behavior and design of structures

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

Syllabus & Student Understandings

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

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

Architectural Structures

- incorporates
  - stability and equilibrium
  - strength and stiffness
  - economy, functionality and aesthetics
- uses
  - sculpture
  - furniture
  - buildings

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

The “Fist”
Detroit, MI
AISC (Steel)
Sculpture
College Station, TX

“Jamborie”
Philadelphia, PA
Daniel Barret

Exploris Mobile
Heath Satow

“Telamones”
Chicago, IL
Walter Arnold
“Free Ride Home” 1974
Kenneth Snelson

“Zauber”
Laudenslager, Jeffery

Conference
Table
Heath Satow

Bar Stool
“Stainless Butterfly”
Daniel Barret
Chair
Paul Freundt

End Tables
Rameu-Richard

Steel House, Lubbock, TX
Robert Bruno

Guggenheim Museum Bilbao
Frank Gehry (1997)
Airport Station, Lyon, France
Santiago Calatrava (1994)

Centre Georges Pompidou, Paris
Piano and Rogers (1978)

Hongkong Bank Building (1986)
Foster and Partners

Meyerson Symphony Center
Dallas, TX
Pei Cobb Freed & Partners
Crystal Cathedral, LA
Philip Johnson (1980)

Federal Reserve Bank
Minneapolis, MN
Gunnar Birkerts & Associates

Hysolar Research Building
Stuttgart, Germany
(1986 -87)
Gunter Behnisch

Notre Dame Cathedral
Paris, France
Maurice de Sully
Habitat 67, Montreal
Moshe Safdie (1967)

Villa Savoye, Poissy, France
Le Corbusier (1929)

Riola Parish Church
Riola, Italy
Alvar Aalto

Kimball Museum, Fort Worth
Kahn (1972)
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......

Stone + Masonry
• columns
• walls
• lintels
• arches

Wood
• columns
• beams
• trusses

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

www.pbs.org/wgbh/buildingbig/
Steel

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

Concrete

- columns
- beams
- slabs
- domes

Structural Components

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

Bearing Walls
**Bearing Walls**

- behavior as “deep beams”

**Beams & Plates**

**Building Framing**

- Components or Assemblages
**Building Framing**

![Building Framing Diagram]

- Horizontal spanning system
- Lateral support system
- Vertical support system

**System Selection**

- evaluation of alternatives

![System Selection Diagram]

**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?

<table>
<thead>
<tr>
<th>DESIGN CRITERIA</th>
<th>RATIONALE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposed, fire-resistant construction</td>
<td>Inherently fire-resistant construction</td>
</tr>
<tr>
<td>Structure frame system</td>
<td>Simple, site-fabricated systems</td>
</tr>
<tr>
<td>Irregular building form</td>
<td>Systems without beams in roof or floors</td>
</tr>
<tr>
<td>Irregular column placement</td>
<td></td>
</tr>
<tr>
<td>Minimize floor thickness</td>
<td>Precast-concrete systems without ribs</td>
</tr>
<tr>
<td>Allow for future renovations</td>
<td>Quickly erected; avoid site-cast concrete</td>
</tr>
<tr>
<td>Permit construction in poor weather</td>
<td>Easily formed or built on site</td>
</tr>
<tr>
<td>Minimize off-site fabrication problems</td>
<td>Highly prefabricated; modular components</td>
</tr>
<tr>
<td>Minimize low-rise construction time</td>
<td>Lightweight, easily formed or prefabricated</td>
</tr>
<tr>
<td>Minimize medium-rise construction time</td>
<td>Precast, site-cast concrete; steel frames</td>
</tr>
<tr>
<td>Minimize high-rise construction time</td>
<td>Strong; prefabricated; lightweight</td>
</tr>
<tr>
<td>Minimize shear walls or diagonal bracing</td>
<td>Capable of forming rigid joints</td>
</tr>
<tr>
<td>Minimize dead load on foundations</td>
<td>Lightweight, short-span systems</td>
</tr>
<tr>
<td>Minimize the number of separate trades on job</td>
<td>Systems without rigid joints</td>
</tr>
<tr>
<td>Minimize the number of supports</td>
<td>Multipurpose components</td>
</tr>
<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>
Physical 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

Geometric Math
• Greek architects relied on proportion
  – ratios of dimensions employed were fixed
• projective geometry
  – Renaissance
  – allowed perspective & sections
  – intersections & proportion

Basic Math
• base:
  – addition, subtraction, multiplication, division
• descriptive geometry
  – relationships existing between geometric elements such as points, lines & planes
• functions, conversions & graphs
  – relationships between quantities of numerical values
  – graphs used to avoid mental sorting and see relationships quickly

Language
• symbols for operations: +, -, /, x
• symbols for relationships: ( ), =, <, >
• algorithms
  – cancellation
    \[ \frac{2}{5} \times \frac{5}{6} = \frac{2}{6} = \frac{1}{3} \]
  – factors
  – signs
    \[ x = \frac{1}{6} \]
  – ratios and proportions
    \[ 10^3 = 1000 \]
  – power of a number
  – conversions, ex. \( 1X = 10Y \)
  – operations on both sides of equality
    \[ \frac{10Y}{1X} = 1 \]
### On-line Practice
- Vista / Study Aids

![Image of Vista or Study Aids](image-url)

### Geometry
- **shapes**
  - rectangle
  - triangle
  - right triangle
  - equilateral triangle
  - rhomboid
  - parallelogram

