

ARCHITECTURAL STRUCTURES:
FORM, BEHAVIOR, AND DESIGN

ARCH 331

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SUMMER 2013

lecture
one

**structural behavior,
systems and design**



Introduction 1
Lecture 1

Architectural Structures
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www.greatbuildings.com
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Course Description

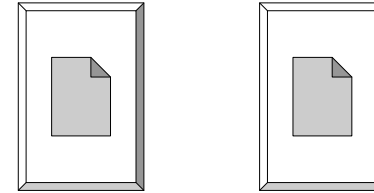
- *statics*
 - *physics of forces and reactions on bodies and systems*
 - *equilibrium (bodies at rest)*
- *structures*
 - *something made up of interdependent parts in a definite pattern of organization*
- *design*
 - *assessing and meeting structural requirements of parts and the whole*

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Syllabus & Student Understandings



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Course Description

- *mechanics of materials*
 - *external loads and effect on deformable bodies*
 - *use it to answer question if structure meets requirements of*
 - *stability and equilibrium*
 - *strength and stiffness*
 - *other principle building requirements*
 - *economy, functionality and aesthetics*

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Structure Requirements

- *stability & equilibrium*
– *STATICS*

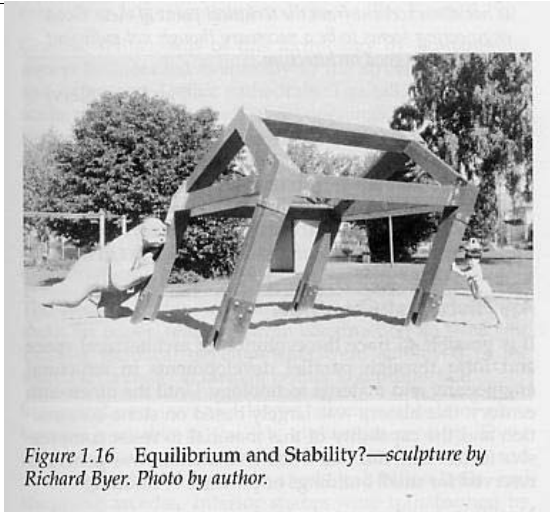


Figure 1.16 Equilibrium and Stability?—sculpture by Richard Byer. Photo by author.

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Structural System Selection

- *kind & size of loads*
- *building function*
- *soil & topology of site*
- *systems integration*
- *fire rating*
- *construction (\$\$, schedule)*
- *architectural form*

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Structure Requirements (cont)

- *strength & stiffness*
– *concerned with stability of components*

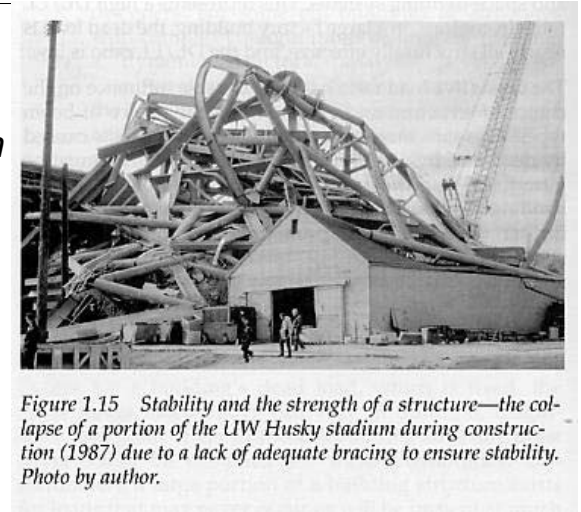


Figure 1.15 Stability and the strength of a structure—the collapse of a portion of the UW Husky stadium during construction (1987) due to a lack of adequate bracing to ensure stability. Photo by author.

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Knowledge Required

- *external forces*
- *internal forces*
- *material properties*
- *member cross sections*
- *ability of a material to resist breaking*
- *structural elements that resist excessive*
– *deflection*
– *deformation*

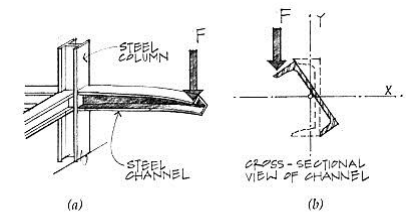


Figure 2.34 An example of torsion on a cantilever beam.

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Problem Solving

1. STATICS:

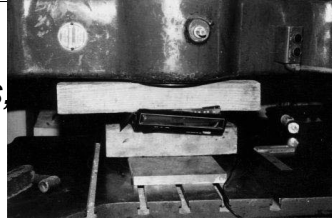
equilibrium of external forces,
internal forces, stresses

2. GEOMETRY:

cross section properties, deformations and
conditions of geometric fit, strains

3. MATERIAL PROPERTIES:

stress-strain relationship for each material
obtained from testing



Relation to Architecture

“The geometry and arrangement of the load-bearing members, the use of materials, and the crafting of joints all represent opportunities for buildings to express themselves. The best buildings are not designed by architects who after resolving the formal and spatial issues, simply ask the structural engineer to make sure it doesn’t fall down.” -Onouye & Kane

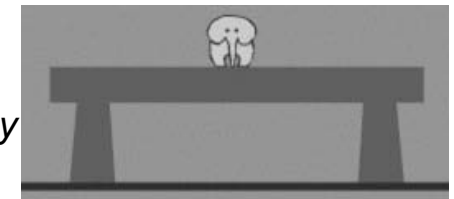
Statics and Strength of Materials for
Architecture and Building Construction

Architectural Space and Form

- evolution traced to developments in structural engineering and material technology
 - stone & masonry
 - timber
 - concrete
 - cast iron, steel
 - tensile fabrics, pneumatic structures.....

Architectural Space and Form

- structure is a device for channeling loads that result from the use and/or presence of the building to the ground
 - span a roof
 - hold up a floor
 - cross a river
 - suspend a canopy



Structural Action

- axial tension
- axial compression
- bending

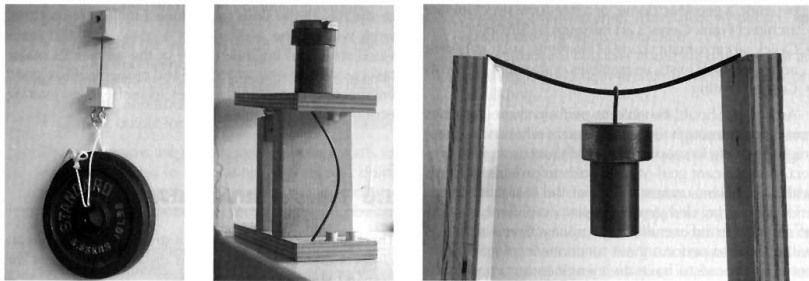


Figure 1.2 (a) Axial tension, (b) axial compression, and (c) bending.

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Structural Action

- stabilization

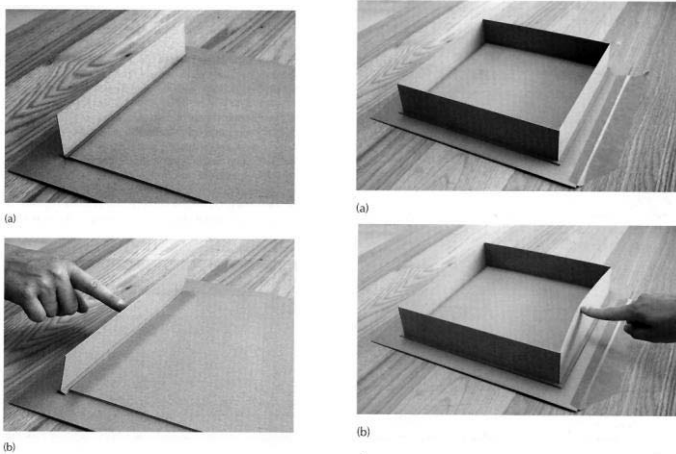


Figure 1.8 (a) A thin wall (b) subjected to lateral force.

