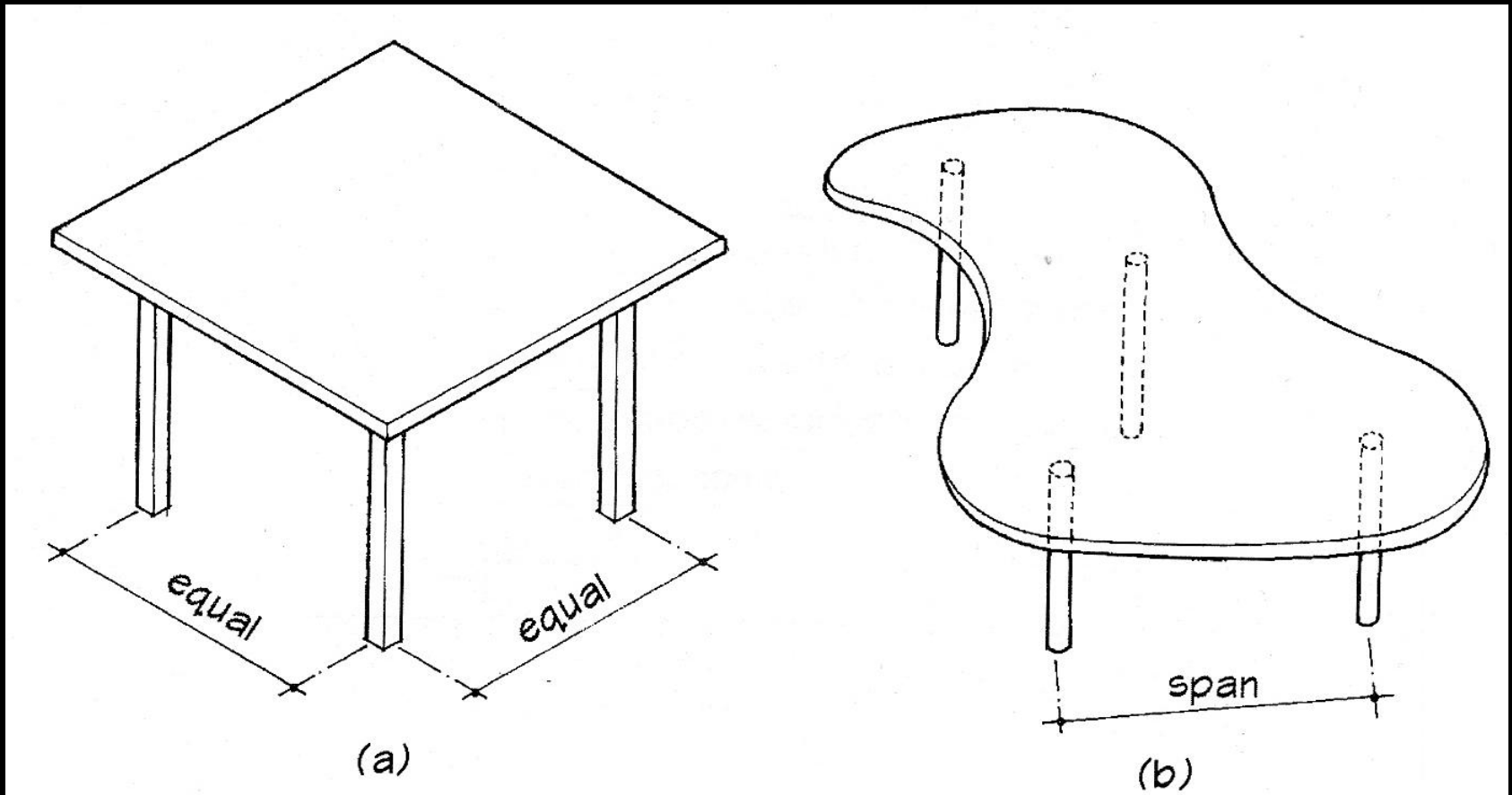
(a) Common types of horizontal spanning systems (one, two, and three level systems) used in relation to different types of load-bearing wall and columnar vertical support systems.

# Building Framing



# System Selection

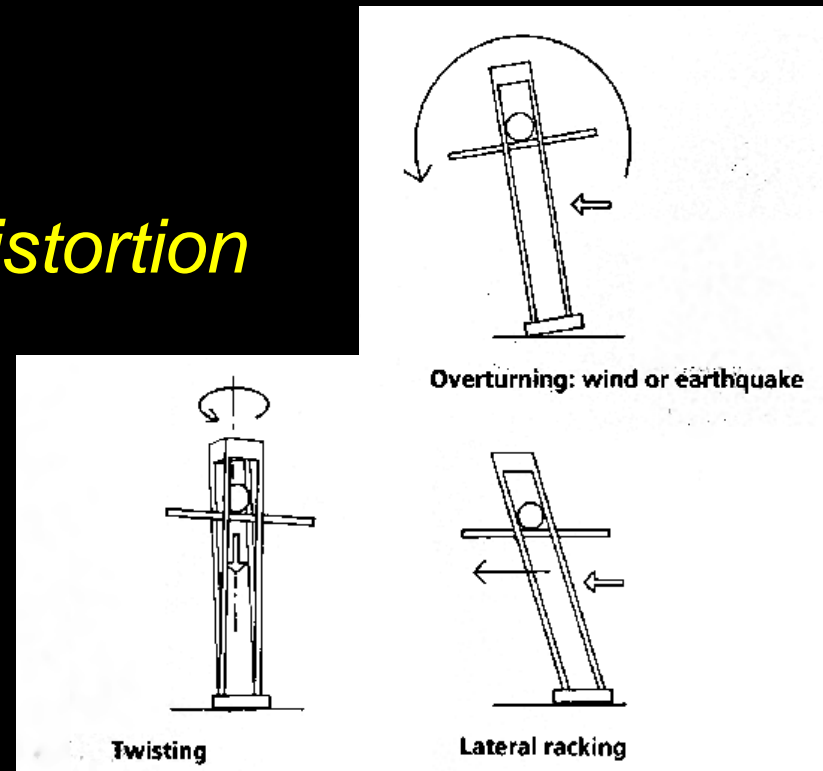
- *evaluation of alternatives*



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*

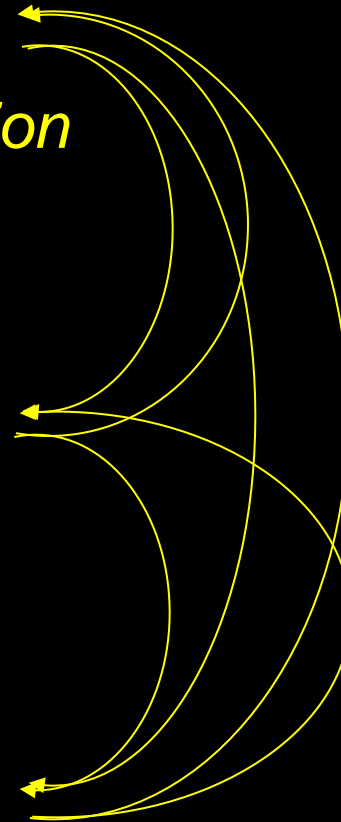




# Structural Design Sequences

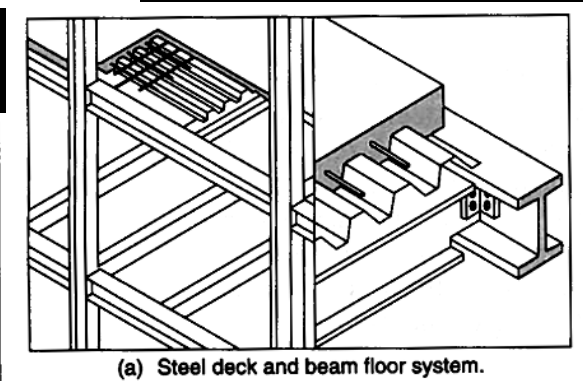
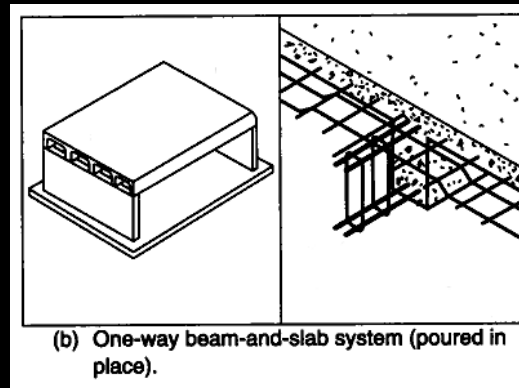
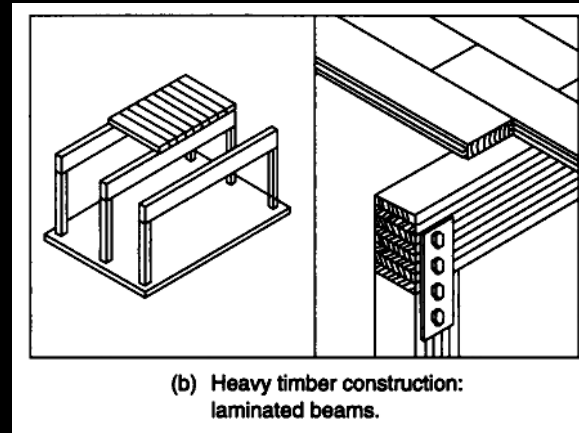
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- *first-order design*
  - *structural type and organization*
  - *design intent*
  - *contextual or programmatic*
- *second-order*
  - *structural strategies*
  - *material choice*
  - *structural systems*
- *third-order*
  - *member shaping & sizing*



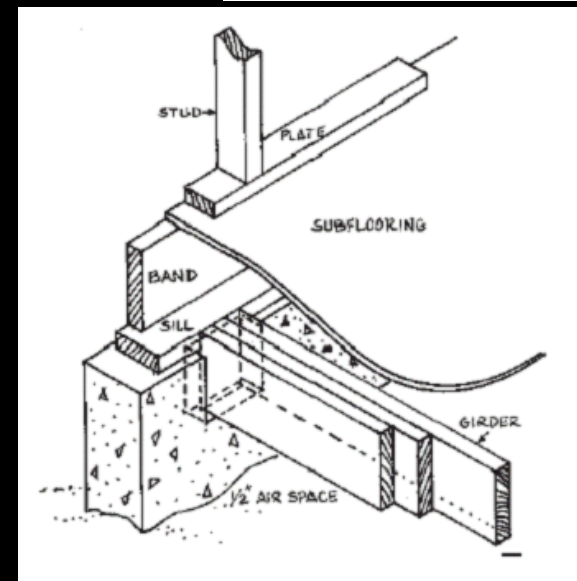
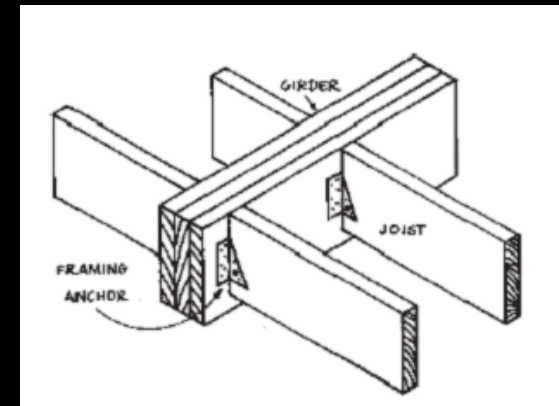
# Systems by Materials

- Wood
- Steel
- Concrete
- Masonry
- Composite



# Timber Construction

- *all-wood framing systems*
  - studs, beams, floor diaphragms, shearwalls
  - glulam arches & frames
  - post & beams
  - trusses
- *composite construction*
  - masonry shear walls
  - concrete
  - steel