- **angles**
  - right $= 90^\circ$
  - acute $< 90^\circ$
  - obtuse $> 90^\circ$
  - $\pi = 180^\circ$

- **triangles**
  - area
  - hypotenuse
  - total of angles $= 180^\circ$
  \[ AB^2 + AC^2 = BC^2 \]
**Geometry**

- intersection of a line with parallel lines results in identical angles

- two lines intersect in the same way, the angles are identical

\[ \alpha \quad \beta \quad \alpha \quad \beta \]

**Geometry**

- sides of two angles are parallel and intersect opposite way, the angles are **supplementary** - the sum is 180°

\[ \alpha \quad \beta \quad \alpha \quad \beta \]

- two angles that sum to 90° are said to be **complimentary**

\[ \beta + \gamma = 90° \]

\[ \beta \quad \gamma \]

**Geometry**

- sides of two angles bisect a right angle (90°), the angles are **complimentary**

\[ \alpha + \gamma = 90° \]

- right angle bisects a straight line, remaining angles are **complimentary**

**Geometry**

- similar triangles have proportional sides

\[ \frac{AB}{AD} = \frac{AC}{AE} = \frac{BC}{DE} \]

\[ \frac{AB}{A'B'} = \frac{AC}{A'C'} = \frac{BC}{B'C'} \]
**Trigonometry**

- **for right triangles**
  - \(\sin = \frac{\text{opposite side}}{\text{hypotenuse}} = \sin \alpha = \frac{AB}{CB}\)
  - \(\cos = \frac{\text{adjacent side}}{\text{hypotenuse}} = \cos \alpha = \frac{AC}{CB}\)
  - \(\tan = \frac{\text{opposite side}}{\text{adjacent side}} = \tan \alpha = \frac{AB}{AC}\)

SOHCAHTOA

**Trigonometry**

- **for angles starting at positive x**
  - \(\sin < 0\) for \(180-360^\circ\)
  - \(\cos < 0\) for \(90-270^\circ\)
  - \(\tan < 0\) for \(90-180^\circ\)
  - \(\tan < 0\) for \(270-360^\circ\)

**Trigonometry**

- **cartesian coordinate system**
  - origin at 0,0
  - coordinates in \((x,y)\) pairs
  - \(x\) & \(y\) have signs

**Trigonometry**

- **for all triangles**
  - sides \(A, B\) & \(C\) are opposite angles \(\alpha, \beta & \gamma\)
  - **LAW of SINES**
    \[
    \frac{\sin \alpha}{A} = \frac{\sin \beta}{B} = \frac{\sin \gamma}{C}
    \]
  - **LAW of COSINES**
    \[
    A^2 = B^2 + C^2 - 2BC \cos \alpha
    \]
Algebra

- **equations** (something = something)
- **constants**
  - real numbers or shown with a, b, c...
- **unknown terms, variables**
  - names like R, F, x, y
- **linear equations**
  - unknown terms have no exponents
- **simultaneous equations**
  - variable set satisfies all equations

Algebra

- **solving one equation**
  - only works with one variable
    - ex: $2x - 1 = 0$
      - add to both sides $2x - 1 + 1 = 0 + 1$
      - divide both sides \( \frac{2x}{2} = \frac{1}{2} \)
      - get x by itself on a side \( x = \frac{1}{2} \)

Algebra

- **solving two equation**
  - only works with two variables
    - ex: $2x + 3y = 8$
      - look for term similarity $12x - \frac{3y}{3} = 6$
      - can we add or subtract to eliminate one term?
        - add $2x + 3y + 12x - 3y = 8 + 6$
        - $14x = 14$
        - get x by itself on a side \( \frac{14x}{14} = \frac{14}{14} \Rightarrow x = 1 \)
Physics for Structures

• measures
• vectors
• motion of particles
• center of mass
• equilibrium of bodies
• gravitation
• fluid mechanics
• temperature

Galileo Galilei

Physics for Structures

• measures
  – US customary & SI

<table>
<thead>
<tr>
<th>Units</th>
<th>US</th>
<th>SI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>in, ft, mi</td>
<td>mm, cm, m</td>
</tr>
<tr>
<td>Volume</td>
<td>gallon</td>
<td>liter</td>
</tr>
<tr>
<td>Mass</td>
<td>lb mass</td>
<td>g, kg</td>
</tr>
<tr>
<td>Force</td>
<td>lb force</td>
<td>N, kN</td>
</tr>
<tr>
<td>Temperature</td>
<td>F</td>
<td>C</td>
</tr>
</tbody>
</table>

Physics for Structures

• scalars – any quantity
• vectors - quantities with direction
  – like displacements
  – summation results in the “straight line path” from start to end
  – normal vector is perpendicular to something

Physics for Structures

• motion of particles
  – displacement
  – velocity
  – acceleration
  – rotation
  – cause by forces

http://www.physics.umd.edu/
Physics for Structures

• gravity
  – acceleration of mass toward the earth
  – weight or force due to gravity

• center of gravity
  – location of mass doesn’t change with motion

Physics for Structures

• equilibrium of particles – no movement

Physics for Structures

• fluid mechanics
  – weight of water or fluid causes pressure on any surface it interacts with
  – pressure is force over an area
  – air pressure causes forces
  – water pressure gets greater as it gets deeper

Physics for Structures

• temperature
  – atoms respond to heat (physical chemistry)
    • with heat solid goes to liquid goes to gas
    • excited electrons move apart
    • movement is linear
  – base 0 or freezing at the temperature water freezes at