Figure 1.9 (a, b) Walls stabilizing each other at the ends.

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Structural Action

- member breadth & depth

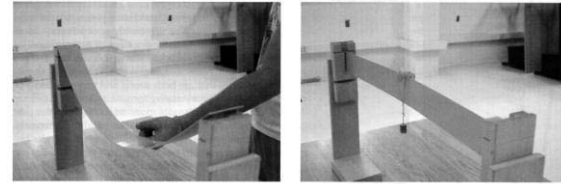


Figure 1.4 (a) A very shallow beam and (b) a deep beam.

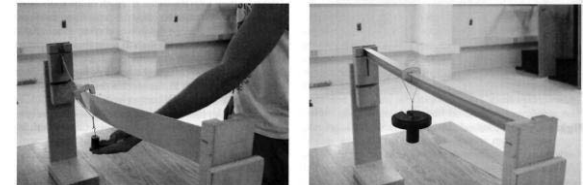


Figure 1.5 A sheet of material (a) set on edge and (b) configured as an I-beam.

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Structural Action

- shear & bracing

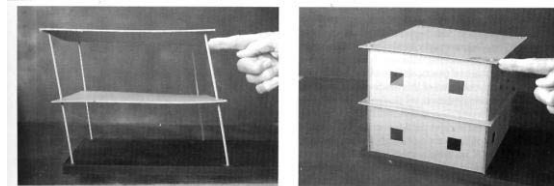


Figure 1.29 (a, b) Structural frame stabilized by adding shear panels.

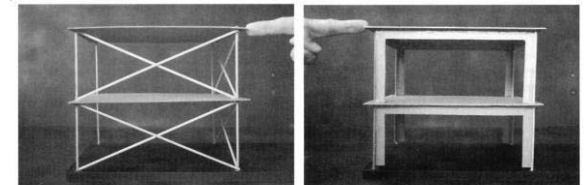


Figure 1.30 Bracing with (a) triangulation and (b) a rigid frame.

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Structural Action

- lateral resistance

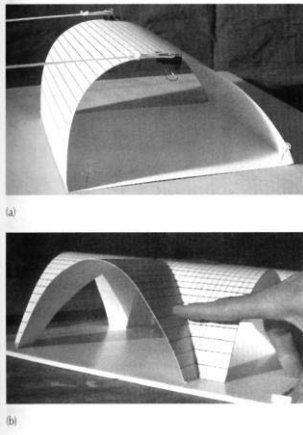


Figure 1.32 (a) A thin-shelled barrel vault and (b) a thin-shelled cross vault.

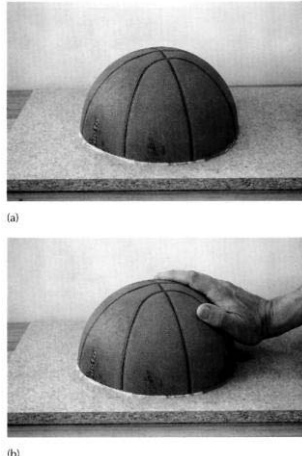
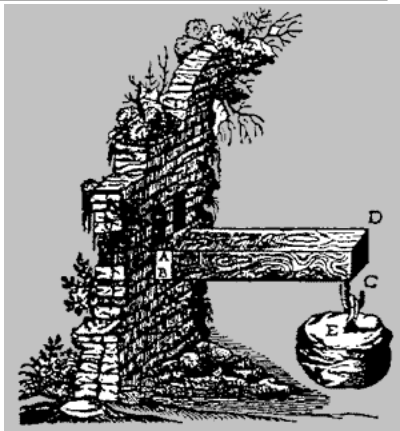


Figure 1.33 (a, b) A dome subjected to lateral load.

Structural Design

- planning
- preliminary structural configuration
- determination of loads
- preliminary member selection
- analysis
- evaluation
- design revision
- final design

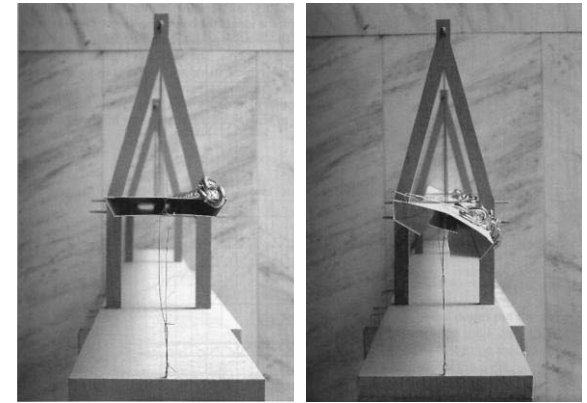


Structural Action

- twisting



Figure 1.35 Torsion in a tube, a slab, and an I-section.



Structural Loads

- **STATIC and DYNAMIC**
- **dead load**
 - static, fixed, includes building weight, fixed equipment
- **live load**
 - transient and moving loads (including occupants), snowfall

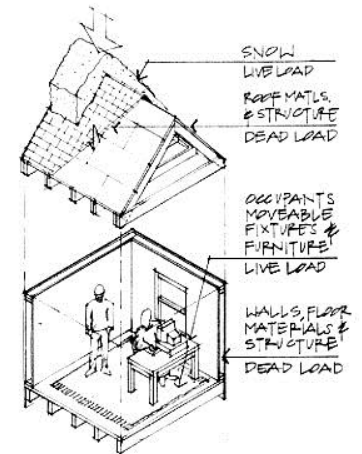


Figure 1.12 Typical building loads.

Structural Loads

- wind loads
 - dynamic, wind pressures treated as lateral static loads on walls, up or down loads on roofs

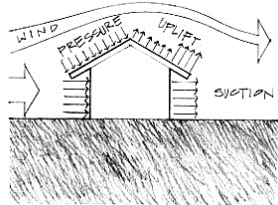
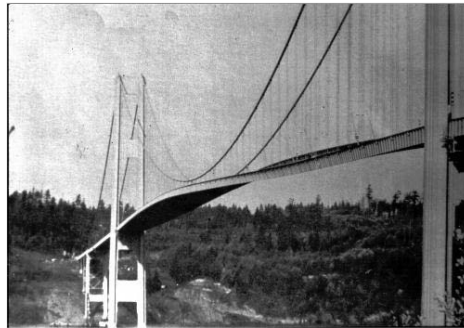


Figure 1.13 Wind loads on a structure.



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Structural Loads

- earthquake loads
 - seismic, movement of ground

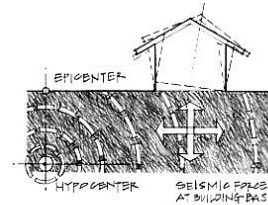
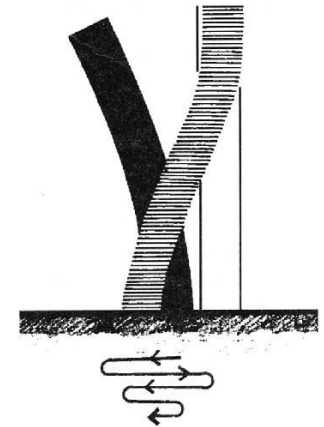


Figure 1.14 Earthquake loads on a structure.