# Timber Construction

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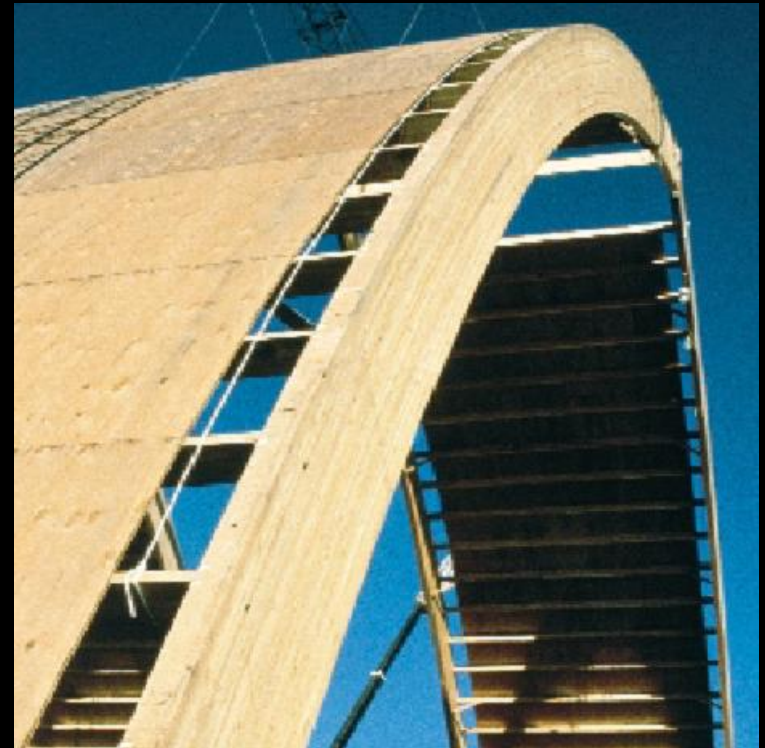
- *studs, beams*
- *floor diaphragms & shear walls*



# Timber Construction

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- *glulam arches & frames*
  - *manufactured or custom shapes*
  - *glue laminated*
  - *bigger members*



# Timber Construction

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- *post & beam*

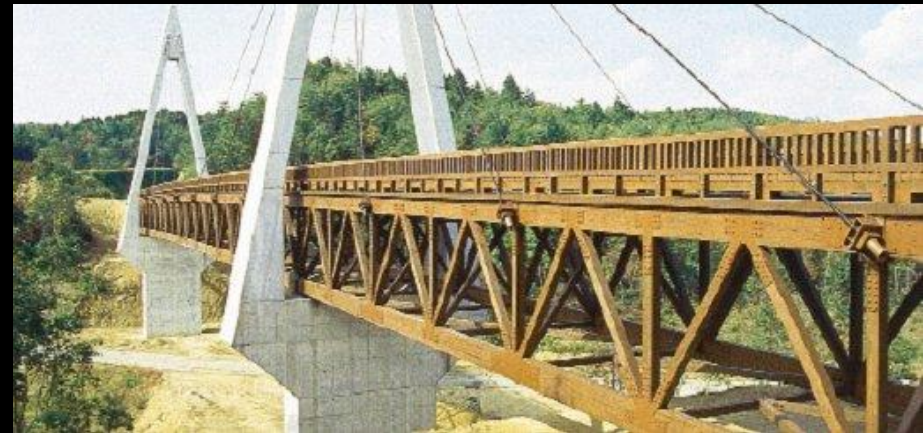
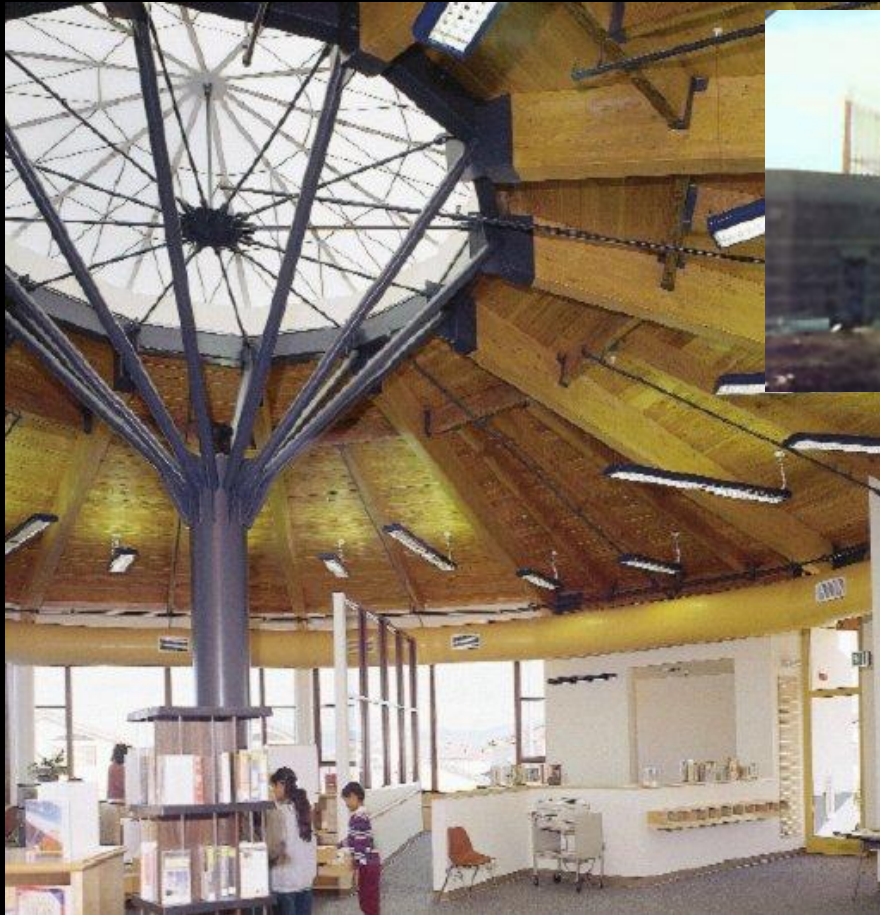


- *trusses*



# Timber Construction

- *composite construction*



# Steel

- *cast iron – wrought iron - steel*
- *cables*
- *columns*
- *beams*
- *trusses*
- *frames*

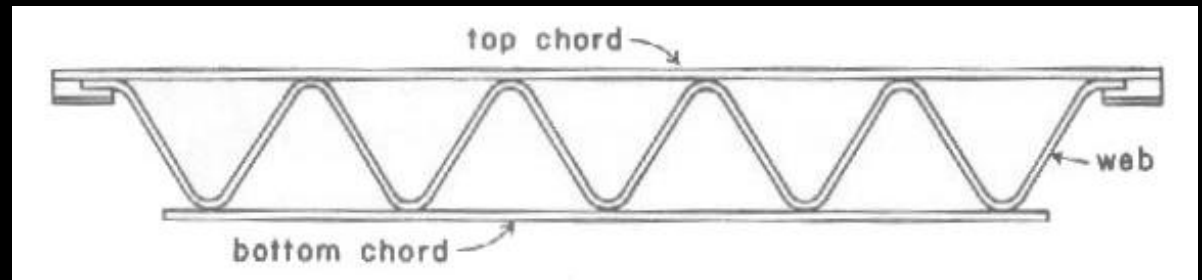
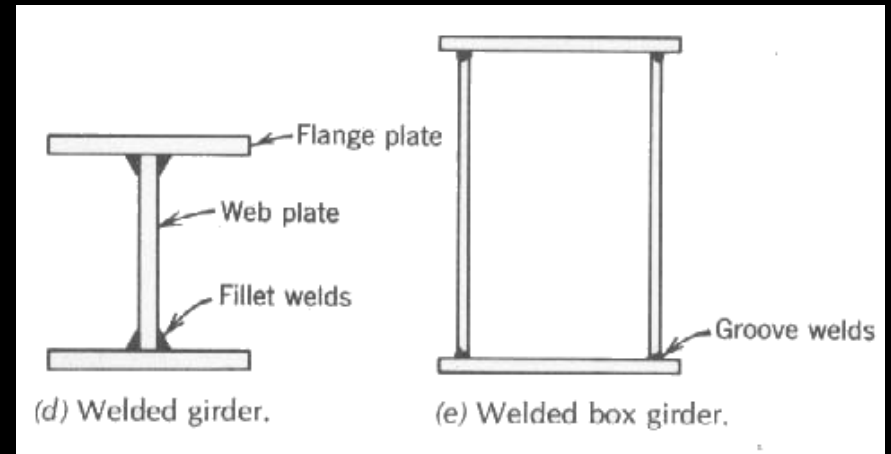
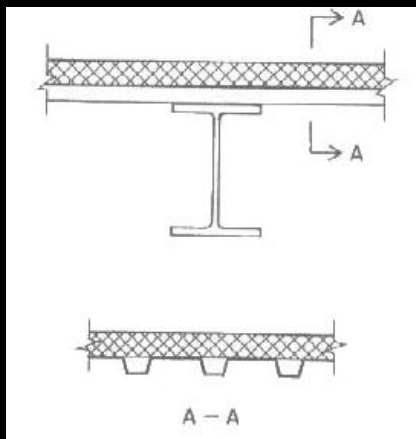


<http://nisee.berkeley.edu/godden>



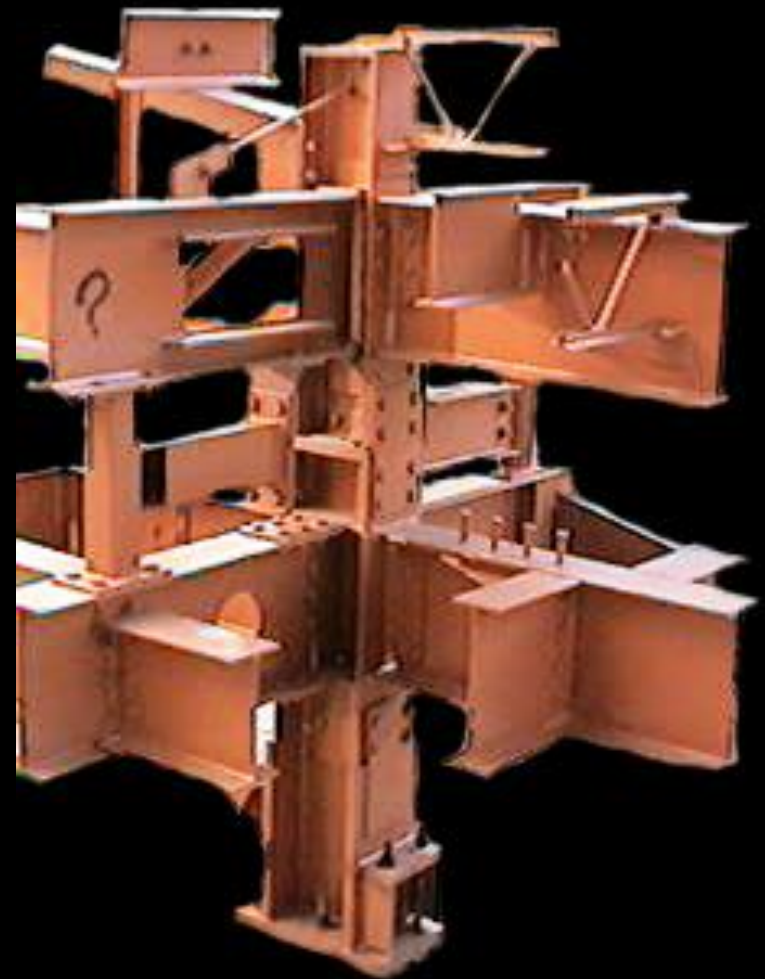
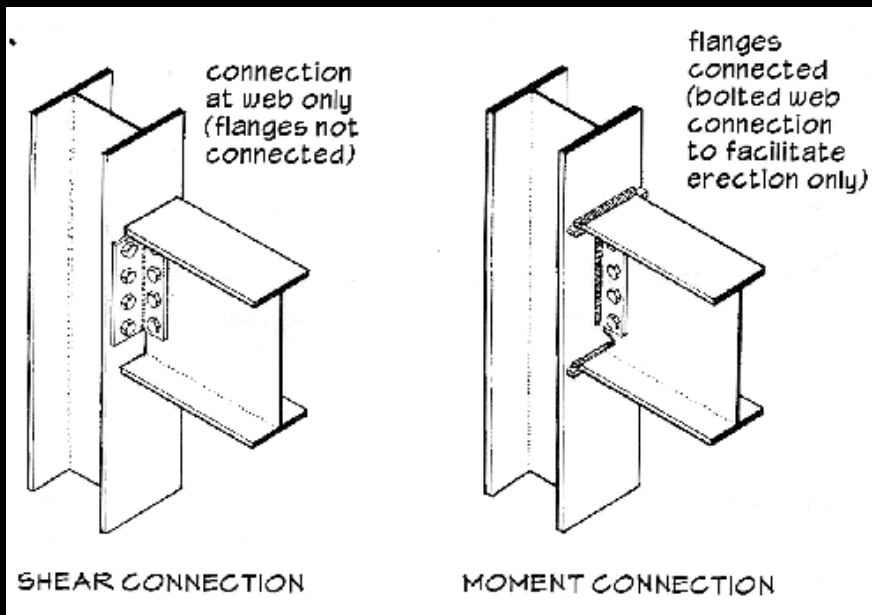
# Steel Construction

