Elements of Architectural Structures: Form, Behavior, and Design

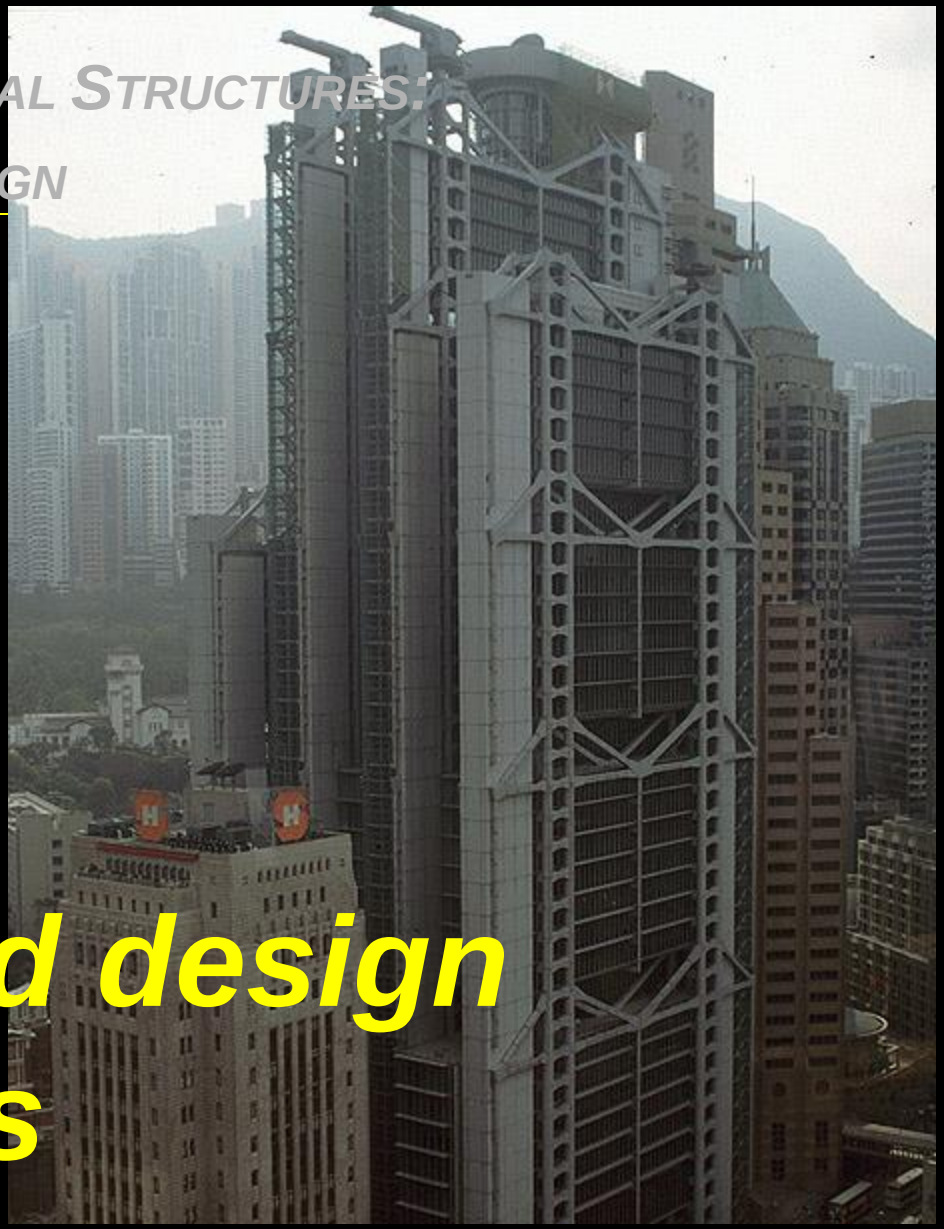
Arch 614

Dr. Anne Nichols

Spring 2014

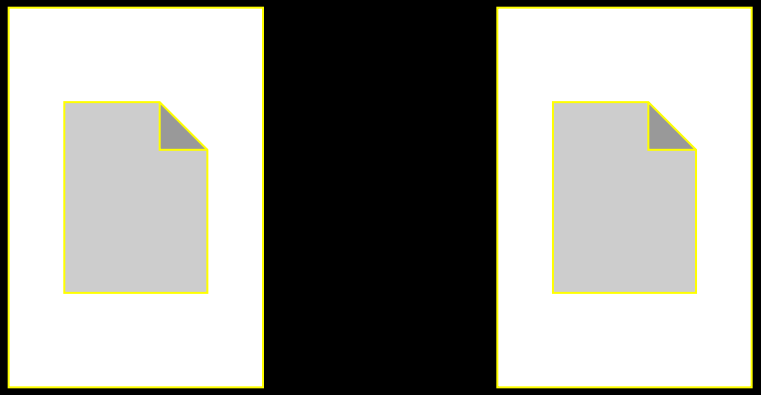
lecture one

behavior and design of structures