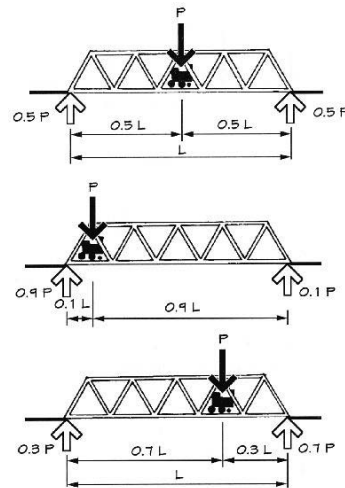
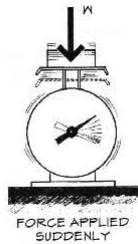
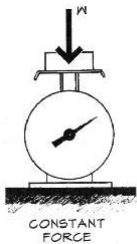
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Structural Loads

- impact loads
 - rapid, energy loads



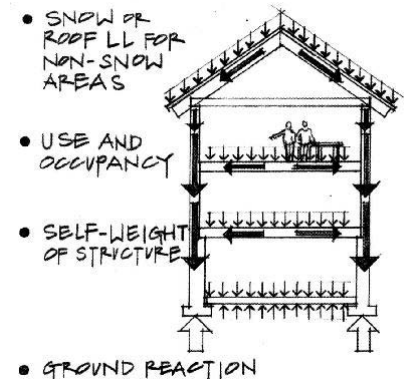
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Structural Loads

- gravity acts on mass ($F=m*g$)
- 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



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Structural Math

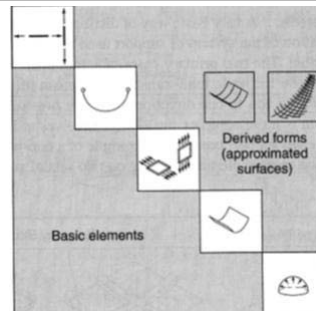
- *quantify environmental loads*
 - *how big is it?*
- *evaluate geometry and angles*
 - *where is it?*
 - *what is the scale?*
 - *what is the size in a particular direction?*
- *quantify what happens in the structure*
 - *how big are the internal forces?*
 - *how big should the beam be?*

Structural Math

- *physics takes observable phenomena and relates the measurement with rules: mathematical relationships*
- *need*
 - *reference frame*
 - *measure of length, mass, time, direction, velocity, acceleration, work, heat, electricity, light*
 - *calculations & geometry*

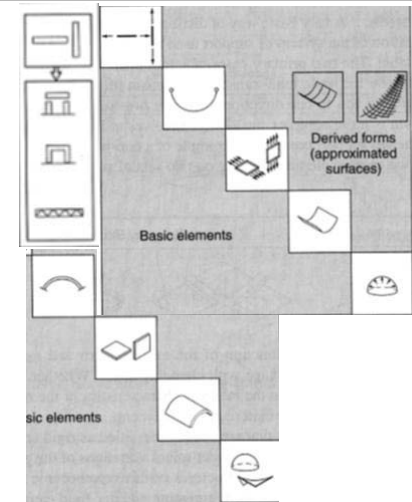
Structural Organization

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

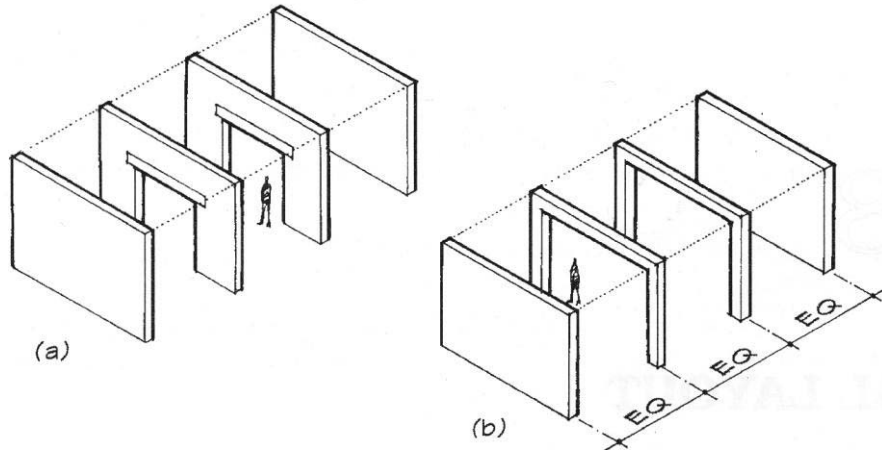


Structural Components

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



Bearing Walls



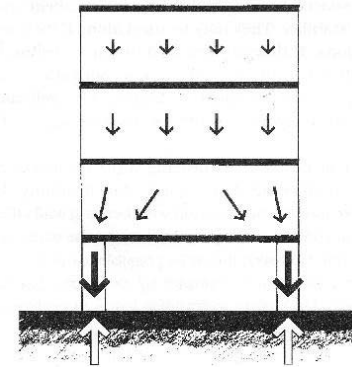
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Bearing Walls

- behavior as “deep beams”