- *standard rolled shapes*
- *open web joists*
- *plate girders*
- *decking*



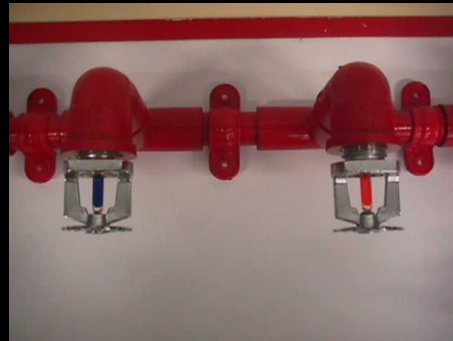
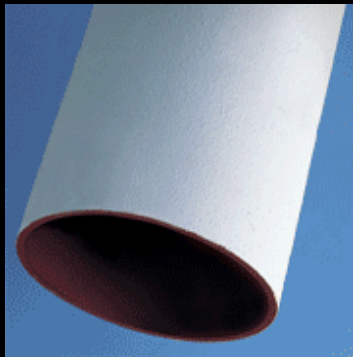
# Steel Construction

- *welding*
- *bolts*



# Steel Construction

- *fire proofing*
  - *cementitious spray*
  - *encasement in gypsum*
  - *intumescent – expands with heat*
  - *sprinkler system*



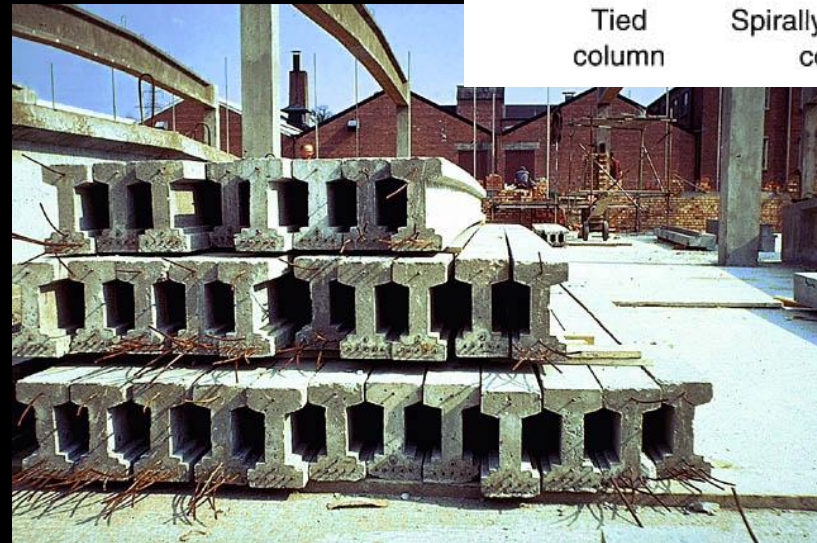
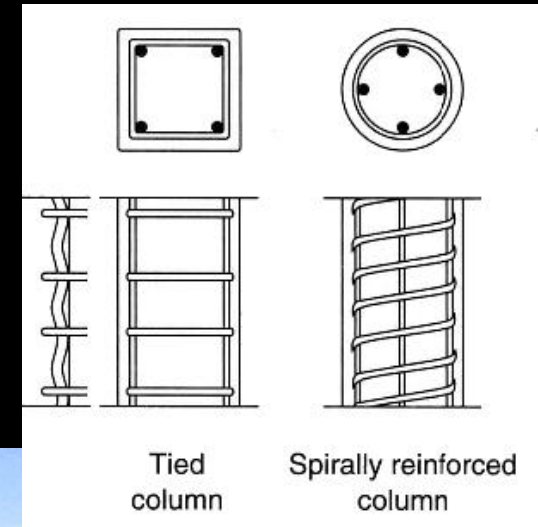
# Concrete

- *columns*
- *beams*
- *slabs*
- *domes*
- *footings*



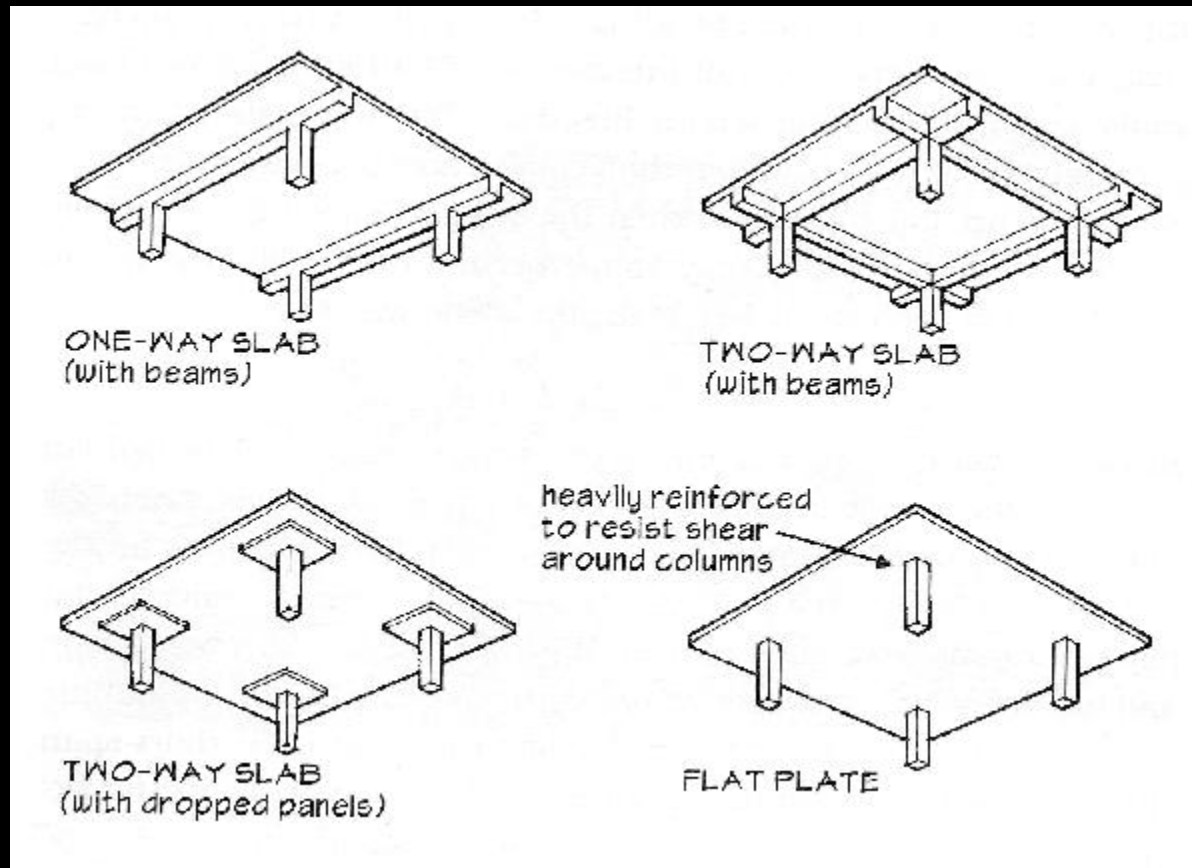
# Concrete Construction

- *cast-in-place*
- *tilt-up*
- *prestressing*
- *post-tensioning*

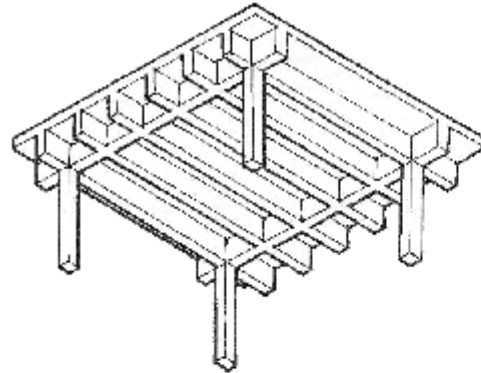


# Concrete Floor Systems

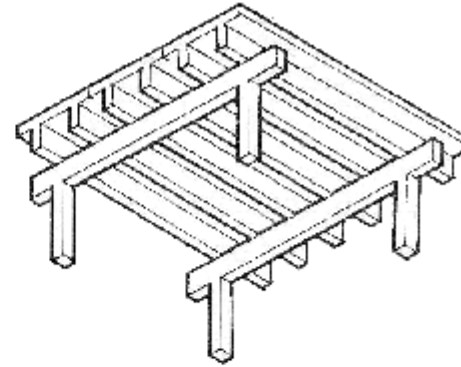
- *types & spanning direction*



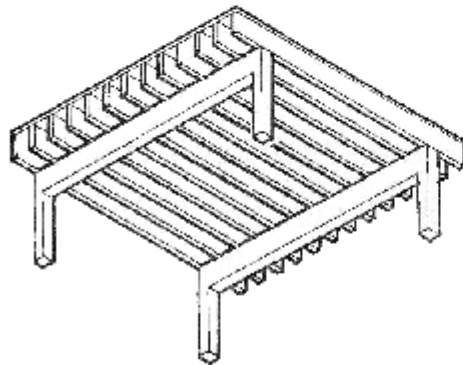
# Concrete Floor Systems



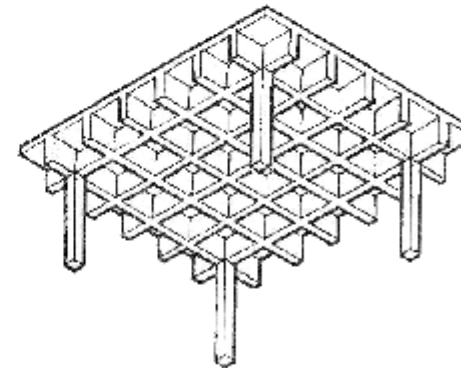
(a) ONE-WAY CONCRETE JOISTS



(b) PRECAST DOUBLE-TEES



(c) WOOD JOISTS



(d) WAFFLE SLAB (two-way joists)

# Masonry

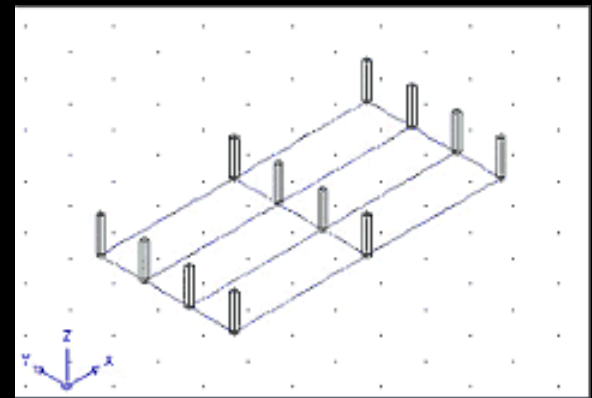
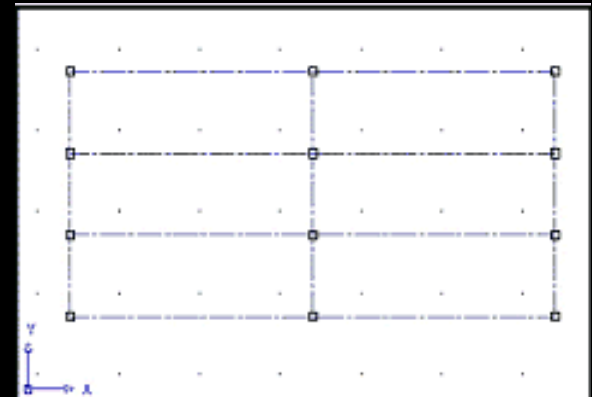
- *columns*
- *beams*
- *arches*
- *walls*
- *footings*