www.greatbuildings.com

Syllabus & Student Understandings



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*

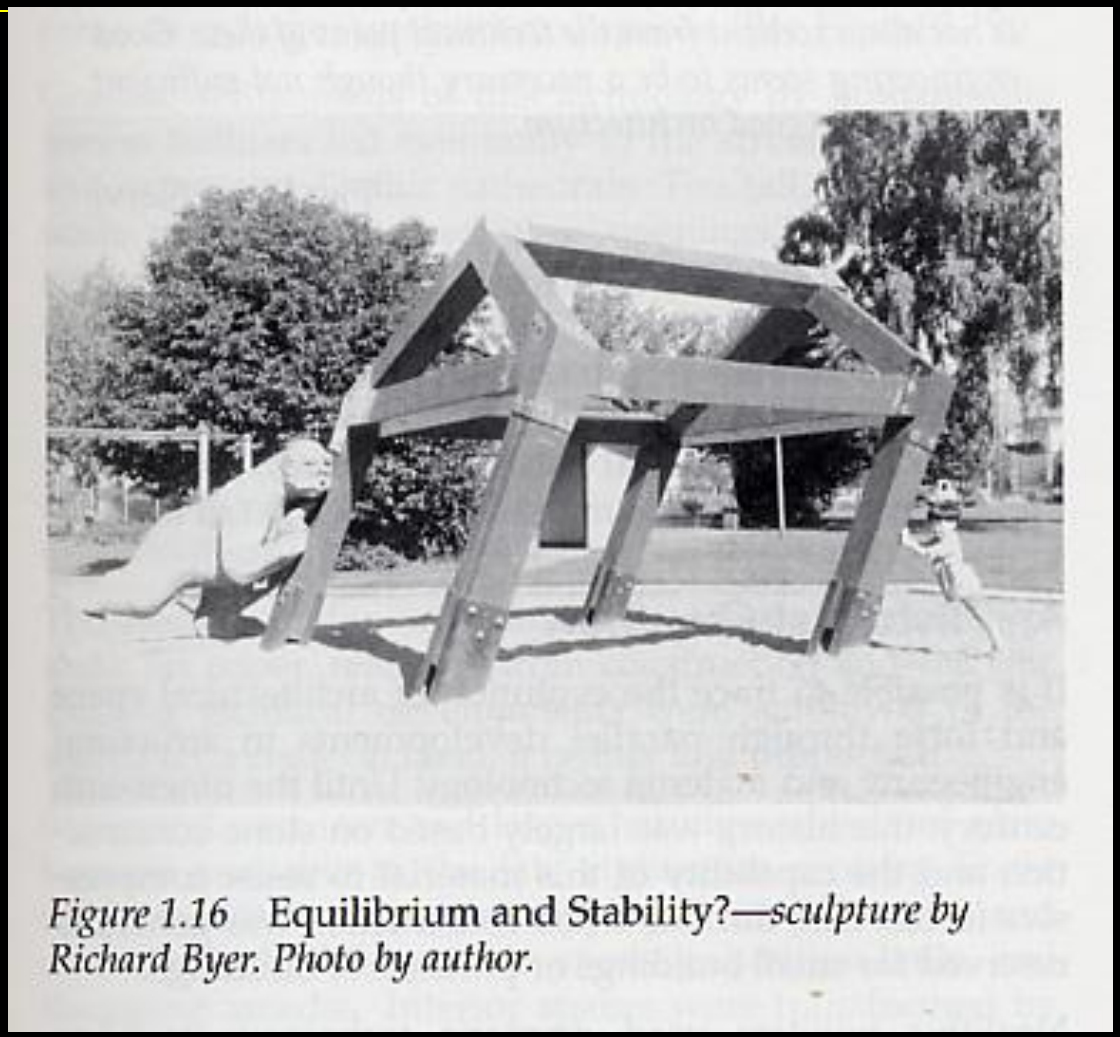


Figure 1.16 Equilibrium and Stability?—*sculpture by Richard Byer. Photo by author.*