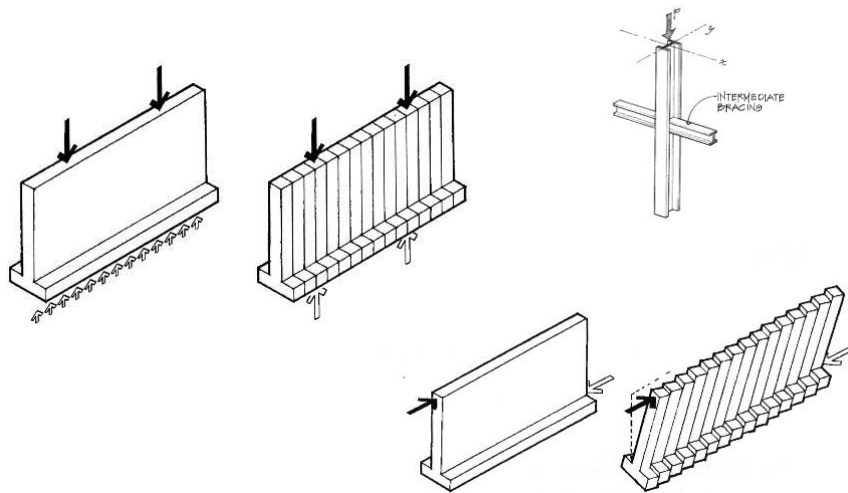


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Columns & Walls

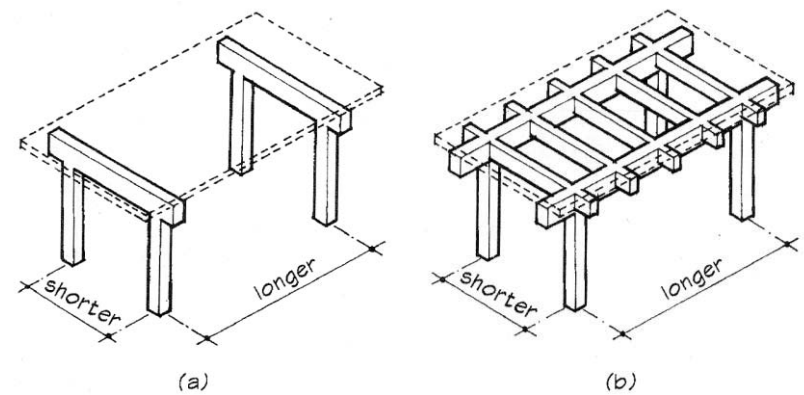


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Beams & Plates

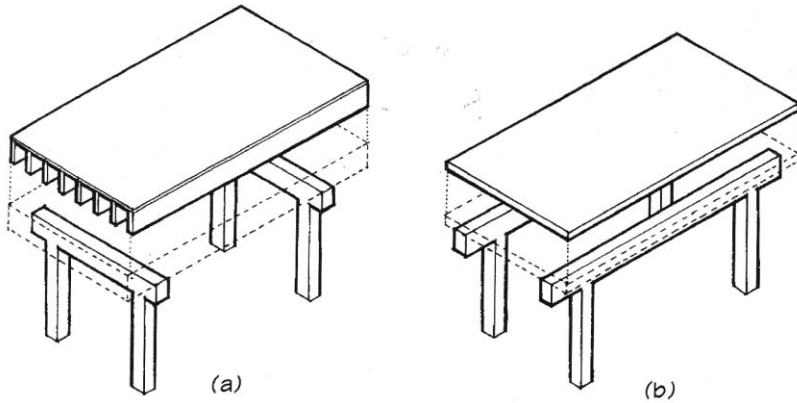


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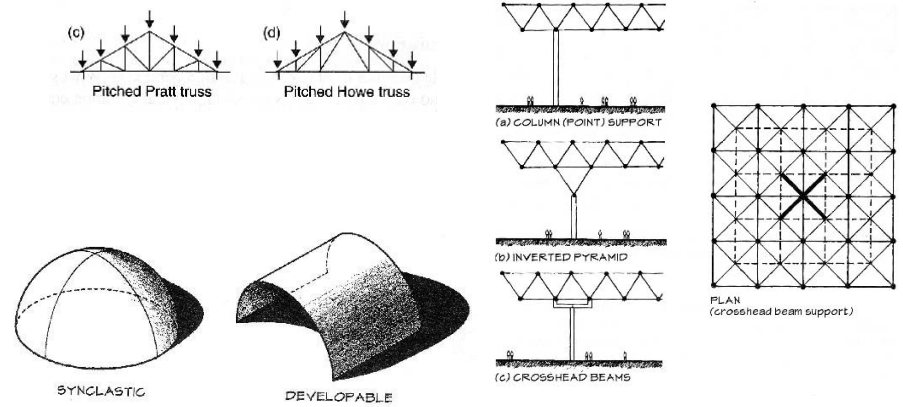
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Beams & Plates



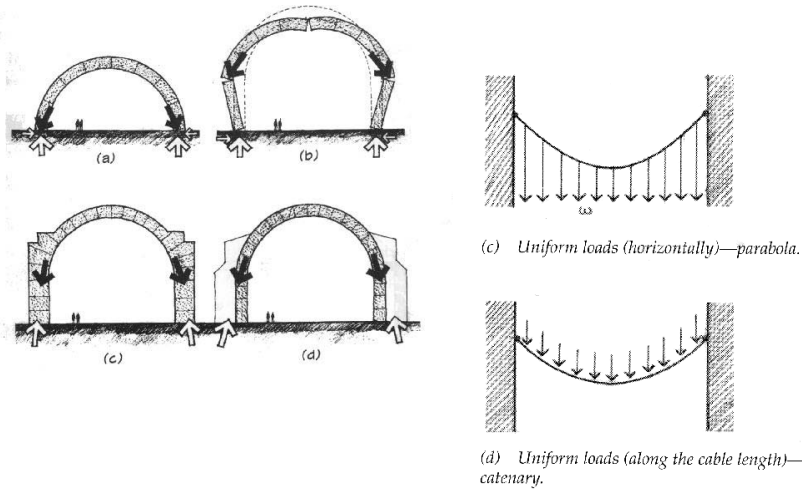
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Trusses and Shells



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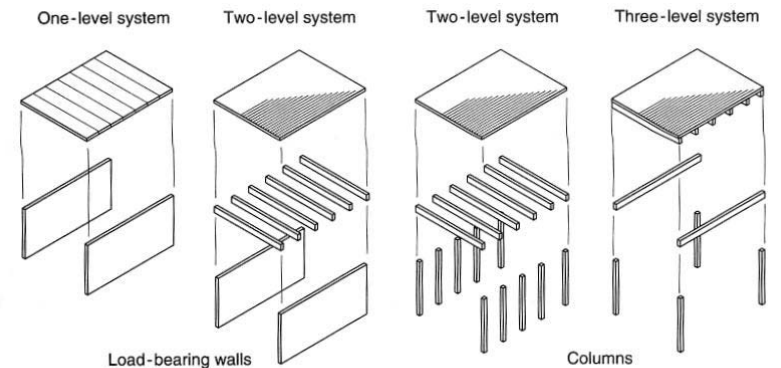
Arches and Cables



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Building Framing

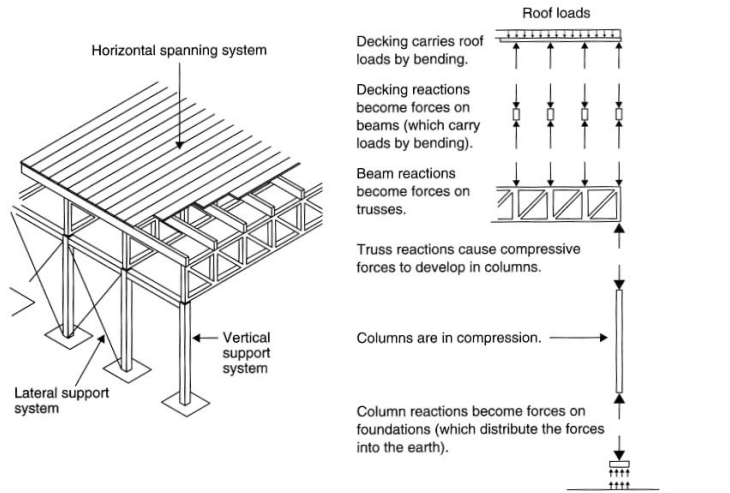
• Components or Assemblages



(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.