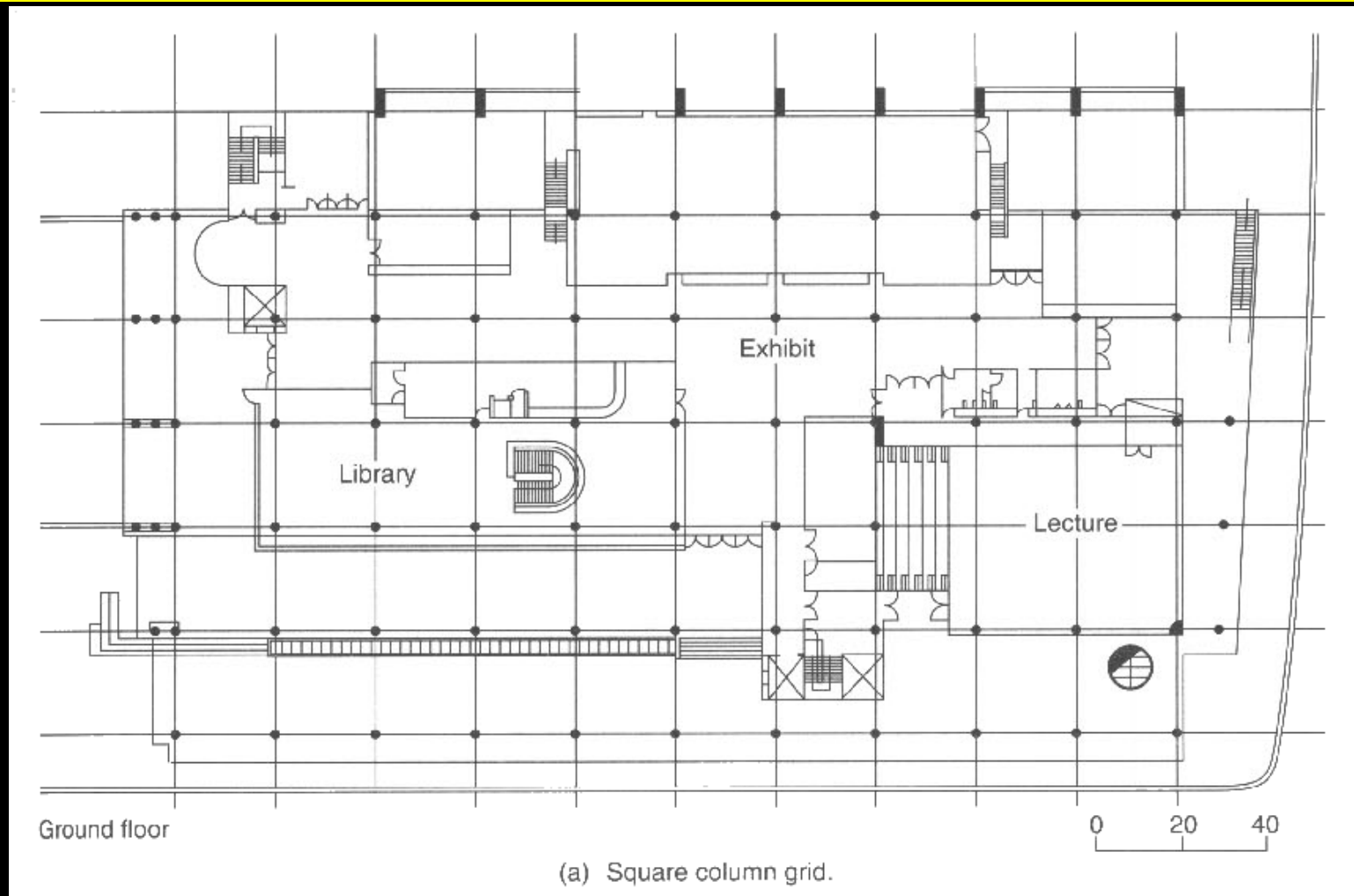


# Grids and Patterns

- *often adopted early in design*
  - *give order*
  - *cellular, ex.*
- *vertical and horizontal*
- *square and rectangular*
  - *single-cell*
  - *aggregated bays*

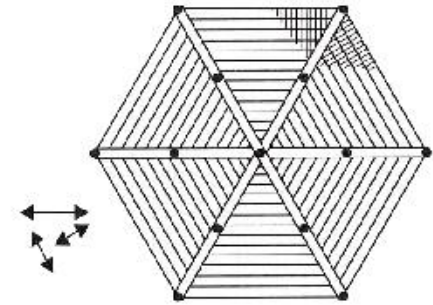


# Grids and Patterns

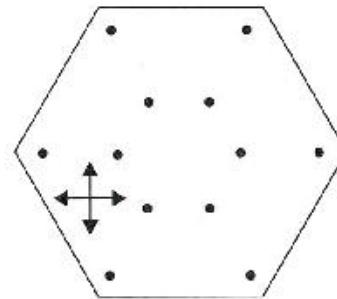


# Systems

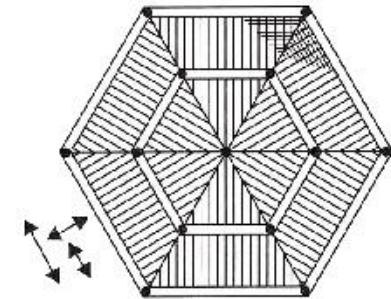
- *total of components*
- *behavior of whole*
- *classifications*
  - *one-way*
  - *two-way*
  - *tubes*
  - *braced*
  - *unbraced*



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



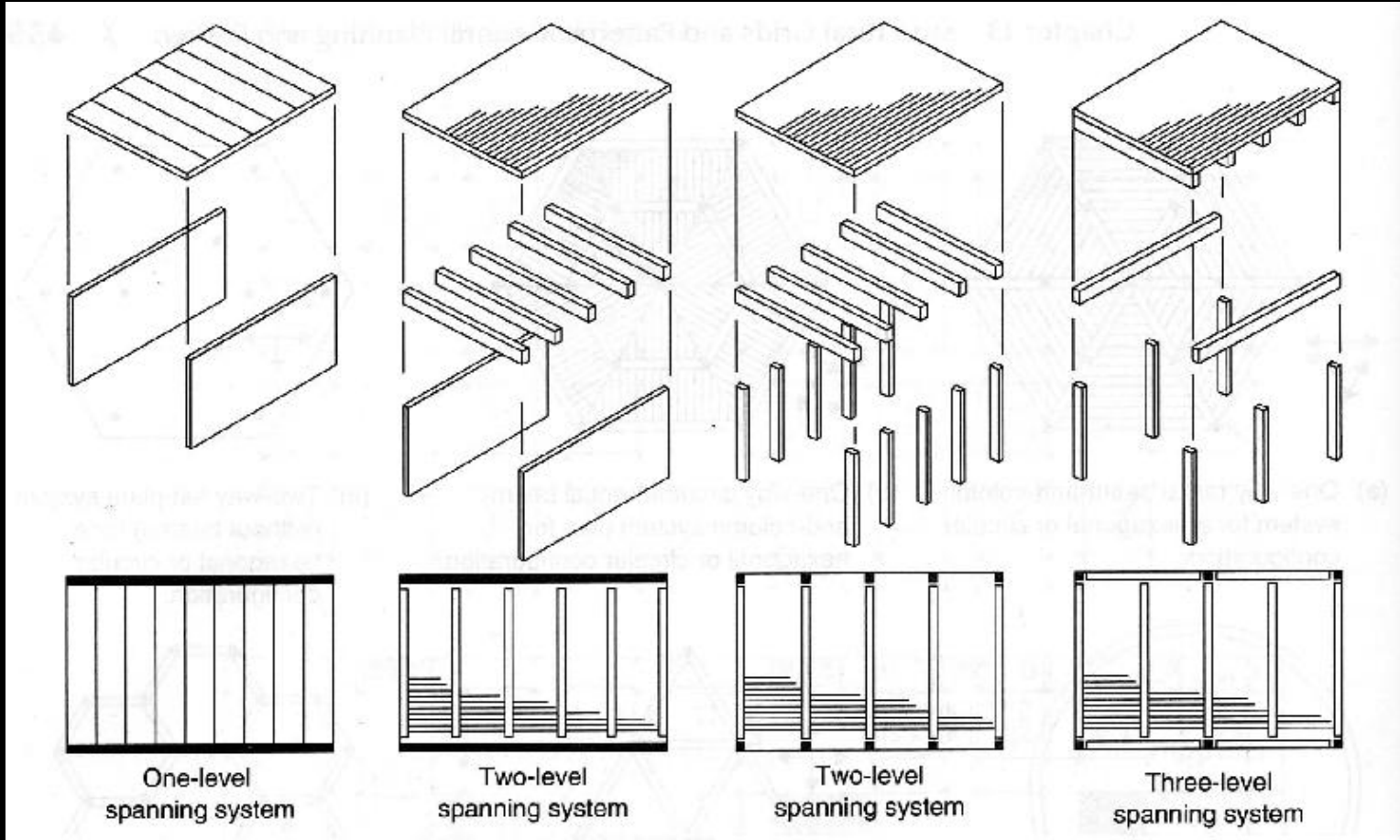
(c) Two-way flat-plate system (without beams) for a hexagonal or circular configuration.



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

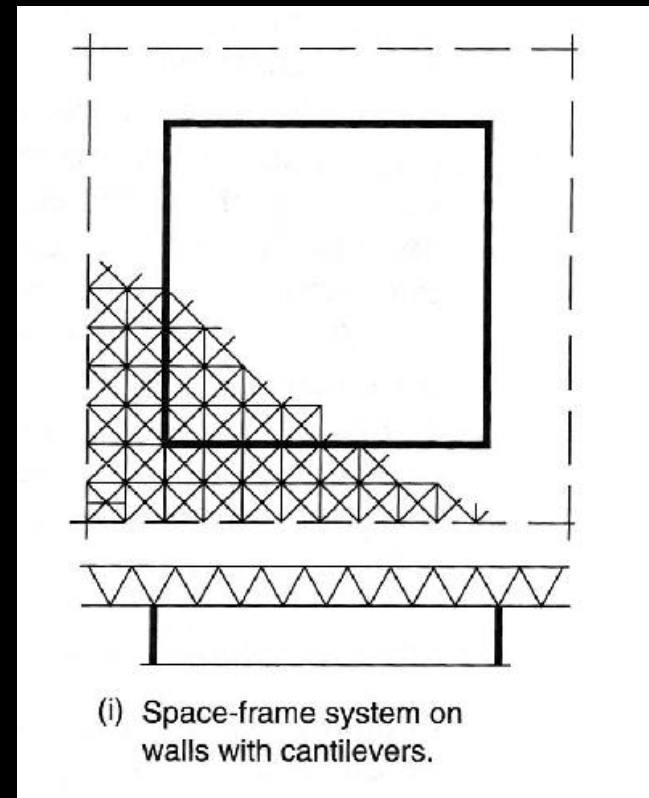
# One-Way Systems

- *horizontal vs. vertical*

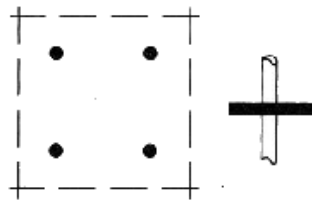


# Two-Way Systems

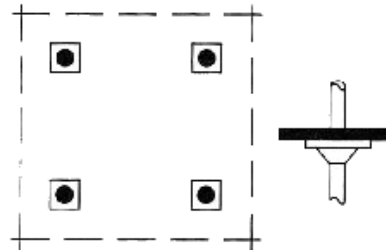
- *spanning system less obvious*
- *horizontal*
  - *plates*
  - *slabs*
  - *space frames*
- *vertical*
  - *columns*
  - *walls*



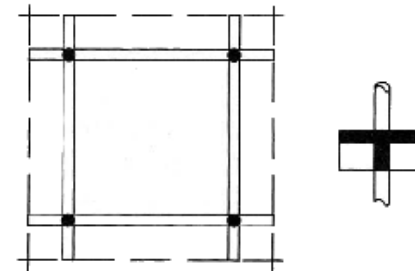
# Two-Way Systems



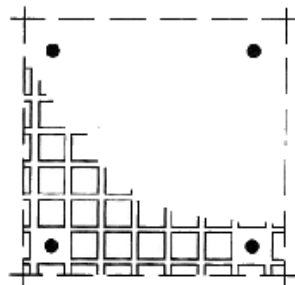
(a) Flat-plate system.



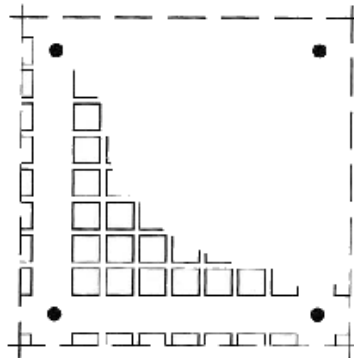
(b) Flat-slab system.



