Syllabus

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

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
Structural System Selection

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

Structure Requirements

- stability & equilibrium
  - STATICS

Structure Requirements (cont)

- strength & stiffness
  - concerned with stability of components

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

Architectural Structures

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

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......
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)

Tjibaou Cultural Center,
New Caledonia
Renzo Piano

Padre Pio Pilgrimage Church, Italy
Renzo Piano

Athens Olympic Stadium
and Velodrome
Santiago Calatrava (2004)
Milwaukee Art Museum
Quadraacci Pavilion (2001)
Santiago Calatrava

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)

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 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?

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

**Language**

- **symbols for operations:** $+, -, /, \times$
- **symbols for relationships:** $(), =, <, >$
- **algorithms**
  - cancellation
  - factors
  - signs
  - ratios and proportions
  - power of a number
  - conversions, ex. $1X = 10Y$
  - operations on both sides of equality

\[
\frac{2}{5} \times \frac{5}{6} = \frac{2}{6} = \frac{2 \times 3}{6} = \frac{1}{3}
\]

**On-line Practice**

- **Webct / Study Tools**

**Geometry**

- **angles**
  - right $= 90^\circ$
  - acute $< 90^\circ$
  - obtuse $> 90^\circ$
  - $\pi = 180^\circ$
- **triangles**
  - area $= \frac{b \times h}{2}$
  - hypotenuse $= \sqrt{a^2 + b^2}$
  - total of angles $= 180^\circ$

\[
AB^2 + AC^2 = BC^2
\]
Geometry

- **lines and relation to angles**
  - parallel lines can't intersect
  - perpendicular lines cross at 90°
  - intersection of two lines is a point
  - opposite angles are equal when two lines cross

Geometry

- intersection of a line with parallel lines results in identical angles
- two lines intersect in the same way, the angles are identical

Geometry

- sides of two angles are parallel and intersect opposite way, the angles are supplementary - the sum is 180°
- two angles that sum to 90° are said to be complimentary
- right angle bisects a straight line, remaining angles are complimentary
**Geometry**

- similar triangles have proportional sides

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

**Trigonometry**

- for right triangles

\[
\sin \alpha = \frac{\text{opposite side}}{\text{hypotenuse}} = \frac{AB}{CB}
\]

\[
\cos \alpha = \frac{\text{adjacent side}}{\text{hypotenuse}} = \frac{AC}{CB}
\]

\[
\tan \alpha = \frac{\text{opposite side}}{\text{adjacent side}} = \frac{AB}{AC}
\]

SOHCAHTOA

**Trigonometry**

- cartesian coordinate system

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

**Trigonometry**

- for angles starting at **positive** \(x\)

  - \(\sin\) is \(y\) side
  - \(\cos\) is \(x\) side

\[\sin < 0 \text{ for } 180-360^\circ\]
\[\cos < 0 \text{ for } 90-270^\circ\]
\[\tan < 0 \text{ for } 90-180^\circ\]
\[\tan < 0 \text{ for } 270-360^\circ\]
**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: $x = \frac{1}{2}$

- solving one equations
  - only works with one variable
  - ex:
    - $2x - 1 = 4x + 5$
      - subtract from both sides: $2x - 1 - 2x = 4x + 5 - 2x$
      - divide both sides: $\frac{-1 - 5}{2} = \frac{4x + 5 - 2x}{2}$
      - get x by itself on a side: $x = -3$
Algebra

• solving two equation
  – only works with two variables
  – ex:
    \[ 2x + 3y = 8 \]
    \[ 12x - 3y = 6 \]
    • look for term similarity
    • 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
  \[ \frac{14x}{14} = \frac{14}{14} = x = 1 \]