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Building Framing



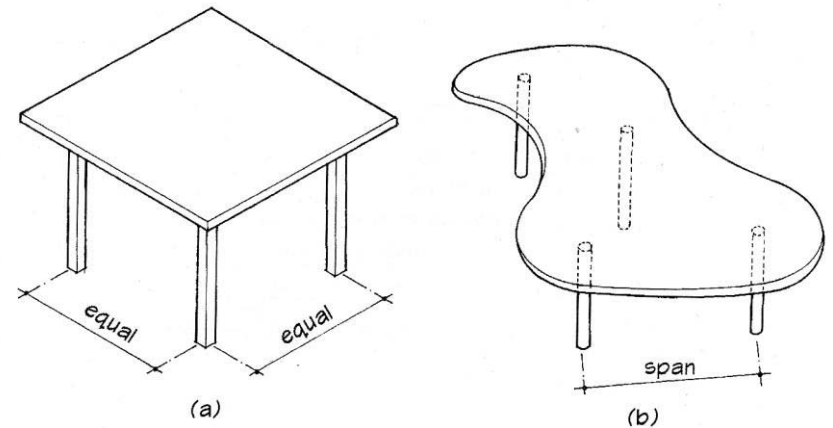
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System Selection

- evaluation of alternatives



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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-resistant 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

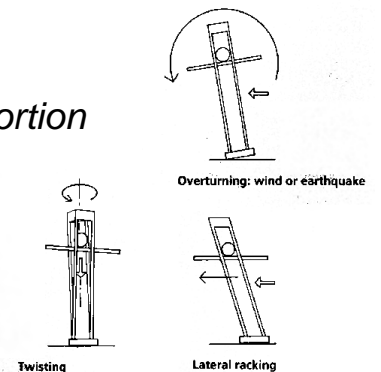
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Structural Design Criteria

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



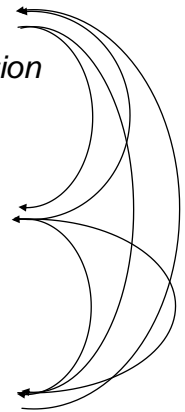
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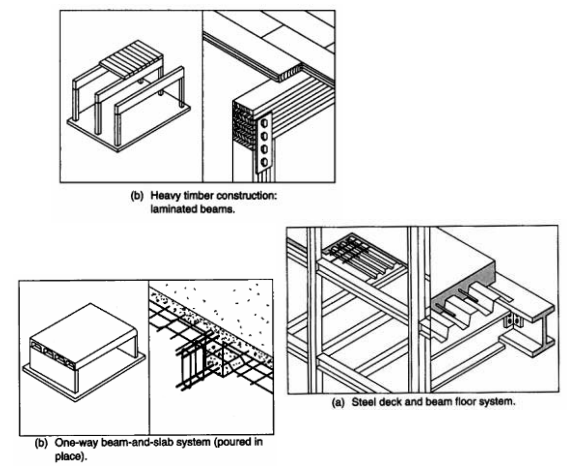
Structural Design Sequences

- *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



Systems by Materials

- *Wood*
- *Steel*
- *Concrete*
- *Masonry*
- *Composite*



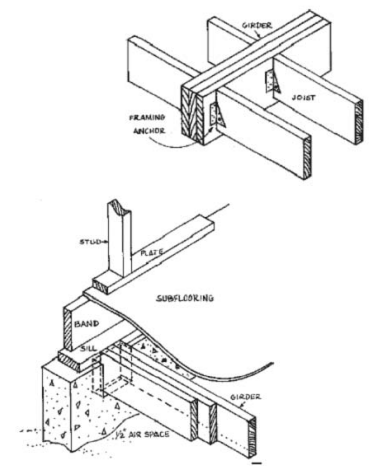
Wood

- *columns*
- *beams*
- *trusses*



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

- studs, beams
- floor diaphragms & shear walls



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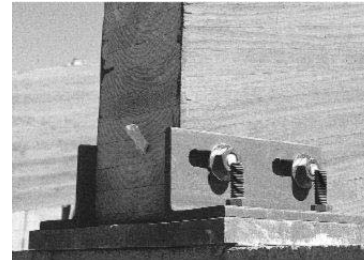


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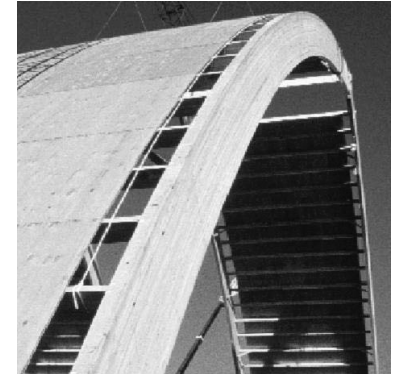
Timber Construction

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



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Timber Construction

- post & beam



- trusses



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Timber Construction

- composite construction



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Steel

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



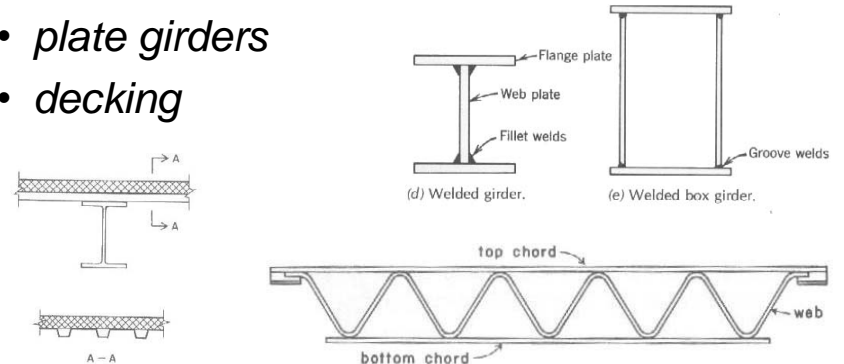
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Steel Construction

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



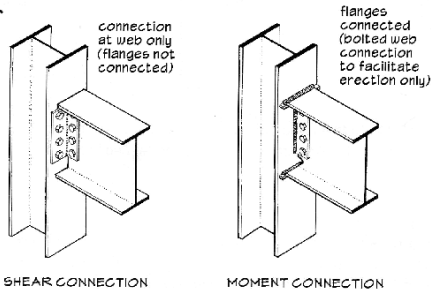
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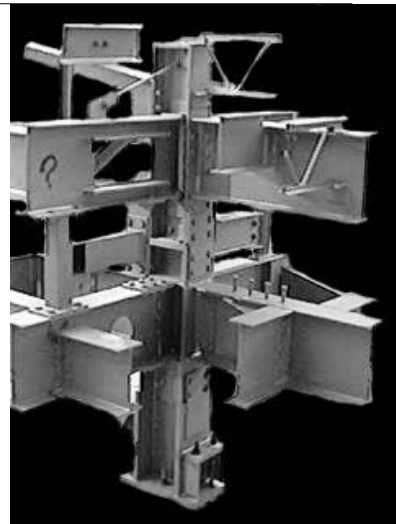
Steel Construction

- welding
- bolts



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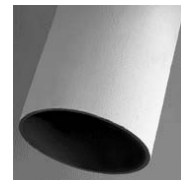
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Steel Construction

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



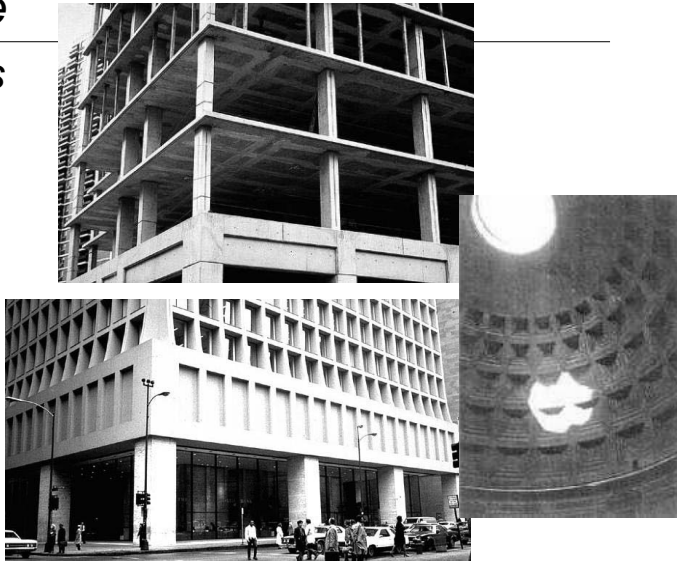
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Concrete