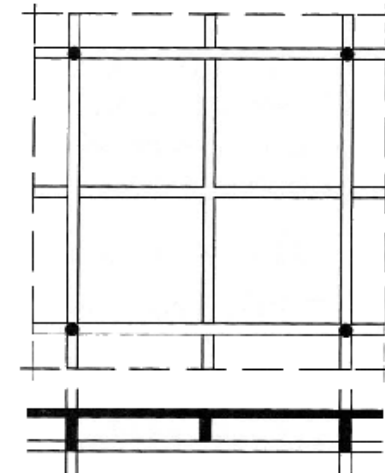
(c) Two-way beam-and-slab system.



(d) Two-way ribbed system (waffle slab).



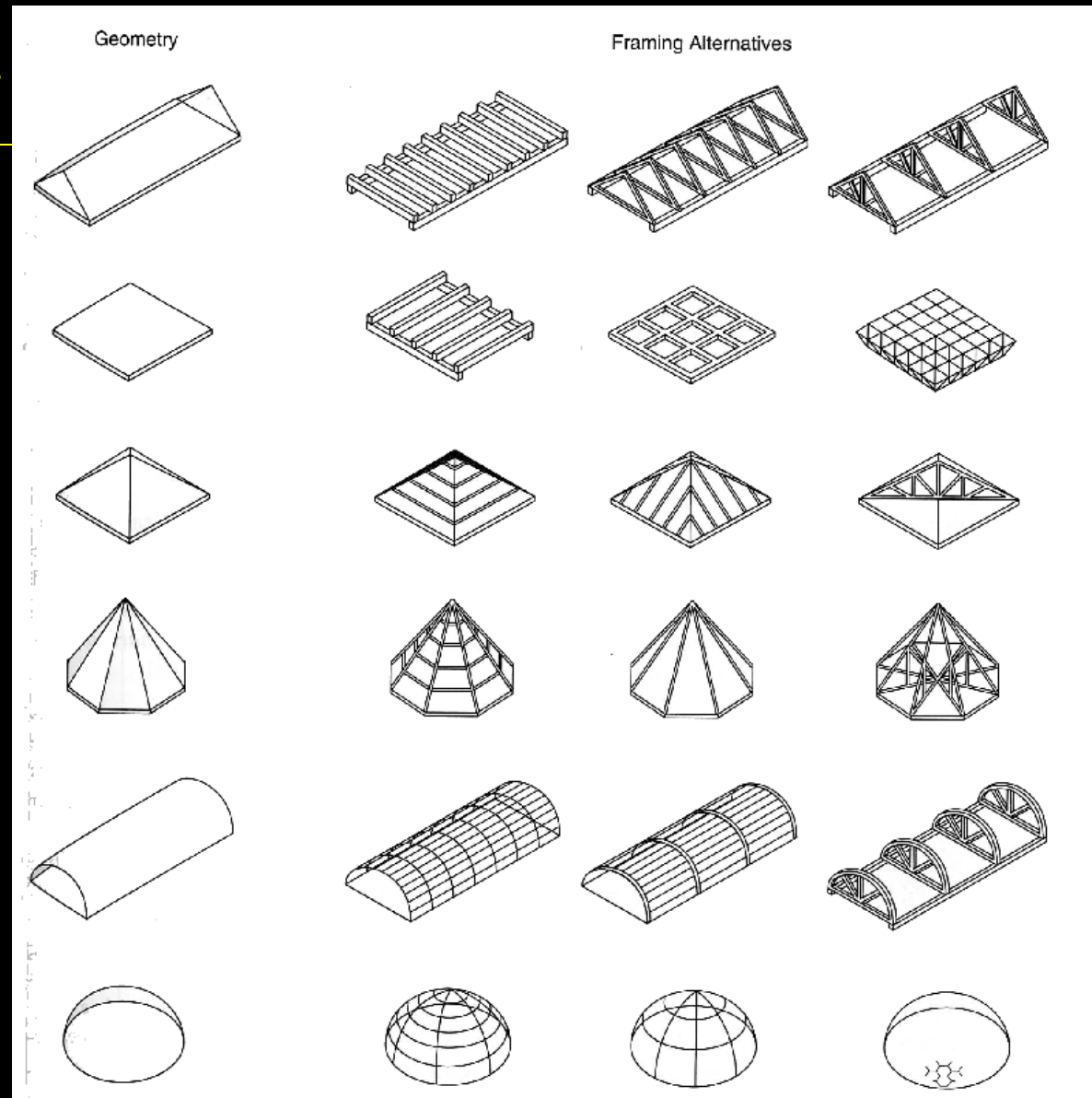
(e) Two-way ribbed system with surrounding beams.



(f) Two-way long-span beam-and-slab system.

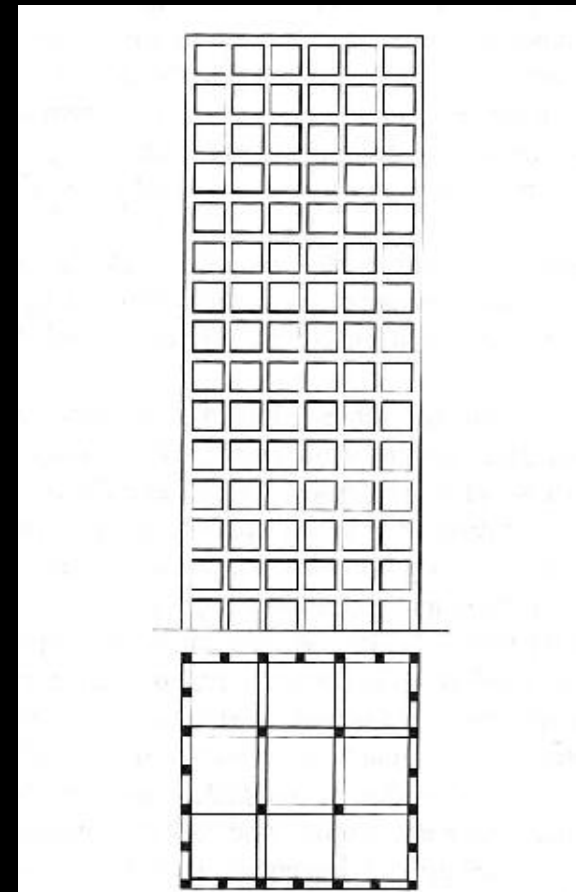
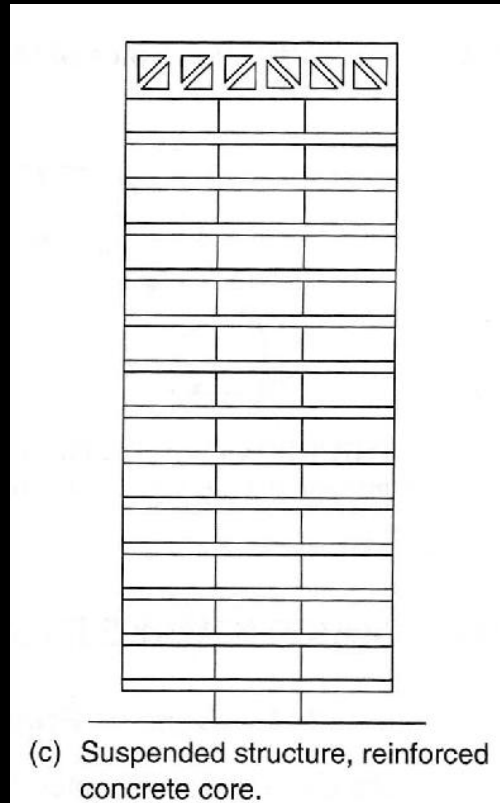
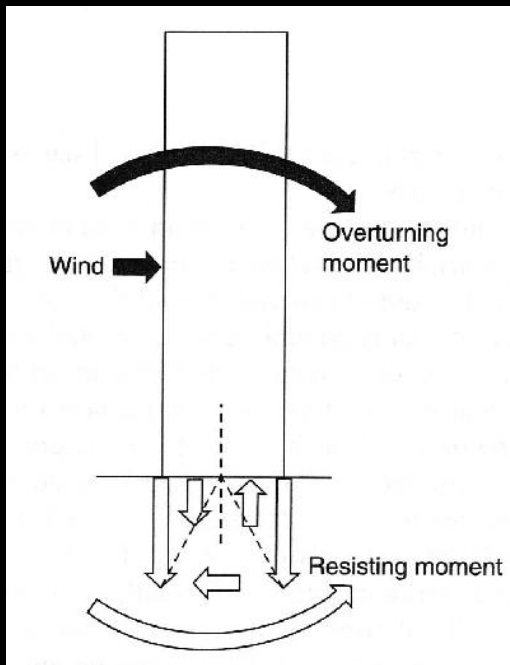
# Roof Shapes