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*

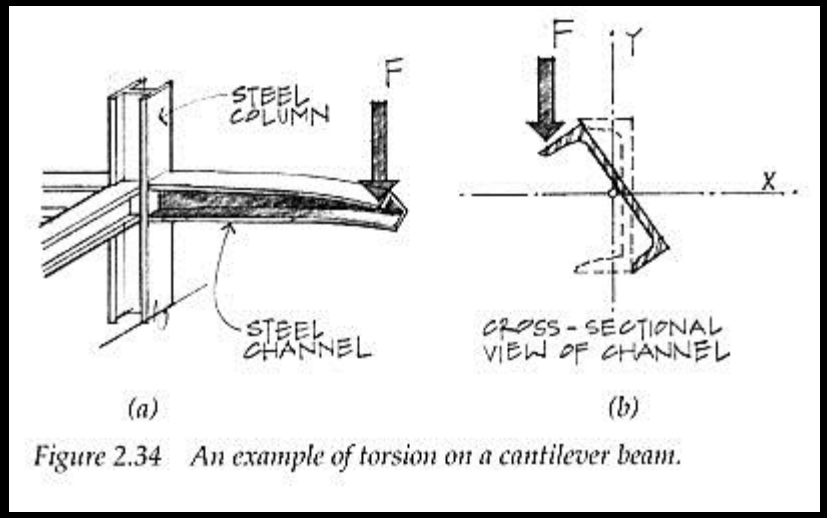


Figure 2.34 An example of torsion on a cantilever beam.

- *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

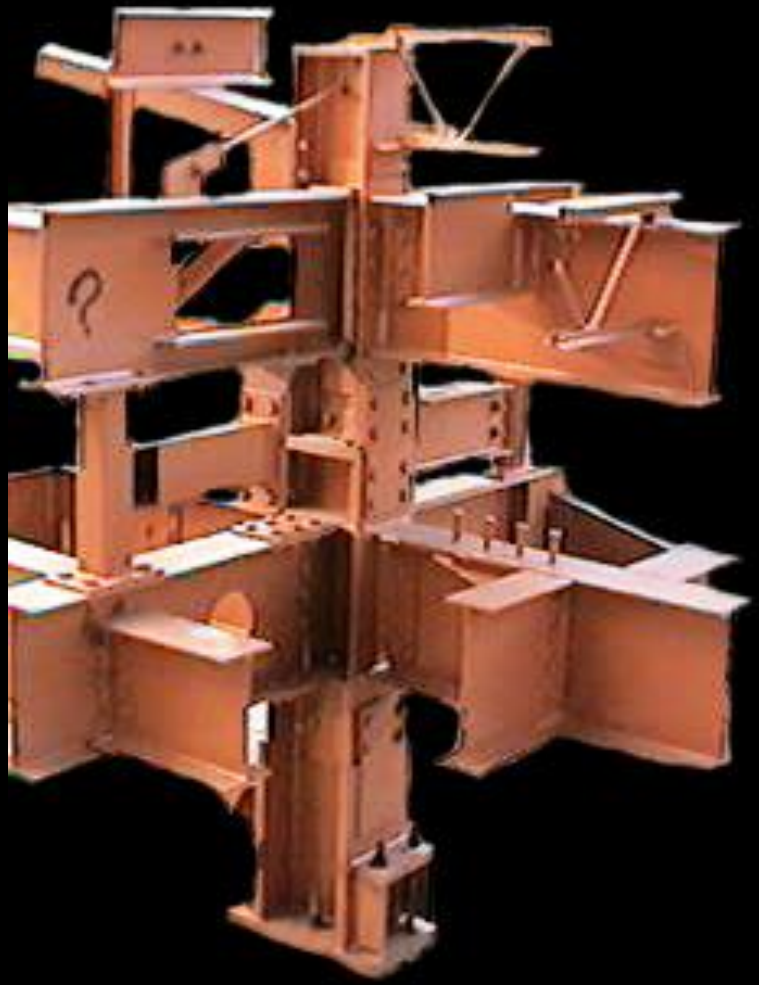
"The geometry and arrangement of the load-bearing members, the use of materials, and the crafting of joints all represent opportunities for buildings to express themselves. The best buildings are not designed by architects who after resolving the formal and spatial issues, simply ask the structural engineer 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*

