CH. 1 – SELECTION OF STRUCTURAL SYSTEMS

STANDARD STRUCTURAL SYSTEMS

Wood

- Oldest & most common
- Typically a one way structural system where load is transmitted thru members in one direction
- **Joist:** span between beams or bearing walls
  - **Spacing:** 12” or 16” o.c.
  - **Span:** 20’ – 25’
- **Bridging:** used to support bottom edge of joist
  - Max interval of 8’-0”
  - Top held in place by sheathing
- **Plank-and-beam framing:** members of 4” or 6” nominal width span between girders or bearing walls at 4’, 6’ or 8’
  - Solid or laminated wood decking span between beams with underside of decking being finished ceiling
  - **Span:** 10’-0” – 20’-0”
- **Glue laminated construction (gluelam):** made from individual pieces fo lumber 3/4” or 1 1/2” thick
  - **Standard widths:** 3 1/8”, 5 1/8”, 6 3/4” and 8 3/4”
  - **Spans:** 15’ – 60’
  - **Advantages:**
    - Appearance
    - Can be tapered or curved, arches
- **Light weight I-shaped joists:** solid top & bottom chord w/ plywood or OSB web
  - Residential and light commercial
  - Efficient structural shape b/c manuf. in factory: eliminates warping, splitting, checks & other common defects
  - Higher modulus of elasticity than a standard wood joist and allowable stress in bending 2x that of Douglas fir Joists
- **Truss:** made of standard wood members connected with plates
  - **Spans:** 24' – 40'
  - ** Depths:** 12” – 36”
  - **Spacing:** 24” o.c.
  - **Advantages:**
    - Easy passage of mechanical ductwork
- **Box beam:** plywood panels glued and nailed to solid members, typically of 2x4 framing
- **Stress skin panels:** plywood glued and nailed to solid 2” nominal thickness lumber for floors, roofs or walls

Steel

- Most commonly used structural material b/c:
  - High strength
  - Availability
  - Ability to adapt to variety of conditions
  - Ductile: (tolerate deformation and return to original shape and that it bends before it breaks
- Suited for multifloor construction b/c strength and structural continuity
- Most common structural steels systems:
  - **Beam-and-girder system:** large members span between vertical supports and smaller beams are framed into those girders
    - Girders span the shorter distances while beams span the longer
    - **Spans:**
      - **Girders:** 25’ – 40’
      - **Beams:** 8’ – 10’
- **Open web steel joist**: span between beams or bearing walls
  - Standard open web joists:
    - Span: 60’
    - Unit depth: 8” – 30” in increments of 2”
- **Long-span joist**:
  - Span: 96’
  - Depth: 18” – 72”
  - Spacing (floor joists): 2’ – 4’
  - Spacing (roof joists): 4’ – 6”
- **Deep long-span joists**:
  - Span: 144’

Concrete

- **Cast-in-place**: utilizes mild steel reinforcement but may used post tensioning
  - **One way concrete system**: slab and beams designed to transfer loads in one direction
    - **Example**: slab will transfer floor loads and intermediate beam which transfer to larger girder supported by columns
    - **Beam-and-girder system**: slab is supported by intermediate beams that are carried by larger girders
      - **Spans**: 15’ – 30’
      - Economical
      - Easy to form
      - Allows penetrations in slab
    - **Concrete joist system**: members spaced 24” – 36” apart in one direction that frame into larger beams
      - **Spans**: 2’ – 30’
      - **Depth**: 12” – 24”
      - Easy to form (prefabricated metal pan forms)
      - Light or medium loads
  - **Two way concrete systems**: commonly in rectangular bays where distance between columns is same or close in both directions
    - **Flat plate**: slab is reinforced to span in both directions directly into columns
      - **Span**: 25’ - Light loads and short spans
      - **Slab thickness**: 6” – 12”
      - Useful where floor-to-floor height must be kept to min. or uncluttered under floor appearance is desired
      - **Drop panel**: increased slab thickness around columns to provide greater resistance against punching shear failures
        - Typically when flat plate span is large or live loads are heavier
    - **Flat slab**: column capitals (truncated pyramids or cones) also used to handle punching shear & barge bending moments in vicinity of column
      - Can accommodate heavy loads w/ economical spans up to 30’
    - **Waffle slab**: support for heavier loads & longer spans
      - **Span**: up to 40’ economically
      - Reusable prefabricated metal or fiberglass forms allow for faster construction
      - Often coffers left exposed with lighting integrated into recesses
- **Precast structural members**: typically pre-stressed and mild reinforcing steel is used
  - When used as structure, typically prestressed with high-strength steel cables stretched before pour U released after concrete attains minimum strength which transfers compressive stresses to concrete ∴ built-in compressive stress that resists tension forces of own weight & love loads
  - **Lift-slab**:
  - **Singe tee or double tee**: Serve as structural supports & floor or roof decking
    - 2” topping slab of concrete used to provide uniform smooth surface
  - **Post-tensioned concrete**:
    - **Tendons**: post-tensioning steel which is stressed after concrete has been poured and cured
    - Small high strength wires, seven-wire strands or solid bar are stressed with hydraulic jacks pulling on ends with pressures of
- 100psi to 250psi for concrete slabs
- 200psi to 500psi for beams