- coincide
- within



# Tubes & Cores

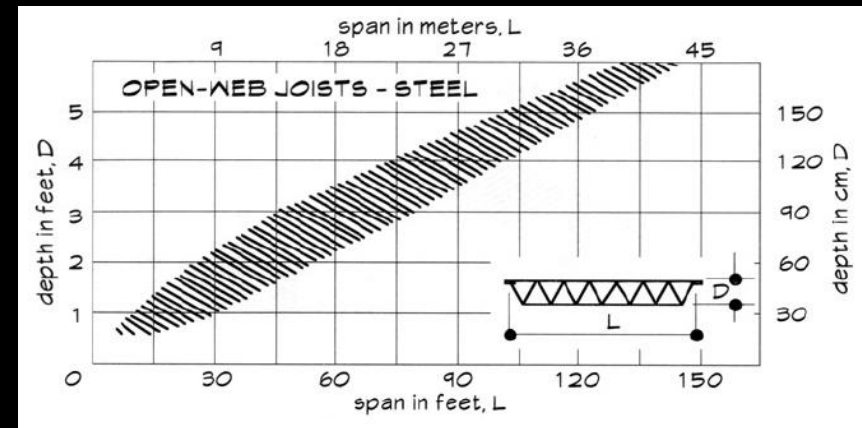
- *stiffness*



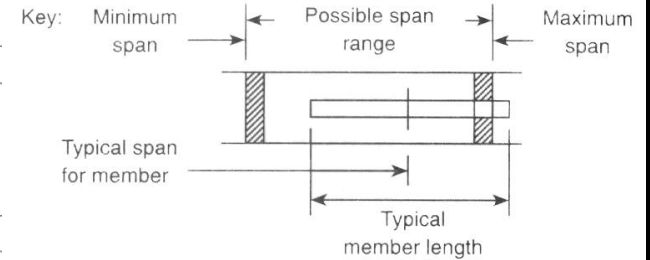
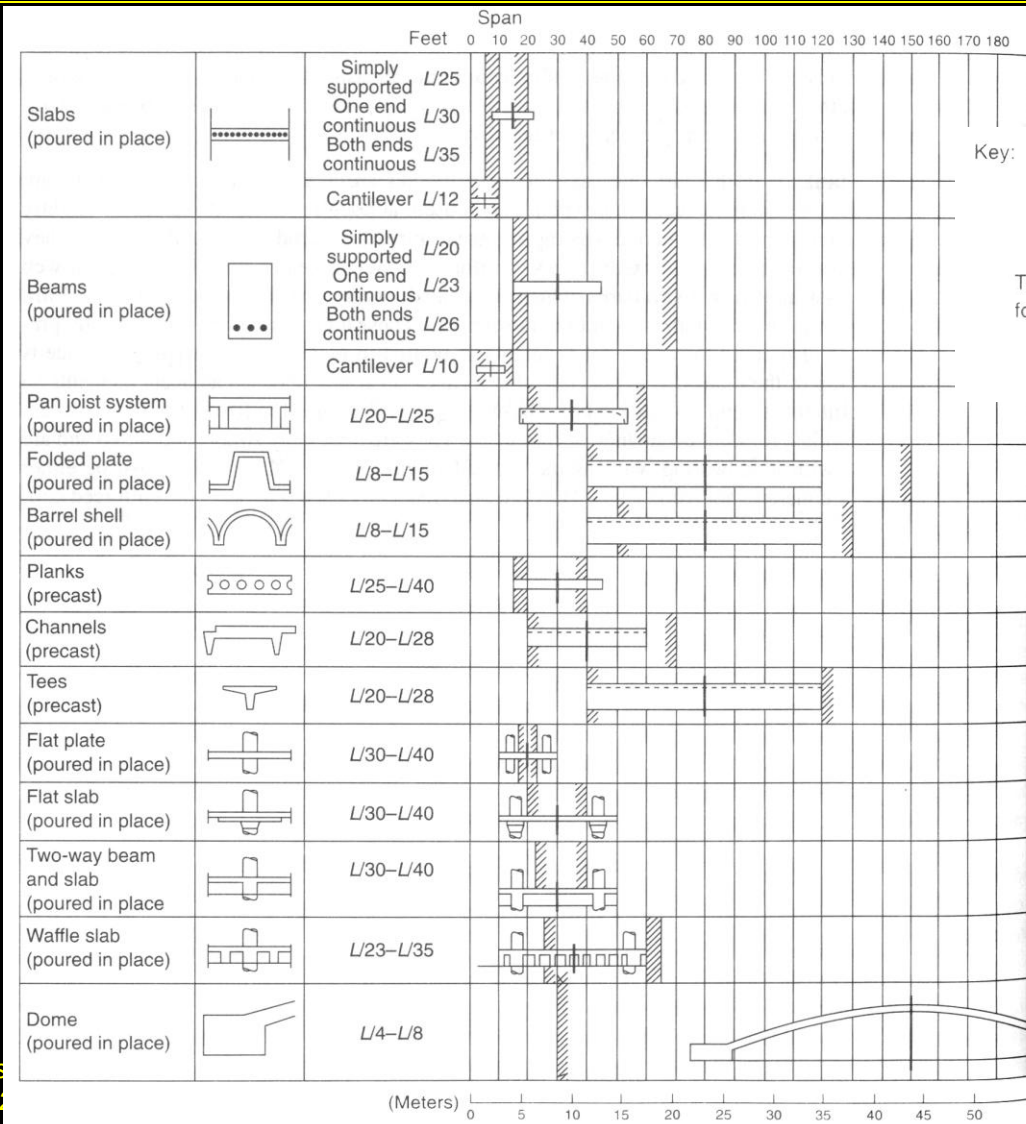


# Span Lengths

- *crucial in selection of system*
- *maximum spans on charts aren't absolute limits, but usual maximums*
- *increase  $L$ , increase  $depth^2$  required (ex. cantilever)*
- *deflections depend on  $L$*



# Approximate Depths



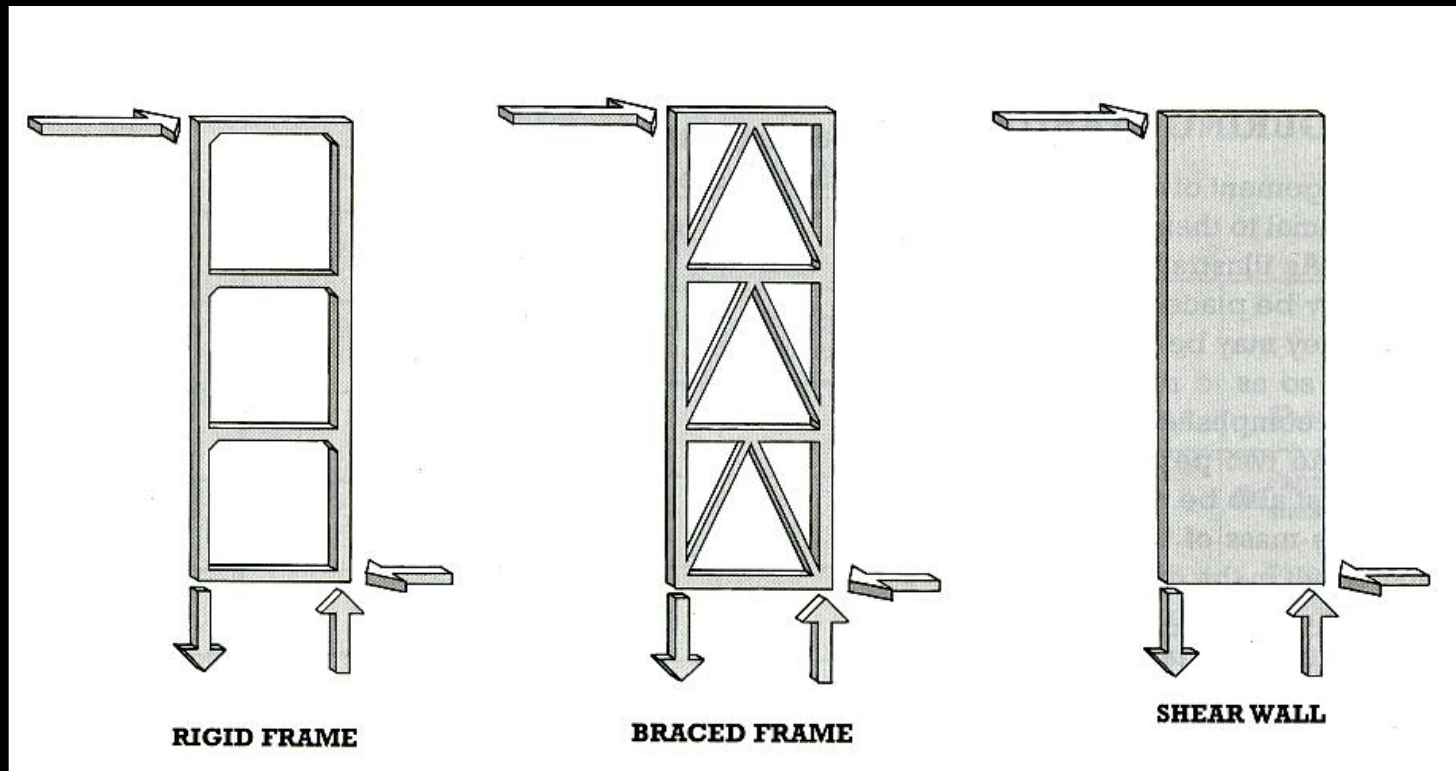
# *Loading Type and Structure Type*

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- *light uniform loads*
  - *surface forming elements*
  - *those that pick up first load dictate spacing of other elements*
- *heavy concentrated loads*
  - *member design unique*
- *distributed vs. concentrated structural strategies*
  - *large beam vs. many smaller ones*

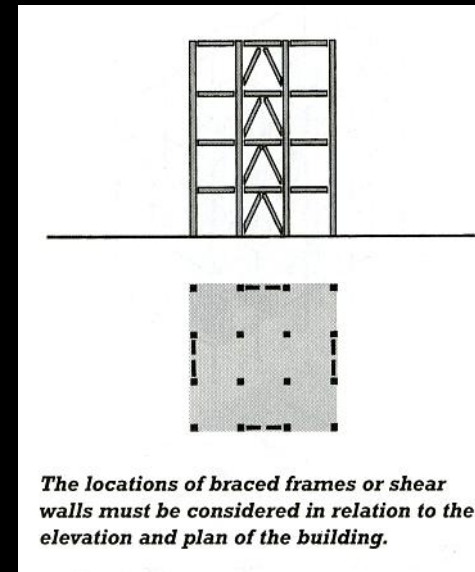
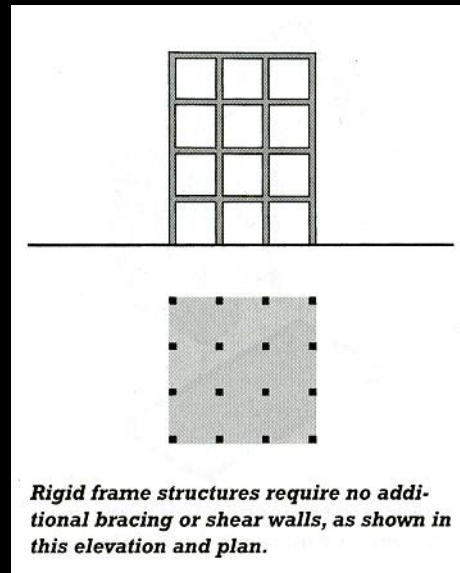
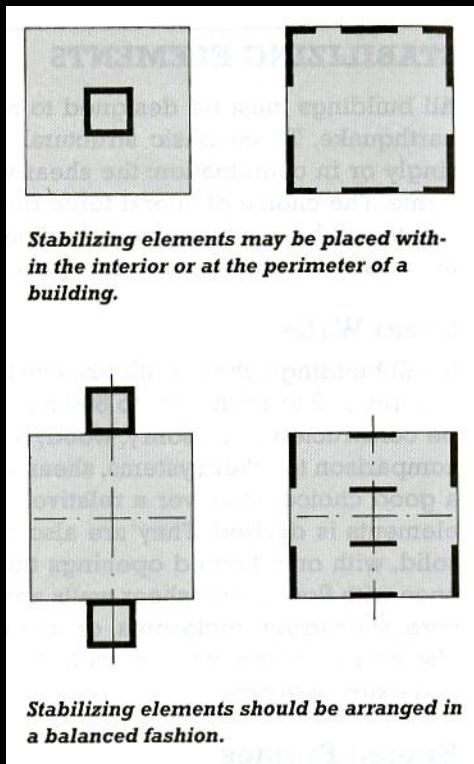
# Design Issues

- *lateral stability – all directions*



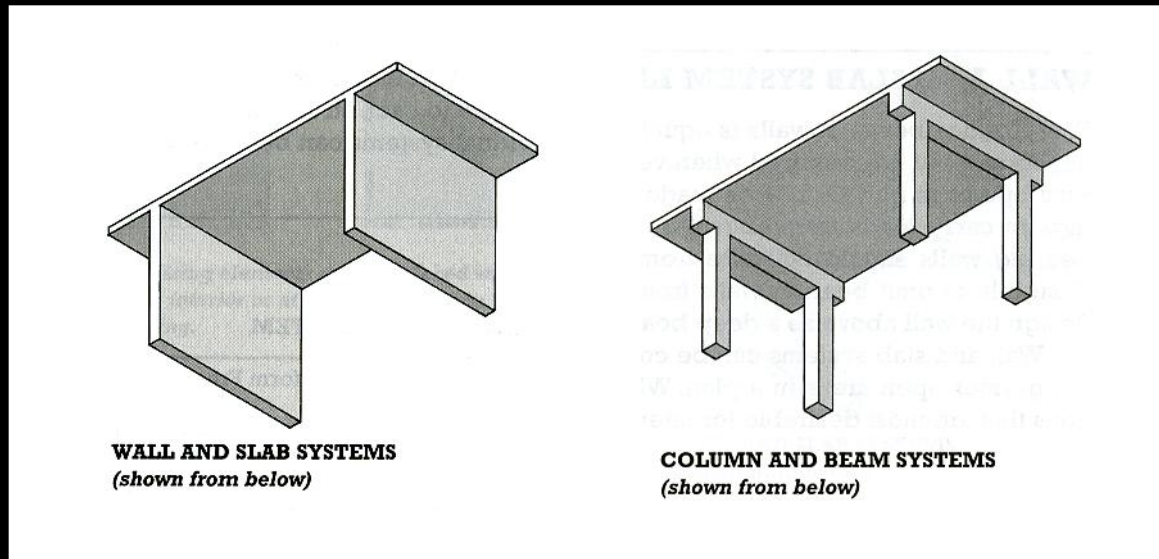
# Design Issues

- *configuration*



# Design Issues

- *vertical load resistance*

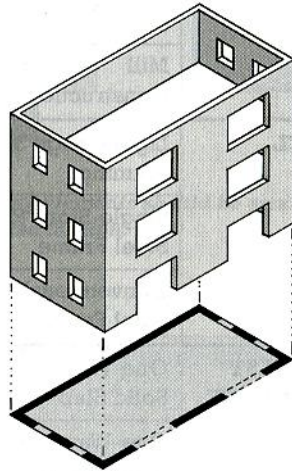


*walls*

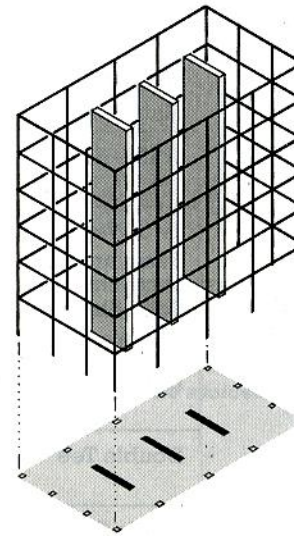
*columns*

# Design Issues

- *lateral load resistance*



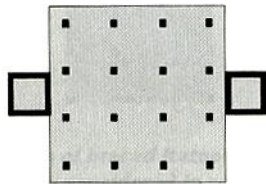
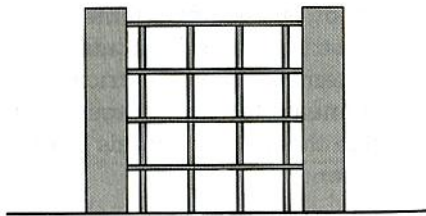
*Shear walls may be arranged in a box form to resist lateral forces from all directions.*



