Elements of Architectural Structures: Form, Behavior, and Design

ARCH 614

Dr. Anne Nichols

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lecture one

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
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

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

Figure 2.34: An example of torsion on a cantilever beam.
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 Structures

- incorporates
  - stability and equilibrium
  - strength and stiffness
  - economy, functionality and aesthetics

- uses
  - sculpture
  - furniture
  - buildings
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

Photographer: John Gollings
Padre Pio Pilgrimage Church, Italy
Renzo Piano

Photographer: Michel Denancé
Athens Olympic Stadium and Velodrome
Santiago Calatrava (2004)
Milwaukee Art Museum
Quadracci Pavilion (2001)
Santiago Calatrava
Airport Station, Lyon, France
Santiago Calatrava (1994)
Introduction 30
Lecture 1
Elements of Architectural Structures
ARCH 614
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)
Gunther 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

www.greatbuildings.com
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
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/
Stone + Masonry

- columns
- walls
- lintels
- arches
Wood

- columns
- beams
- trusses
Steel

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

http://nisee.berkeley.edu/godden
Concrete

- columns
- beams
- slabs
- domes

http://nisee.berkeley.edu/godden
Structural Components

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

- behavior as “deep beams”
Beams & Plates

(a) shorter longer

(b) shorter longer
Beams & Plates
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.
Building Framing

Horizontal spanning system

Vertical support system

Lateral 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
<table>
<thead>
<tr>
<th>DESIGN CRITERIA</th>
<th>RATIONALE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposed, fire-resistive construction</td>
<td>Inherently fire-resistive construction</td>
</tr>
<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>
</tr>
<tr>
<td>Allow for future renovations</td>
<td>Short-span, one-way, easily modified</td>
</tr>
<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 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 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>
</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>
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?
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
  - factors
  - signs
  - ratios and proportions
  - power of a number
  - conversions, ex. \(1X = 10\ Y\)
  - operations on both sides of equality

\[
\begin{align*}
\frac{2}{5} \times \frac{5}{6} &= \frac{2}{6} = \frac{2}{2 \times 3} = \frac{1}{3} \\
\frac{x}{6} &= \frac{1}{3} \\
10^3 &= 1000 \\
\frac{10Y}{1X \ or \ \frac{1X}{10Y}} &= 1
\end{align*}
\]
On-line Practice

• Vista / Study Aids

Math Practice
Anne B Nichols
Started: August 31, 2007 10:47 AM
Questions: 20

Instructions
This assessment is only for self-grading.

1. **Force - metric to US (kN)** (Points: 10.0)
   Convert the force 6.85 kN to pounds (1) and kips (2).
   [Provide the number without the units.]

1. 
2. 

Check Answer

Finish  Help
Geometry

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

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

- **triangles**
  - area $= \frac{b \times h}{2}$
  - hypotenuse
  - 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°

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

– two angles that sum to 90° are said to be complimentary

\[ \beta + \gamma = 90^\circ \]
Geometry

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

\[ \alpha + \gamma = 90^\circ \]

- 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

\[
\begin{align*}
\sin \alpha &= \frac{\text{opposite side}}{\text{hypotenuse}} = \frac{AB}{CB} \\
\cos \alpha &= \frac{\text{adjacent side}}{\text{hypotenuse}} = \frac{AC}{CB} \\
\tan \alpha &= \frac{\text{opposite side}}{\text{adjacent side}} = \frac{AB}{AC}
\end{align*}
\]

SOHCAHTOA
Trigonometry

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

![Graph showing the Cartesian coordinate system with quadrants labeled Quadrant I, Quadrant II, Quadrant III, and Quadrant IV.](image)
Trigonometry

• for angles starting at positive $x$
  – $\sin$ is $y$ side
  – $\cos$ is $x$ side

$\sin<0$ for 180-360°
$\cos<0$ for 90-270°
$\tan<0$ for 90-180°
$\tan<0$ for 270-360°
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:
    • add to both sides
      \[ 2x - 1 = 0 \]
      \[ 2x - 1 + 1 = 0 + 1 \]
      \[ 2x = 1 \]
    • divide both sides
      \[ \frac{2x}{2} = \frac{1}{2} \]
      \[ x = \frac{1}{2} \]
    • get x by itself on a side
Algebra

• solving one equations
  – only works with one variable
  – ex:
    \[ 2x - 1 = 4x + 5 \]
    • subtract from both sides
      \[ 2x - 1 - 2x = 4x + 5 - 2x \]
    • subtract from both sides
      \[ -1 - 5 = 2x + 5 - 5 \]
    • divide both sides
      \[ \frac{-6}{2} = \frac{-3 \cdot 2}{2} = \frac{2x}{2} \]
    • 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
  
  \[2x + 3y + 12x - 3y = 8 + 6\]
  \[14x = 14\]
  \[\frac{14x}{14} = 1\]
  \[x = 1\]
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><strong>Length</strong></td>
<td>in, ft, mi</td>
<td>mm, cm, m</td>
</tr>
<tr>
<td><strong>Volume</strong></td>
<td>gallon</td>
<td>liter</td>
</tr>
<tr>
<td><strong>Mass</strong></td>
<td>lb mass</td>
<td>g, kg</td>
</tr>
<tr>
<td><strong>Force</strong></td>
<td>lb force</td>
<td>N, kN</td>
</tr>
<tr>
<td><strong>Temperature</strong></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
  - caused 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

http://www.physics.umd.edu/
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