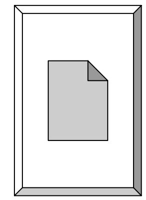
ARCHITECTURAL STRUCTURES I:
STATICS AND STRENGTH OF MATERIALS
ENDS 231
DR. ANNE NICHOLS
SPRING 2007

lecture
one

# statics and strength of materials



## 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 (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.



## Structure Requirements

- stability & equilibrium
  - STATICS

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



## Knowledge Required

- external forces
- internal forces
- material properties
- member cross sections

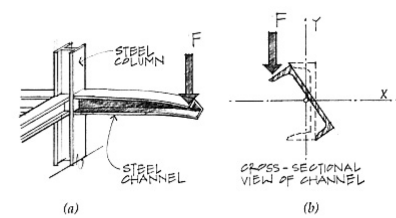



Figure 2.34 An example of torsion on a cantilever beam.

- 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 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

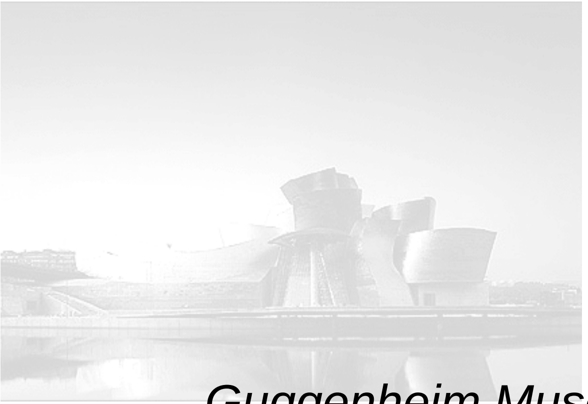


## End Tables
## Rameu-Richard





## Steel House, Lubbock, TX
## Robert Bruno



Guggenheim Museum Bilbao

Frank Gehry (1997)



Tjibaou Cultural Center, New Caledonia

Renzo Piano

**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)*





*Centre Georges Pompidou, Paris*

*Piano and Rogers (1978)*



*Hongkong Bank*
*Building (1986)*

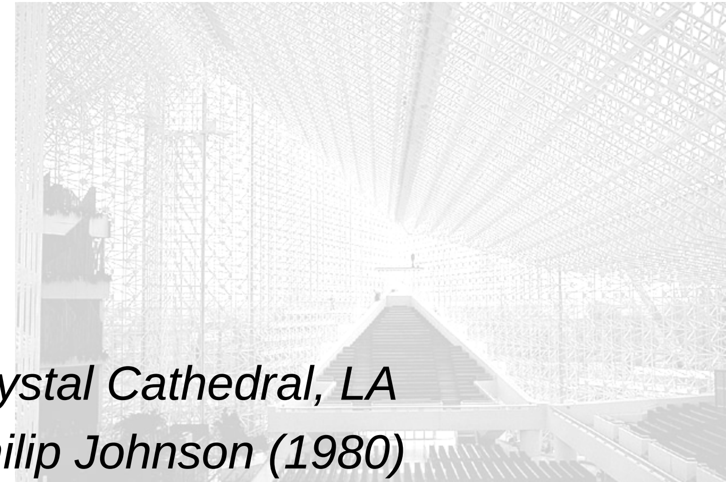
*Foster and Partners*

*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

- 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



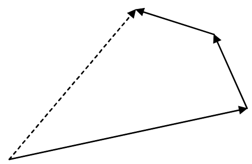
## Physics for Structures

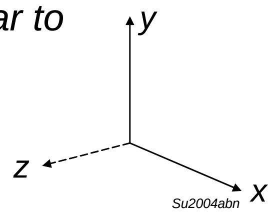
- measures
  - US customary & SI

| Units | US | SI |
|---|---|---|
| Length | in, ft, mi | mm, cm, m |
| Volume | gallon | liter |
| Mass | lb mass | g, kg |
| Force | lb force | N, kN |
| Temperature | F | C |

# 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: +,-, /, 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

$$\frac{2}{\not 5} \times \frac{\not 5}{6} = \frac{2}{6} = \frac{\not 2}{\not 2 \times 3} = \frac{1}{3}$$

$$\frac{x}{6} = \frac{1}{3}$$

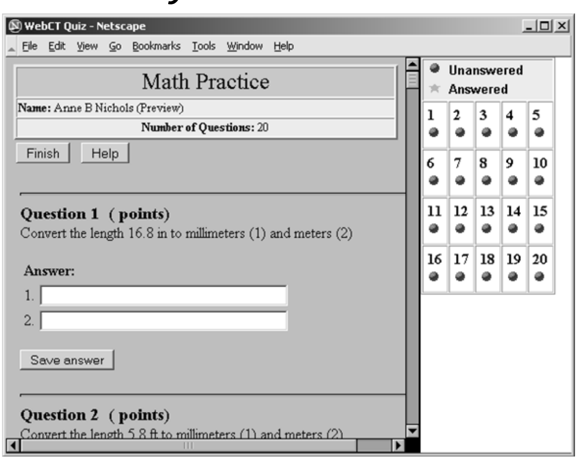
$$10^3 = 1000$$

$$\frac{10Y}{1X} \text{ or } \frac{1X}{10Y} = 1$$



# On-line Practice

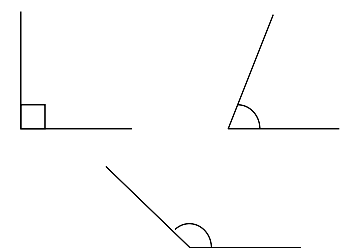
- Webct / Study Tools

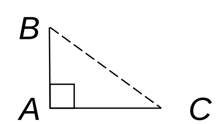





# Geometry

- angles
  - right = 90º
  - acute < 90º
  - obtuse > 90º
  - $\pi$ = 180º
- triangles
  - area $= \frac{b \times h}{2}$
  - hypotenuse
  - total of angles = 180º