Masonry
- High compressive strength
- Unitized nature makes it weak in tension and bending
- Three basic types
  - **Single wythe**: No requirements for reinforcing or grouting and rely on a substrate for support
  - **Double wythe**: Material for both wythes may be the same & may be grouted and reinforced or ungrouted
  - **Cavity walls**: may be grouted and reinforced or ungrouted
- **Advantages**:
  - Strength
  - Flexibility
  - Appearance
  - Resistance to weathering
  - Fire resistance
  - Sound insulation
  - Passive solar energy applications as thermal mass
- **Joints**:
  - Horizontal joint reinforcement:
    - 16”o.c.
    - Must be reinforced horizontally at regular intervals to
    - Strengthens wall & control shrinkage cracks
    - Ties multi wythe walls together
    - Provides way to anchor veneer facing to structural backup wall or substrate
- **Wall thickness**:
  - Determines:
    - **Slenderness ratio**: ratio of walls unsupported height to thickness and is an indication of walls ability to resist buckling when a compressive load is applied
    - Flexural strength: when wall is subjected to lateral forces such as wind
    - Fire resistance rating: depends on material and thickness

Composite Construction
- Two or more materials designed to act together to resist loads
- Reinforced concrete construction: most typical
- Concrete & steel beams with headed stud anchors used to transfer load between them making the two materials act as one unit
- Composite open web joists: provide a nailable surface for floor and ceiling while using high strength-to-weight ratio of steel for web members

Walls and Building Envelope
- **Considerations**: when deciding how to attach exterior nonstructural skin to structural frame
  - How weight of envelope will be supported
  - How exterior loads (wind) will be transferred
- **Stone & masonry**: attached with clip angles, continuous angles or special fastenings to structural frame at floor lines
  - When attaching exterior facing to structural frame, allow for expansion and contraction
    - Temperature changes
    - Movement of structural frame
COMPLEX STRUCTURAL SYSTEM

Trusses
- Structures comprised of straight members forming a number of triangles with connections arranged so that stresses in members are either in tension or compression
- Can be field-fabricated or in factory

Arches
- Hinged or fixed supports
- **Hinged arch** is primarily subjected to compressive forces

![Arches](image)

- **Funicular shape**: shape of an arch to resist a given set of loads only in compression
  - Found by suspending the anticipated loads from flexible cable upside down (Gaudi)
  - For hinged arch supporting uniform load across its span is a parabola
  - **However**: this never happens. No arch is subjected to just one set of loads. There are always combinations of compression and some bending stresses

- **Supports of a hinged arch**: Vertical reactions & horizontal actions or **thrust**
  - Loads on arch tend to force it to spread out. thrust must be resisted
    - **Tie rods**: hold two lower portions together
    - **Foundations**: specific to prevent thrust
  - For a given span thrust is inversely proportional to the rise/height of the arch
    - If rise is reduced by one half, the thrust doubles

- Shape of arch selected for aesthetic appeal not always ideal shape for loading

- **Typical arch spans**:
  - **Wood**: 50’ – 240’
  - **Concrete**: 20’ – 320’
  - **Steel**: 50’ – 500’

- Although arches may have fixed supports, they are usually top hinged to allow it to remain flexible and avoid developing high bending stresses under live loading and loading due to temperature changes and settlement

- **Three hinged arch**: additional hinged connection at apex which makes structure statically determinate
- Two-hinged or fixed arches are statically indeterminate

Rigid Frames
- In contrast to a simple post-and-beam system, a rigid frame is constructed so vertical and horizontal members work as a single structural unit
- Efficient structure b/c three members resist vertical and lateral loads together
- **Beam**: restrained by columns and becomes more rigid to vertical bending forces
- **Columns**: resist lateral forces b/c tied together by beam

