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

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
Structure Requirements

- stability & equilibrium
  - STATICS

Structure Requirements (cont)

- strength & stiffness
  - concerned with stability of components

Structural System Selection

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

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
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......
Structural Action

- axial tension
- axial compression
- bending

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

Structural Action

- member breadth & depth

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

Structural Action

- stabilization

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

Structural Action

- shear & bracing

Figure 1.6 (a) A thin wall and (b) subjected to lateral forces.

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

Figure 1.10 (a) Shear and bracing stabilized by adding shear walls.

Figure 1.20 (a) Walls with (a) triangulation and (b) a rigid frame.
Structural Action

- lateral resistance

- twisting

Structural Design

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

Structural Loads

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

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

• earthquake loads
  – seismic, movement of ground

• impact loads
  – rapid, energy loads

• gravity acts on mass \((F=m\cdot g)\)

• 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
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

- behavior as “deep beams”

Columns & Walls

Beams & Plates
**Beams & Plates**

![Beam and Plate Diagrams](image)

**Trusses and Shells**

![Truss and Shell Diagrams](image)

**Arches and Cables**

![Arches and Cables Diagrams](image)

**Building Framing**

- **Components or Assemblages**

  ![Building Framing Diagrams](image)

(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

Horizontal spanning system

Vertical support system

Decking carries roof loads by bending.
Decking reactions become forces on beams (which carry loads by bending).
Beam reactions become forces on trusses.
Truss reactions cause compressive forces to develop in columns.

Columns are in compression.

Column reactions become forces on foundations (which distribute the forces into the earth).

System Selection

• evaluation of alternatives

System Selection

Structural Design Criteria

• components stay together
  • resist sliding
  • resist overturning
  • resist twisting and distortion

• internal stability
  • interconnectedness

• strength & stiffness

<table>
<thead>
<tr>
<th>DESIGN CRITERIA</th>
<th>RATIONALE</th>
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</thead>
<tbody>
<tr>
<td>Expansive, fire-resistant construction</td>
<td>Inherently fire-resistant construction</td>
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<tr>
<td>Irregular building form</td>
<td>Simple, site fabricated systems</td>
</tr>
<tr>
<td>Irregular column placement</td>
<td>Systems without beams in roof or floors</td>
</tr>
<tr>
<td>Minimize floor thickness</td>
<td>Precast-concrete systems without ribs</td>
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<tr>
<td>Allow for future renovations</td>
<td>Short-span, one-way, easily modified</td>
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<tr>
<td>Permit construction in poor weather</td>
<td>Quickly erected, avoid site cast concrete</td>
</tr>
<tr>
<td>Minimize off-site fabrication time</td>
<td>Easily formed or built on site</td>
</tr>
<tr>
<td>Minimize on-site erection time</td>
<td>Highly precast: modular components</td>
</tr>
<tr>
<td>Minimize cost of construction</td>
<td>Lightweight, easily formed or precast concrete</td>
</tr>
<tr>
<td>Minimize cost of materials</td>
<td>Precast, site-cast concrete, steel frames</td>
</tr>
<tr>
<td>Minimize environmental impact</td>
<td>Strong: precast: lightweight</td>
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<tr>
<td>Minimize shear or diagonal bracing</td>
<td>Capable of forming rigid joints</td>
</tr>
<tr>
<td>Minimize dead load on foundations</td>
<td>Lightweigh, short-span systems</td>
</tr>
<tr>
<td>Minimize damage due to foundation settlement</td>
<td>Systems without rigid joints</td>
</tr>
<tr>
<td>Minimize the number of separate trades on job</td>
<td>Multipurpose components</td>
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<tr>
<td>Provide concealed space for mech. services</td>
<td>Systems that inherently provide voids</td>
</tr>
<tr>
<td>Minimize the number of supports</td>
<td>Two-way, long-span systems</td>
</tr>
<tr>
<td>Long spans</td>
<td>Long-span systems</td>
</tr>
</tbody>
</table>
**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**

**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

Timber Construction

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

Timber Construction

- post & beam

Timber Construction

- trusses

- composite construction
Steel

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

Steel Construction

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

Steel Construction

- welding
- bolts

Steel Construction

- fire proofing
  - cementicious 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](image-url)
Masonry (& Stone)

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

Grids and Patterns

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

Systems

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

Grids and Patterns

- one-way radial beam and column system for a hexagonal or circular configuration.
- two-way flexural beam and column system for a 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

**Roof Shapes**

- coincide
- within
**Tubes & Cores**

- stiffness

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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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**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

Design Issues

• configuration

Design Issues

• vertical load resistance

Design Issues

• lateral load resistance

walls columns
**Design Issues**

- lateral load resistance

- 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

- 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

• 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

• 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

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

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

Project