- columns
- beams
- slabs
- domes
- footings



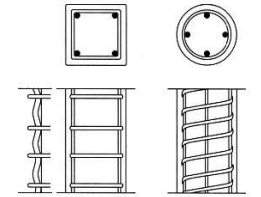
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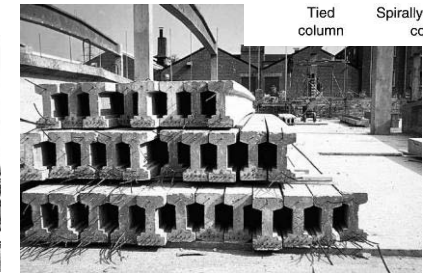
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Concrete Construction

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



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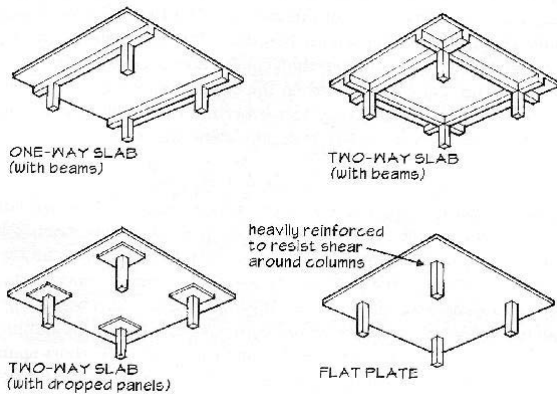


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Concrete Floor Systems

- types & spanning direction

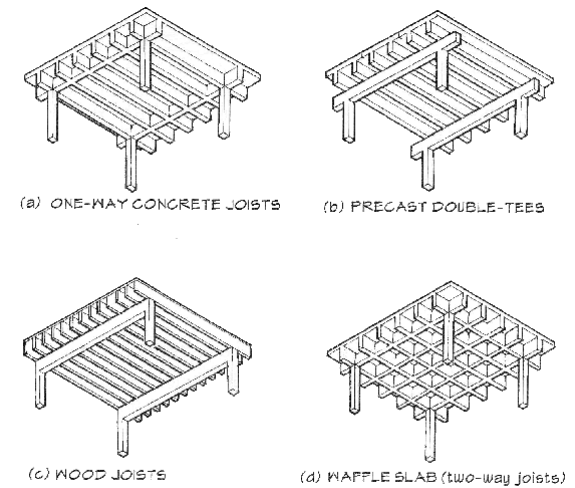


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Concrete Floor Systems



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Masonry (& Stone)

- columns
- walls
- lintels
- beams
- arches
- footings



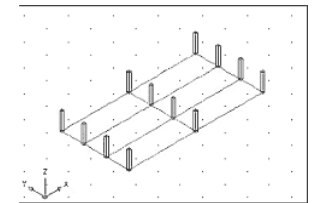
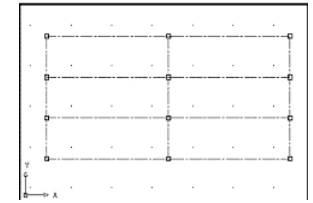
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Grids and Patterns

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

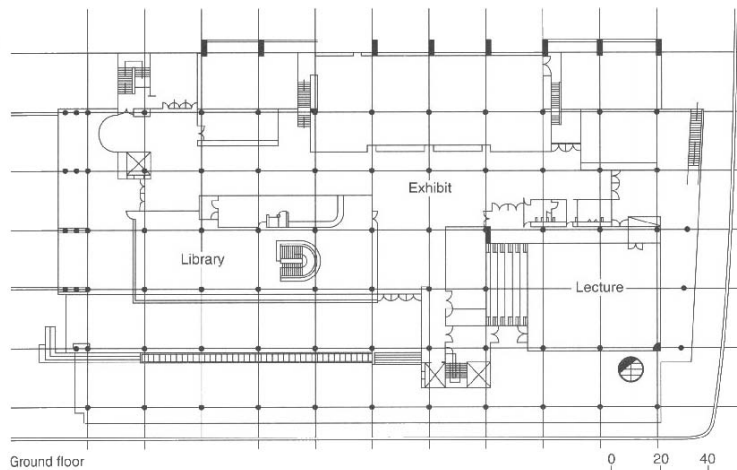


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Grids and Patterns



(a) Square column grid.

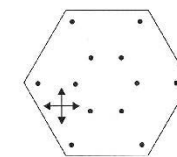
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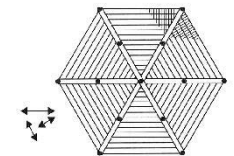
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Systems

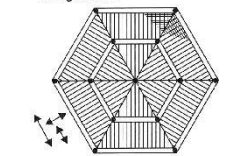
- total of components
- behavior of whole
- classifications
 - one-way
 - two-way
 - tubes
 - braced
 - unbraced



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



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



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

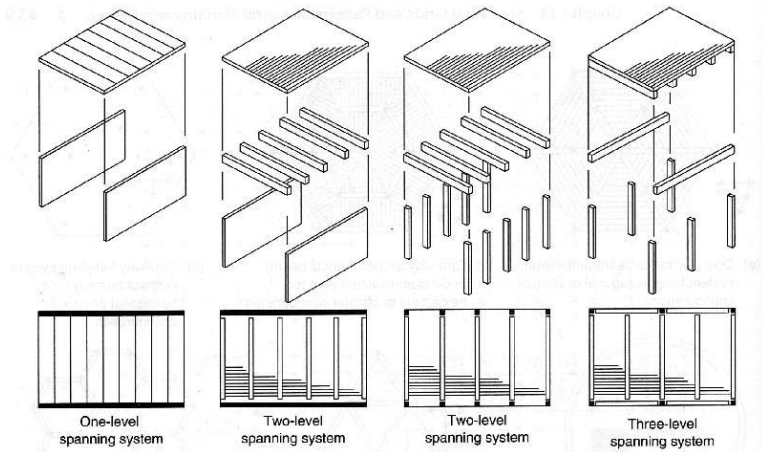
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One-Way Systems

- horizontal vs. vertical



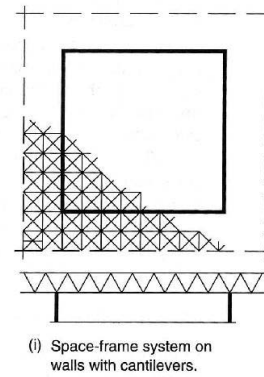
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Two-Way Systems