![Rigid Frames](image)
Diagram shows results in columns subjected to compressive and bending forces and a thrust induced by vertical loads on beam transferred to the columns
- Similar to arch, thrust must be resisted with tie rods or appropriate foundations
- Rigid vs hinged column attachments to foundations may result in different loads on the column
  - **Fixed frame**: stiffer than hinged frame thrust is greater
  - **Gabled frame**: when a horizontal beam is not required, often in one story construction
    - This shape decreases bending stresses in two inclined members and increases compression making configuration more efficient
    - Because these rigid frames develop a high moment at connections between horizontal and vertical members, amount of material is increased

**Space Frames**
- Very stiff system consisting of trusses in two directions rigidly connected at intersections
- To and bottom chords directly above and below one another
- Bays created by intersection of two sets of trusses then form square or rectangles
- **Triangulated space frame**: more common type where bottom chord is offset from top by half a bay and ea is connected with inclined web members
- **Advantages**:
  - **Span**: 350’
  - **Span-to-depth ratio**: 20:1 to 30:1
  - Lightweight & extremely stiff
  - Repetitive nature of connectors and struts for easy fabrication & erection

**Folded Plates**
- Structure where loads are carried in two directions
  - **First**: load carried in transverse direction thru each plate supported by adjacent plates
  - **Second**: longitudinal direction with each plate acting as a girder spanning between vertical supports
- Since plates act as beams between supports, there are compressive stresses above the neutral axis and tensile stresses below
- Reinforced concrete 3” – 6” thick

**Thin-Shell Structure**
- Curved surface that resists loads thru tension, compression and shear in the plane of the shell only
- No moment or bending stresses in a thin shell
- Typically always reinforced concrete 3” – 6”
- **Forms**: domes, parabolas, saddle shaped hyperbolic paraboloid or barrel vaults
- **Span**: 40’ – 200’
  - Hyperbolic paraboloid: 30’ – 160’

**Stressed Skin**
- Panels of sheathing attached on one or both sides of intermediate web members that panel acts as a series of I-beams with sheathing being the flange and intermediate being the webs.
- Since two or more pieces, connection between parts must transfer all the horizontal stress developed
- Typically made of wood

**Suspension Structures**
- Typically bridges
  - **Building example**: Federal Reserve Bank in Minneapolis
- Structures are similar to arches: loads must be resisted by vertical reactions and horizontal thrust reactions
  - **Difference from arches**: vertical reactions are up and the horizontal thrust reactions are outward
  - Since sag tends to pull ends together, horizontal reaction is dependent on amount of sag in cable
    - Shallow sags result in high horizontal reactions
    - Deep sags result in lower horizontal reactions
- Suspension structures only resist loads with tension, shape of cable used changes as load changes
- No bending stresses are possible
• With single concentrated load, cable assumes shape of two straight lines (not counting the intermediate sag due to the weight of cable)
• With two concentrated loads, the shape is three straight lines, and so on……

![Diagram of cable shapes](image)

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**Disadvantage:** since only resist loads in tension, instability due to wind must be stabilized or stiffened with heavy infill material, with cables attached to ground or secondary grid of cables above primary set

### Inflatable Structures

- Only resist loads in tension and are held in place with constant air pressure that is greater than the outside air pressure
- **Simplest form:** single membrane anchored continuously at ground level & inflated
- **Double skin inflatable structure:** created by inflation of a series of voids (sim. Air mattress)
  - Need for airlock is eliminated
  - **Other example:** one large air pocket supported on bottom by a cable suspension system and with top supported by the air pressure
- Unstable in wind and cannot support concentrated loads
  - Stabilized with a network of cables over top of membrane

### STRUCTURAL SYSTEM SELECTION CRITERIA

#### Resistance to Loads

- Primary consideration
- Anticipated loads calculated from known weights of materials and equipment and requirements of building codes
- Unanticipated loads such as changes in use, overloading by extra people or equipment, unusual snow load, ponding of water & degradation of structure itself
- Often, an unusual loading condition will be primary determinant of structural system

#### Building Use and Function

- Occupancy type is one of the primary determinants of a system
  - Parking garage vs other
- Some needs not so apparent
  - **Example:** Building height is limited & client wants to squeeze as many floors into a multistory building as possible
    - Result may be concrete flat plate with closely spaced columns
  - **Example:** Laboratory may need large spaces between floors to run mechanical service
    - Result may be deep span, open web trusses but if were to house delicate motion sensitive equipment, then a rigid massive concrete structure