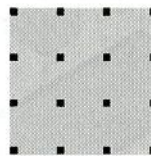
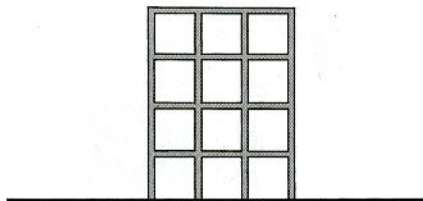
*When combined with other stabilizing mechanisms, shear walls may be arranged so as to resist forces in only one direction of a building.*

# Design Issues

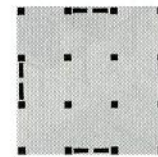
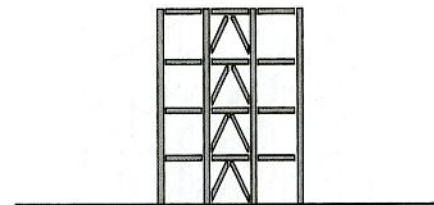
- *lateral load resistance*



*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.*

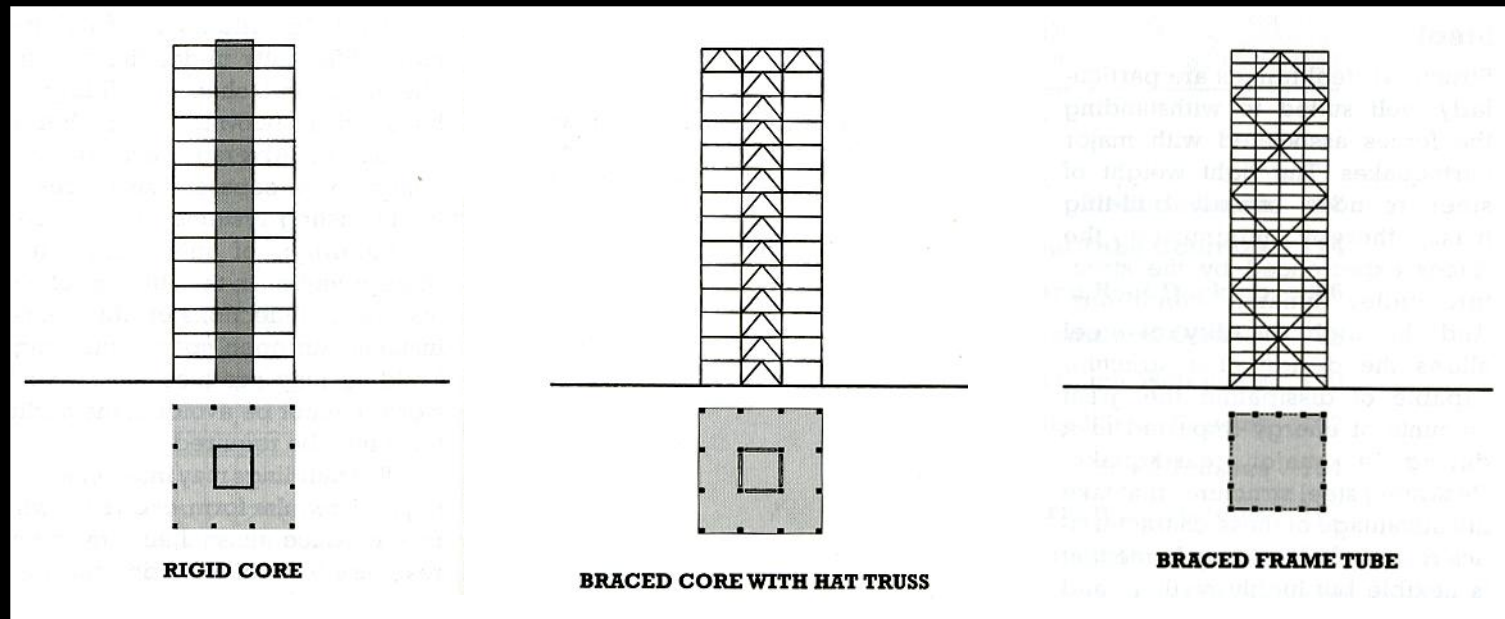


*The locations of braced frames or shear walls must be considered in relation to the elevation and plan of the building.*



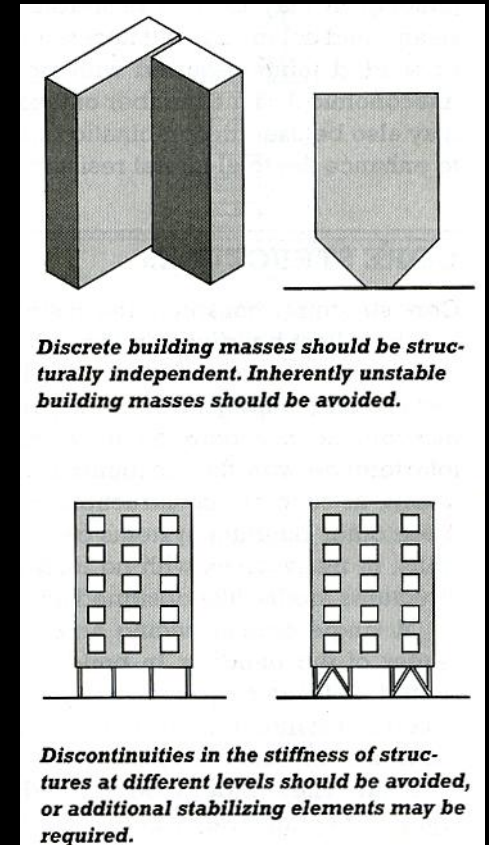
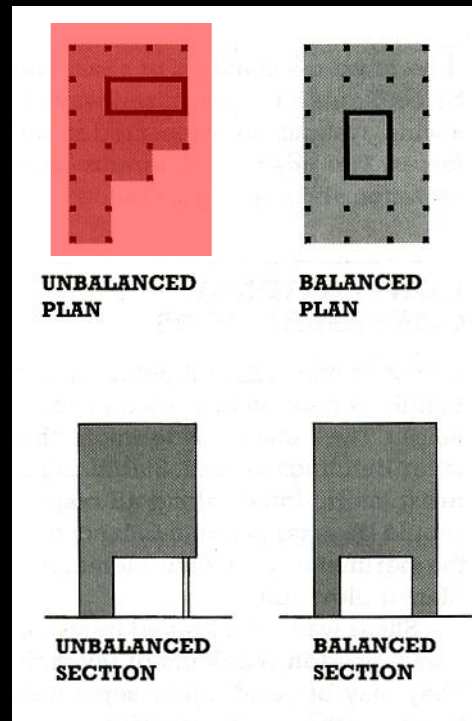
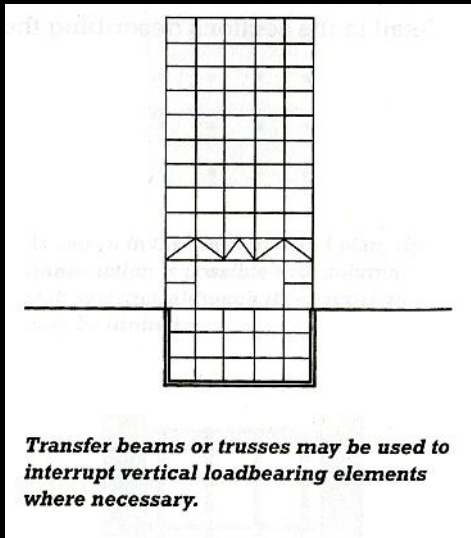
# Design Issues

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



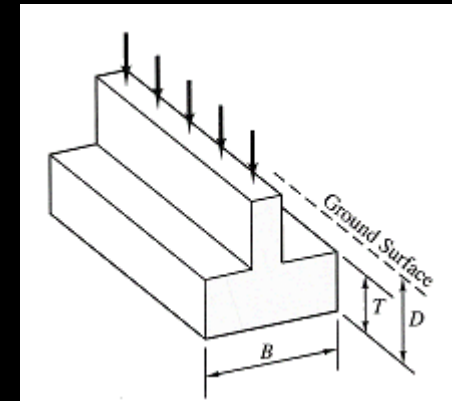
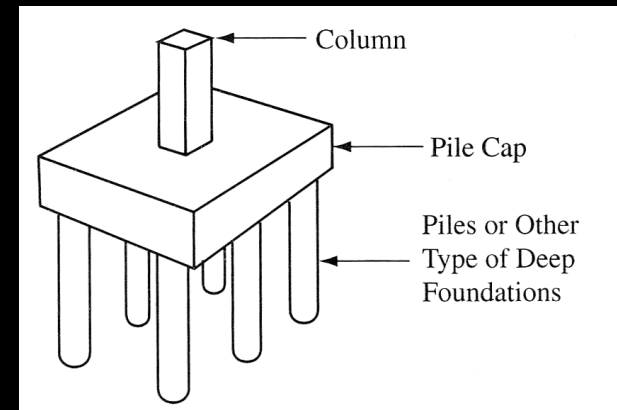
# Design Issues

- *multi-story*
  - *avoid discontinuities*
    - *vertically*
    - *horizontally*



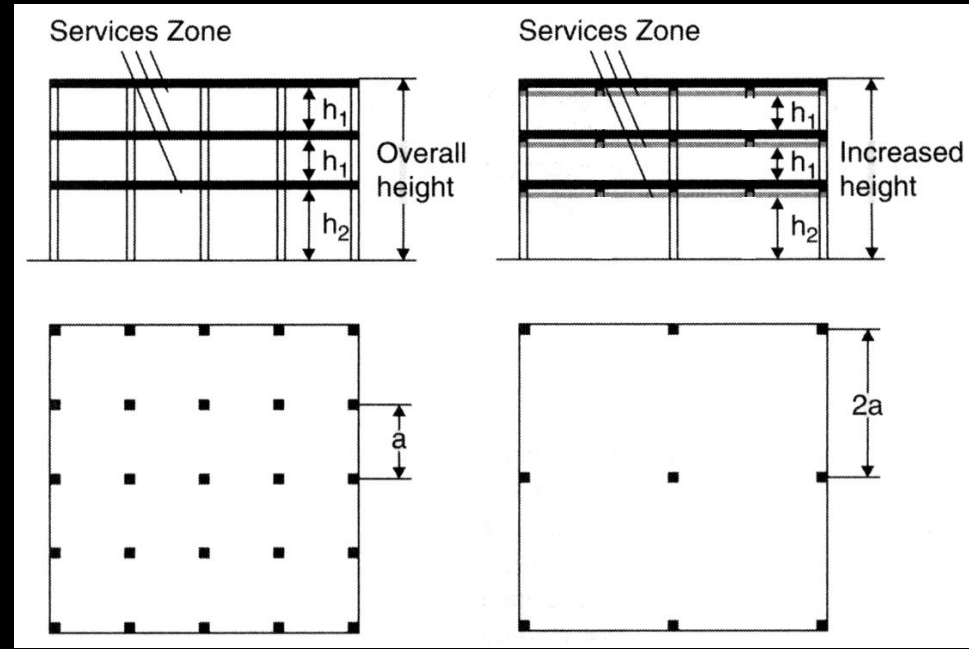
# Foundation Influence

- *type may dictate fit*
  - *piles vs. mats vs. spread*
  - *capacity of soil to sustain loads*
    - *high capacity – smaller area of bearing needing and can spread out*
    - *low capacity – multiple contacts and big distribution areas*