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

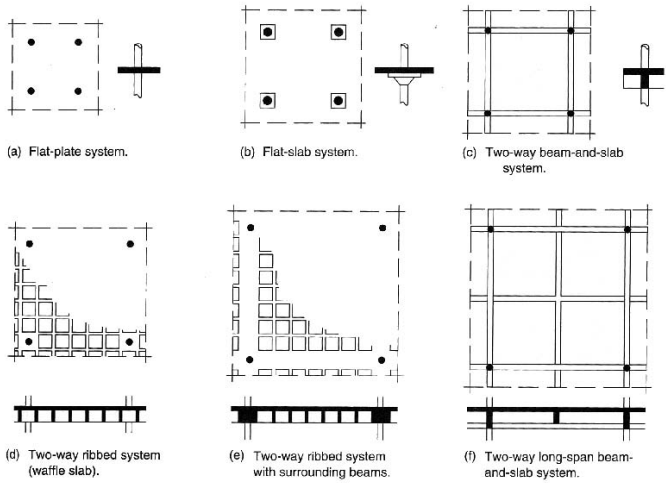


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Two-Way Systems



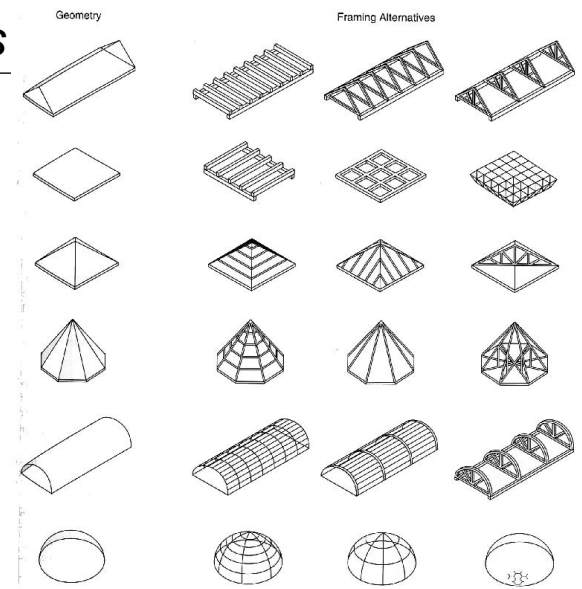
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Roof Shapes

- coincide
- within



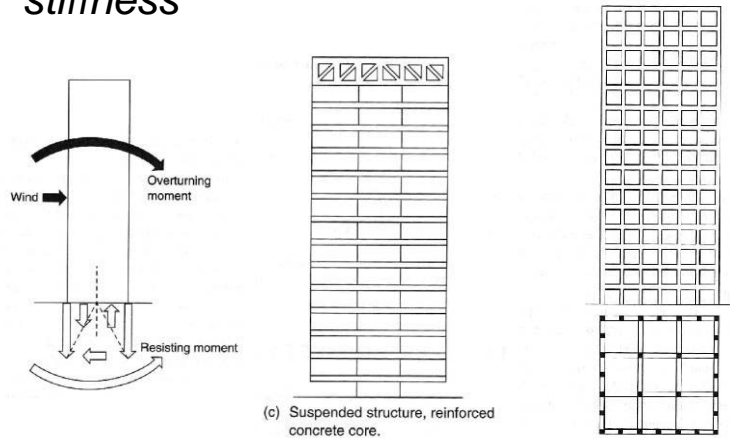
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Tubes & Cores

- stiffness



(c) Suspended structure, reinforced concrete core.

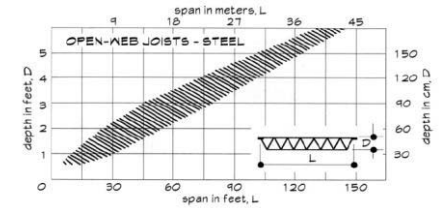
(c) Tube structure. The exterior columns are closely spaced. Horizontal spandrel beams are rigidly connected to columns to form an exterior tube, which carries all lateral forces and some gravity forces. Interior columns carry only vertical forces.

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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

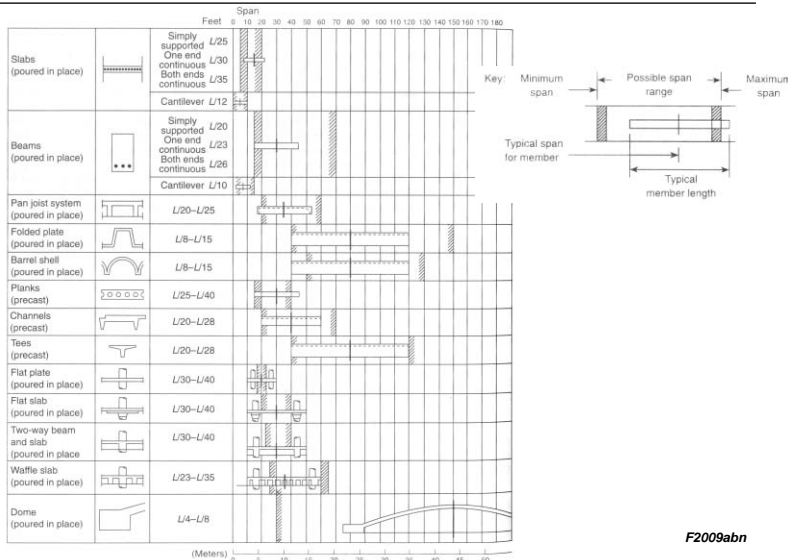


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Approximate Depths



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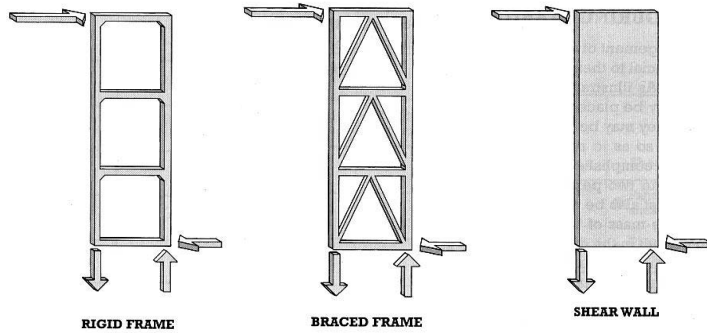
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Loading Type and Structure Type

- 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



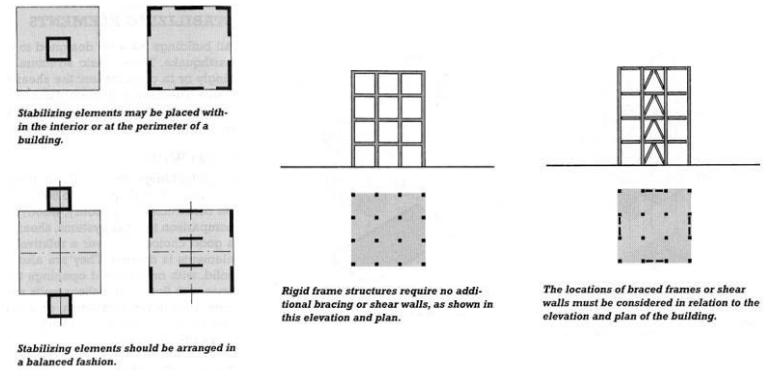
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Design Issues

- configuration



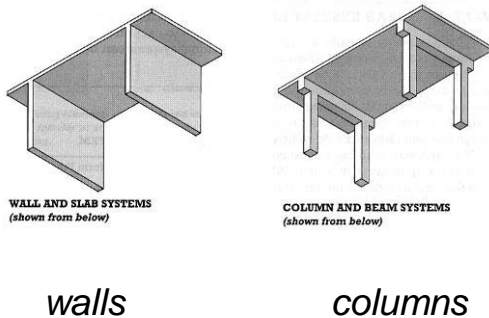
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Design Issues

- vertical load resistance



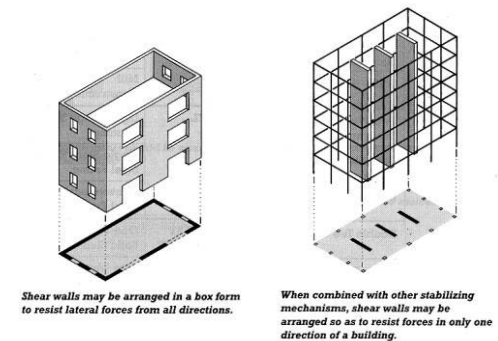
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Design Issues