The "Fist"
Detroit, MI



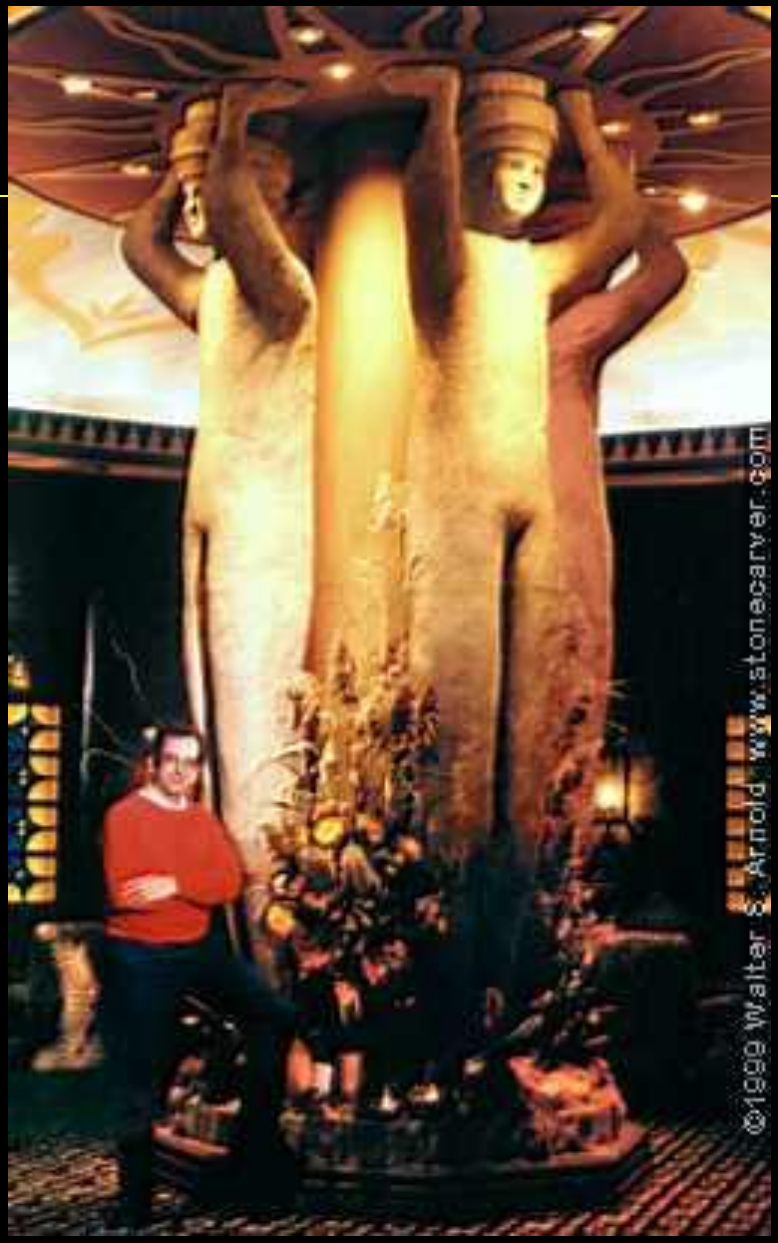
AISC (Steel) Sculpture

College Station, TX

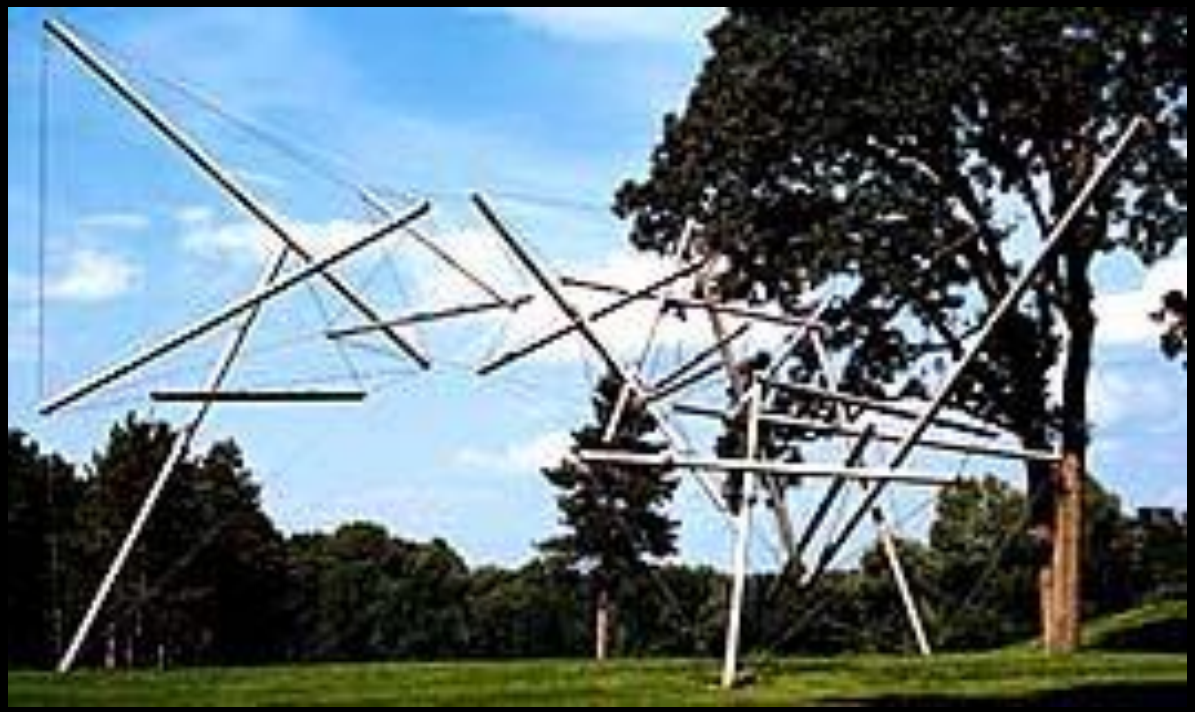
http://wwweng.uwyo.edu/connections/

“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

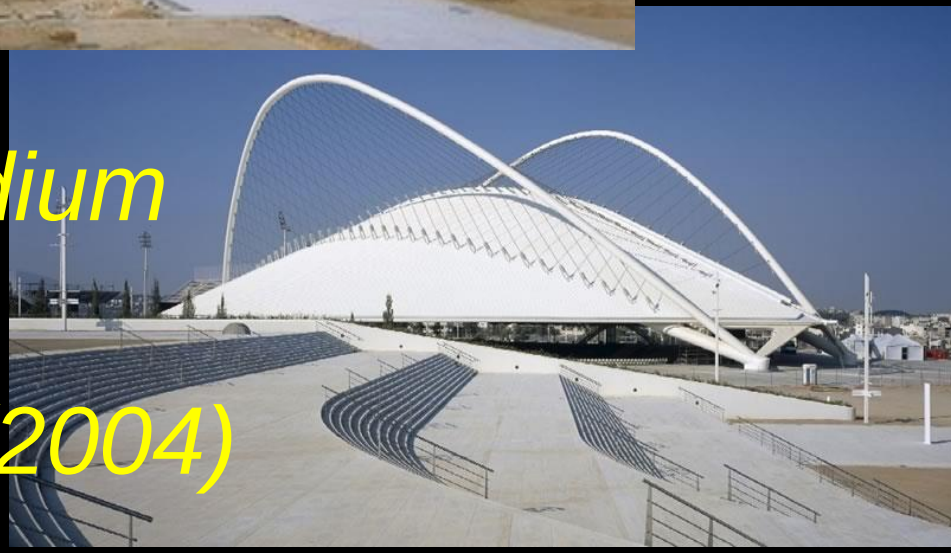