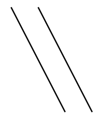




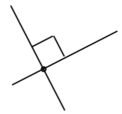

$$AB^2 + AC^2 = BC^2$$

## Geometry

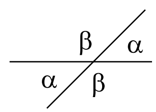
- *lines and relation to angles*
  - *parallel lines can't intersect*



  - *perpendicular lines cross at 90º*
  - *intersection of two lines is a point*



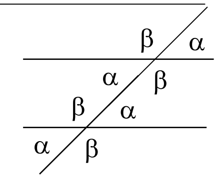
  - *opposite angles are equal when two lines cross*



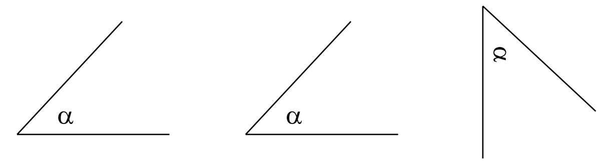



## Geometry

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




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



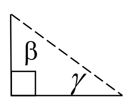



## Geometry

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


- *two angles that sum to 90° are said to be* <u>*complimentary*</u>

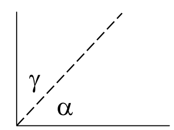
$$\beta + \gamma = 90°$$





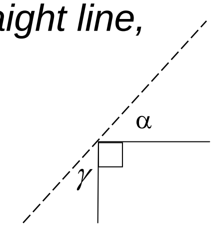

## Geometry

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



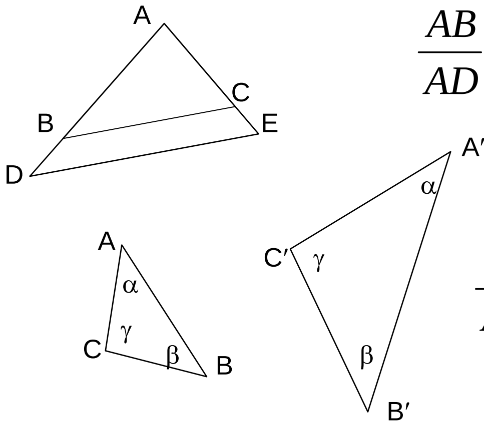

$$\alpha + \gamma = 90°$$

- *right angle bisects a straight line, remaining angles are* <u>*complimentary*</u>



# Geometry

– similar triangles have proportional sides



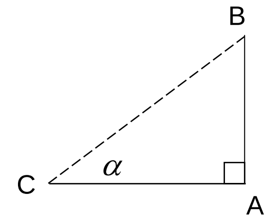

$$\frac{AB}{AD} = \frac{AC}{AE} = \frac{BC}{DE}$$

$$\frac{AB}{A'B'} = \frac{AC}{A'C'} = \frac{BC}{B'C'}$$



# Trigonometry

- for right triangles




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

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

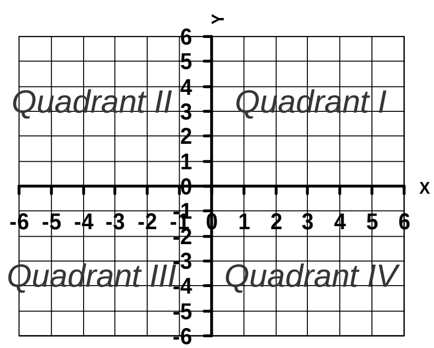
$$\tan = \frac{\text{opposite side}}{\text{adjacent side}} = \tan\alpha = \frac{AB}{AC}$$

*SOHCAHTOA*



# Trigonometry

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

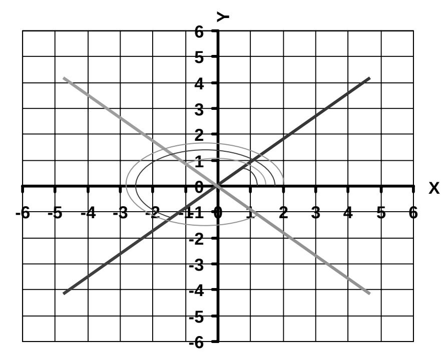





# Trigonometry

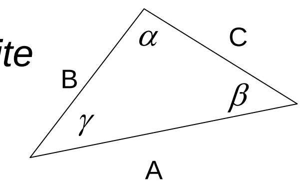
- for angles starting at <u>positive x</u>
  - sin *is y side*
  - cos *is x side*

*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 <u>all equations</u>



# Algebra

- solving one equation
  - only works with one variable
  - ex: $2x - 1 = 0$
    - add to both sides $2x - 1 + 1 = 0 + 1$

$$2x = 1$$

    - divide both sides $\frac{\cancel{2}x}{\cancel{2}} = \frac{1}{2}$
    - get x by itself on a side $x = \frac{1}{2}$



# 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 $\frac{-6}{2} = \frac{-3\cdot\cancel{2}}{\cancel{2}} = \frac{\cancel{2}x}{\cancel{2}}$
    - get x by itself on a side

$$x = -3$$

## *Algebra*

- *solving two equation*
  - *only works with two variables*
  - *ex:*

$$2x + \underline{3y} = 8$$
$$12x - \underline{3y} = 6$$

    - *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*

$$\frac{14x}{14} = \frac{14}{14} = x = 1$$