- lateral load resistance



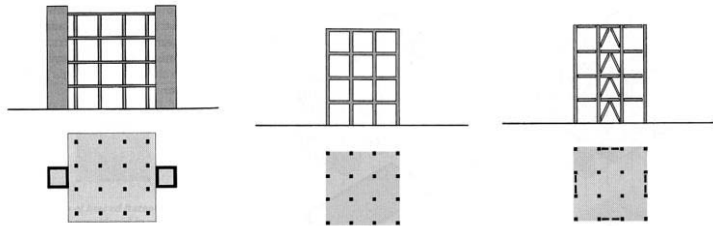
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Design Issues

- lateral load resistance



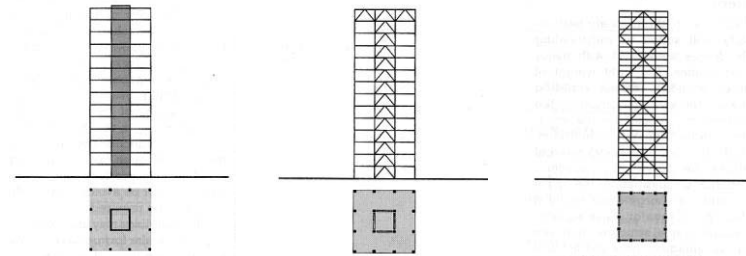
Shear walls are commonly used with column and slab systems. In this elevation and plan, the shear walls are shown incorporated into a pair of vertical cores.

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

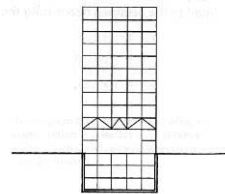
BRACED CORE WITH HAT TRUSS

BRACED FRAME TUBE

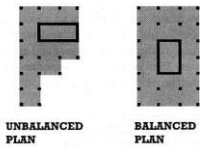
Design Issues

- multi-story
 - avoid discontinuities

- vertically
- horizontally

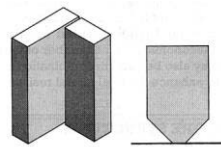


Transfer beams or trusses may be used to interrupt vertical loadbearing elements where necessary.

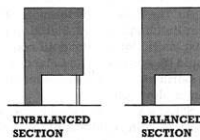


UNBALANCED PLAN

BALANCED PLAN

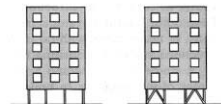


Discrete building masses should be structurally independent. Inherently unstable building masses should be avoided.



UNBALANCED SECTION

BALANCED SECTION

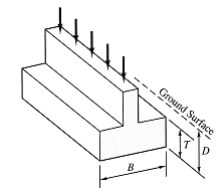
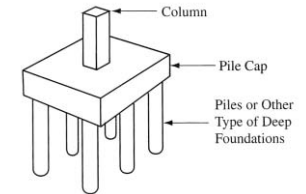


Discontinuities in the stiffness of structures at different levels should be avoided, or additional stabilizing elements may be required.

Foundation Influence

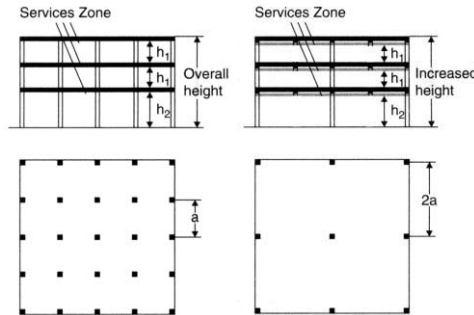
- type may dictate fit
 - piles vs. mats vs. spread
 - capacity of soil to sustain loads

- 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



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Meeting of Grids

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

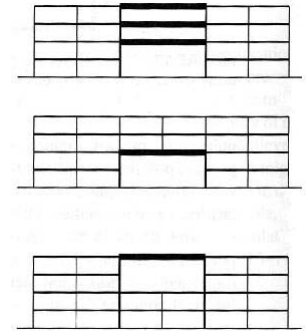
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Large Spaces

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



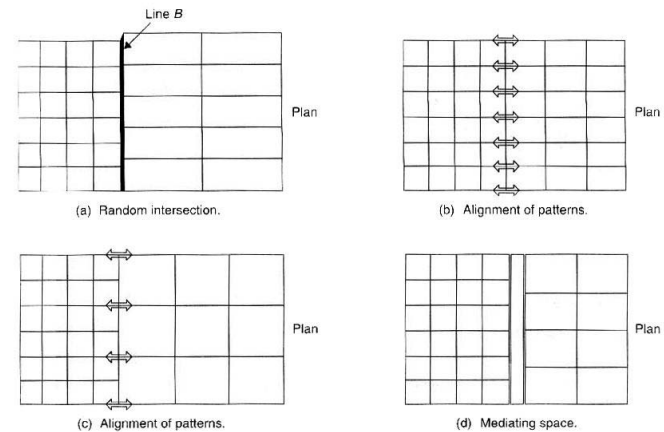
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Meeting of Grids

- horizontal choices



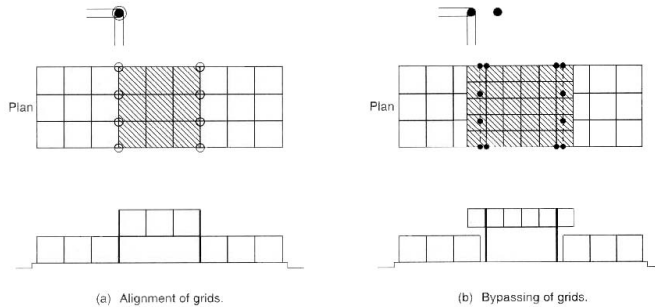
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Meeting of Grids

- *vertical choices*



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Other Conditions

- *poking holes for member services*

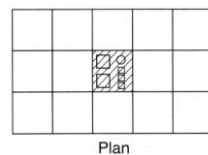
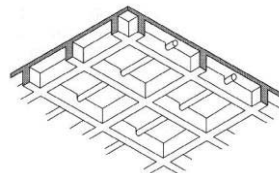
– *horizontal*

- *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*



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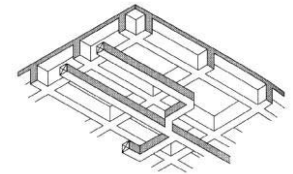
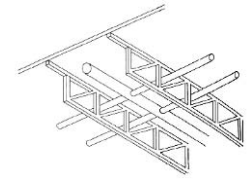
Other Conditions

- *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*



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Fire Safety & Structures

- *fire safety requirements can impact structural selection*

- *construction types*

– *light*

- *residential*
- *wood-frame or unprotected metal*

– *medium*

- *masonry*

– *heavy*

- *protected steel or reinforced concrete*

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Fire Safety & Structures

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

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Fire Safety & Structures

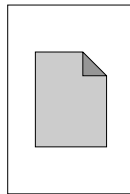
- *resistance ratings by failure type*
 - *transmission failure*
 - *fire or gasses move*
 - *structural failure*
 - *high temperatures reduce strength*
 - *failure when subjected to water spray*
 - *necessary strength*
- *ratings do not pertain to usefulness of structure after a fire*

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Project



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