Padre Pio Pilgrimage Church, Italy

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

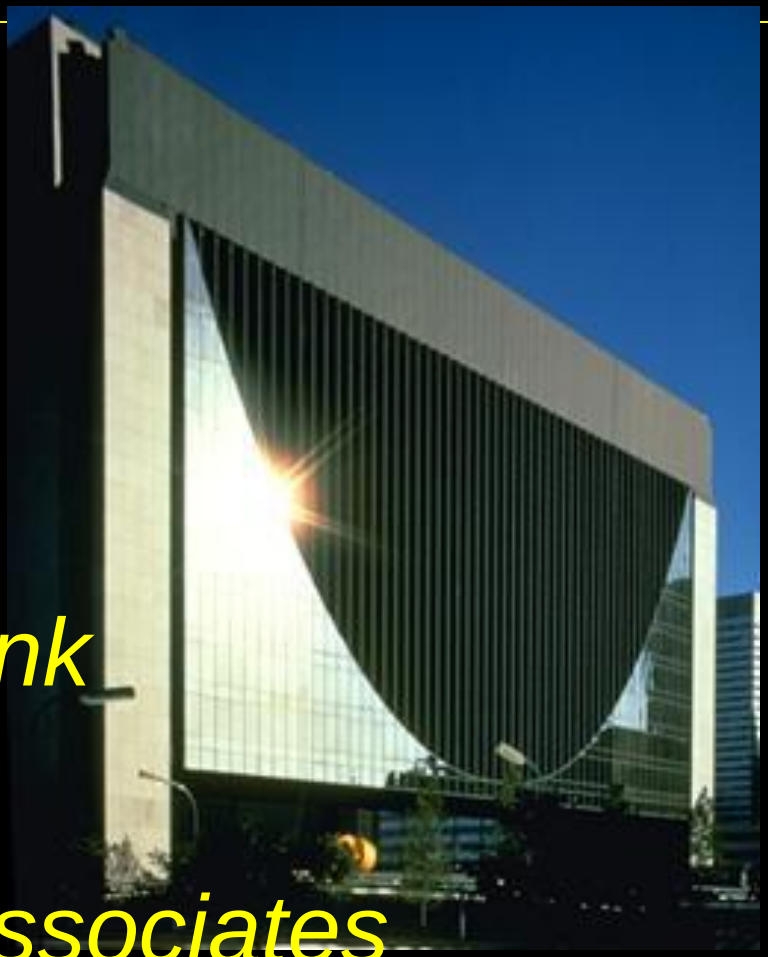
Meyerson Symphony Center

Dallas, TX

Pei Cobb Freed & Partners

Crystal Cathedral, LA

Philip Johnson (1980)



Federal Reserve Bank
Minneapolis, MN
Gunnar Birkerts & Associates