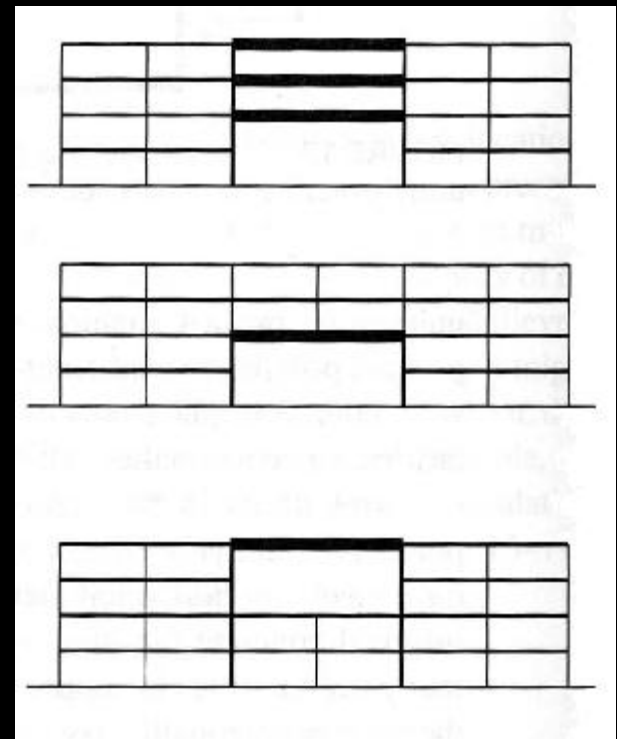
# Grid Dependency on Floor Height

- *wide grid = deep beams*
  - *increased building height*
  - *heavier*
  - *foundation design*
- *codes and zoning may limit*
- *utilize depth for mechanical*



# Large Spaces

- *ex. auditoriums, gyms, ballrooms*
- *choices*
  - *separate two systems completely and connect along edges*
  - *embed in finer grid*
  - *staggered truss*



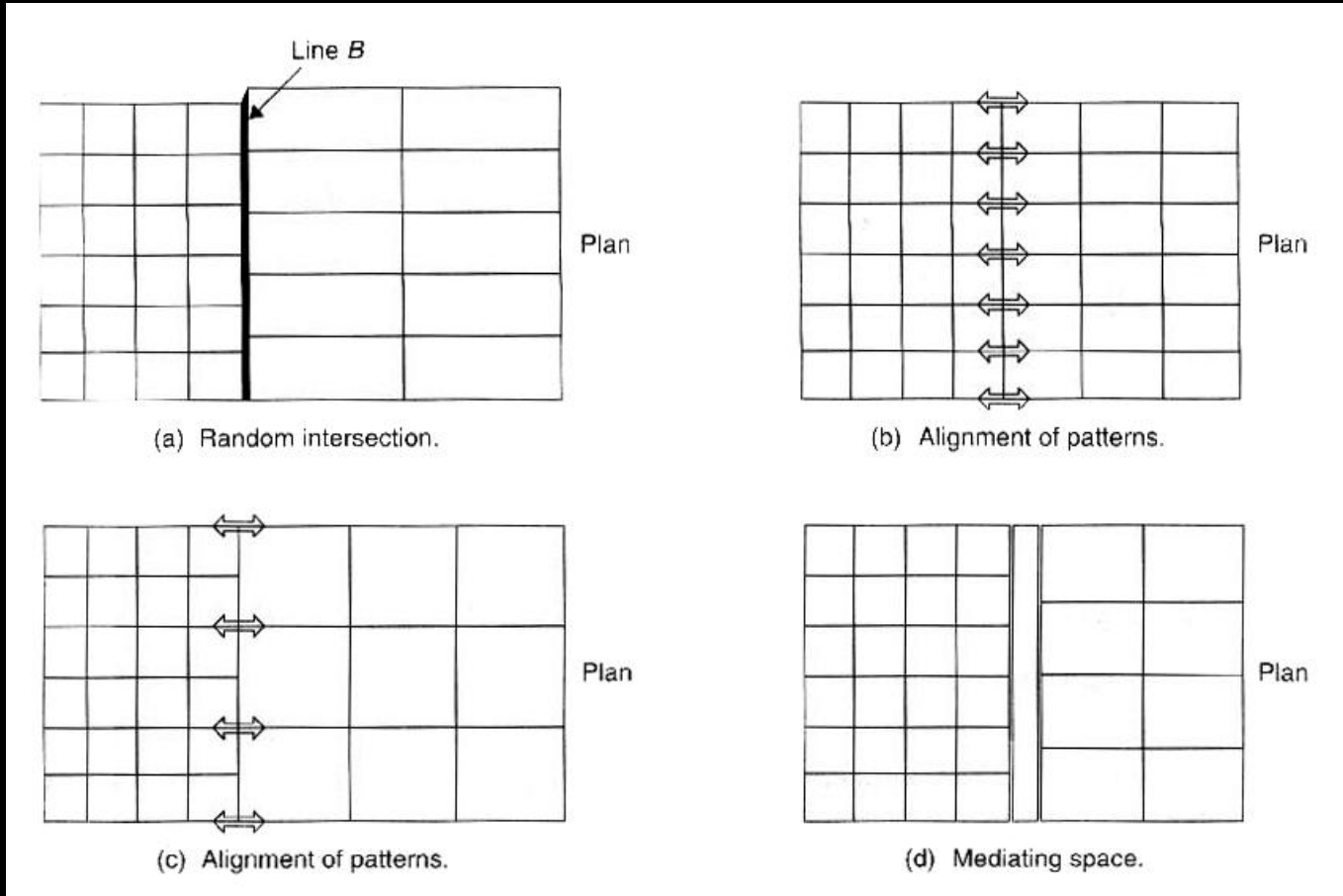
# Meeting of Grids

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- *common to use more than one grid*
- *intersection important structurally*
- *can use different structural materials*
  - *need to understand their properties*
    - *mechanical*
    - *thermal*

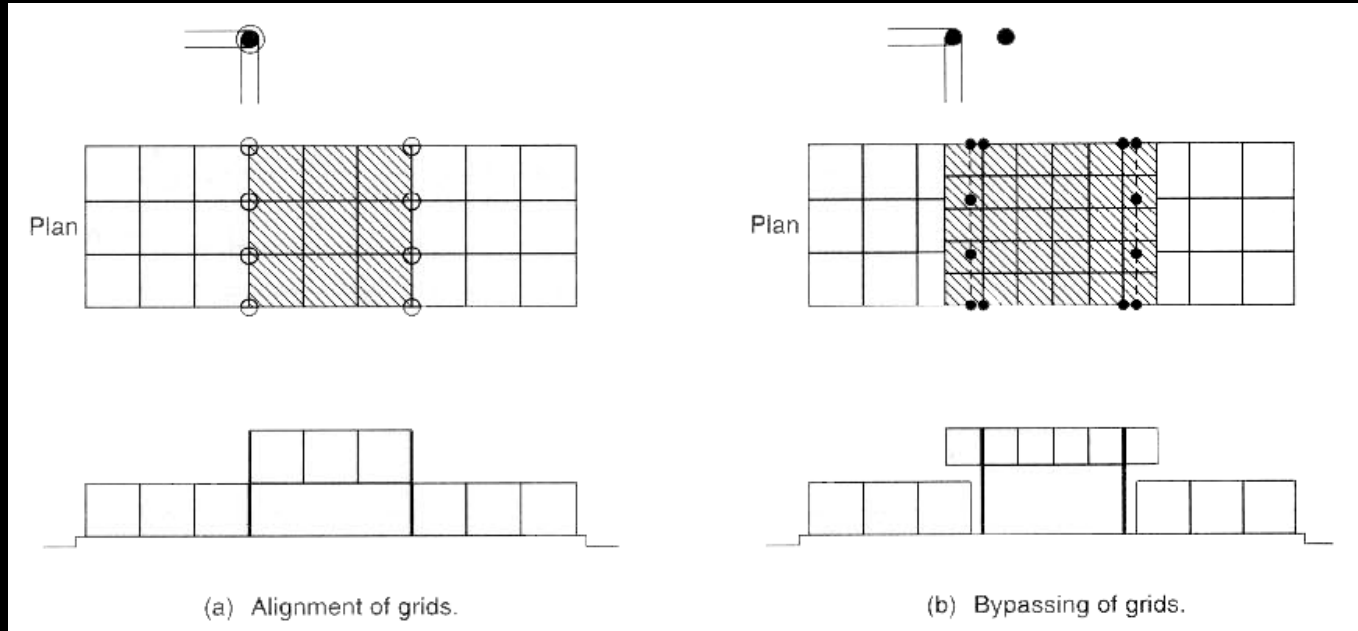
# Meeting of Grids

- *horizontal choices*



# Meeting of Grids

- *vertical choices*

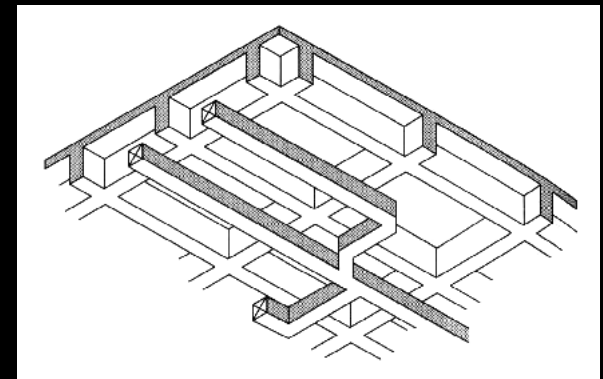
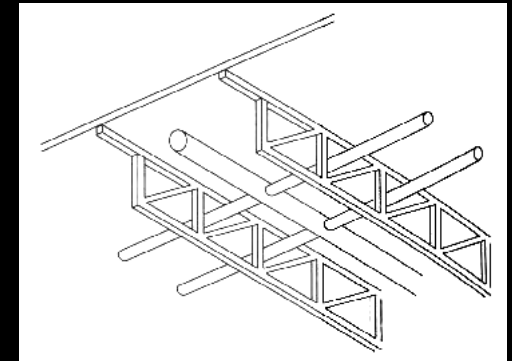




# Other Conditions

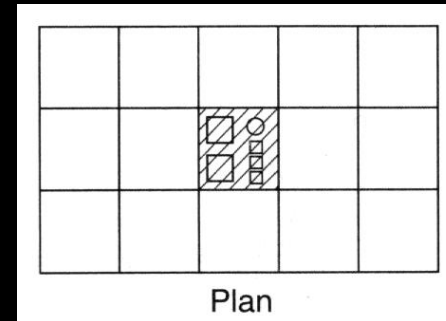
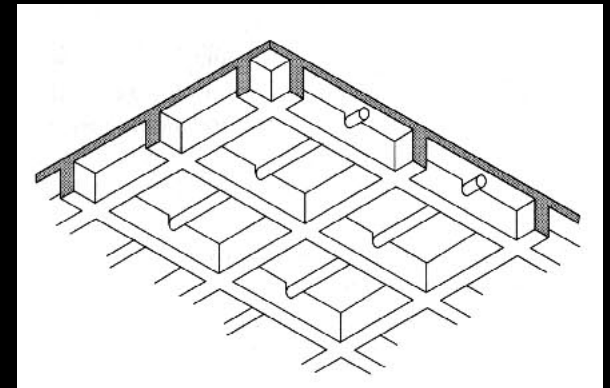
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- *circulation*
- *building service systems*
  - *one-way systems have space for parallel runs*
  - *trusses allow for transverse penetration*
  - *pass beneath or interstitial floors*
    - *for complex or extensive services or flexibility*



# Other Conditions

- *poking holes for member services*
  - *horizontal*
    - *need to consider area removed, where removed, and importance to shear or bending*
  - *vertical*
    - *requires framing at edges*
    - *can cluster openings to eliminate a bay*
  - *double systems*



# *Fire Safety & Structures*

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- *fire safety requirements can impact structural selection*
- *construction types*
  - *light*
    - *residential*
    - *wood-frame or unprotected metal*
  - *medium*
    - *masonry*
  - *heavy*
    - *protected steel or reinforced concrete*

# *Fire Safety & Structures*

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- *degree of occupancy hazards*
- *building heights*
- *maximum floor areas between fire wall divisions*
  - *can impact load bearing wall location*

# Fire Safety & Structures

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- *resistance ratings by failure type*
  - *transmission failure*
    - *fire or gasses move*
  - *structural failure*
    - *high temperatures reduce strength*
  - *failure when subjected to water spray*
    - *necessary strength*
- *ratings do not pertain to usefulness of structure after a fire*