www.greatbuildings.com

Hysolar Research Building

Stuttgart, Germany (1986 -87)

Gunter Behnisch

www.greatbuildings.com

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

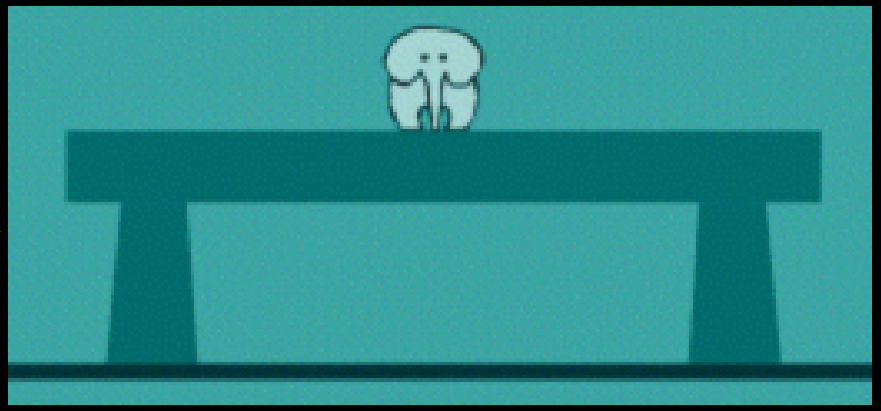
Kahn (1972)

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*

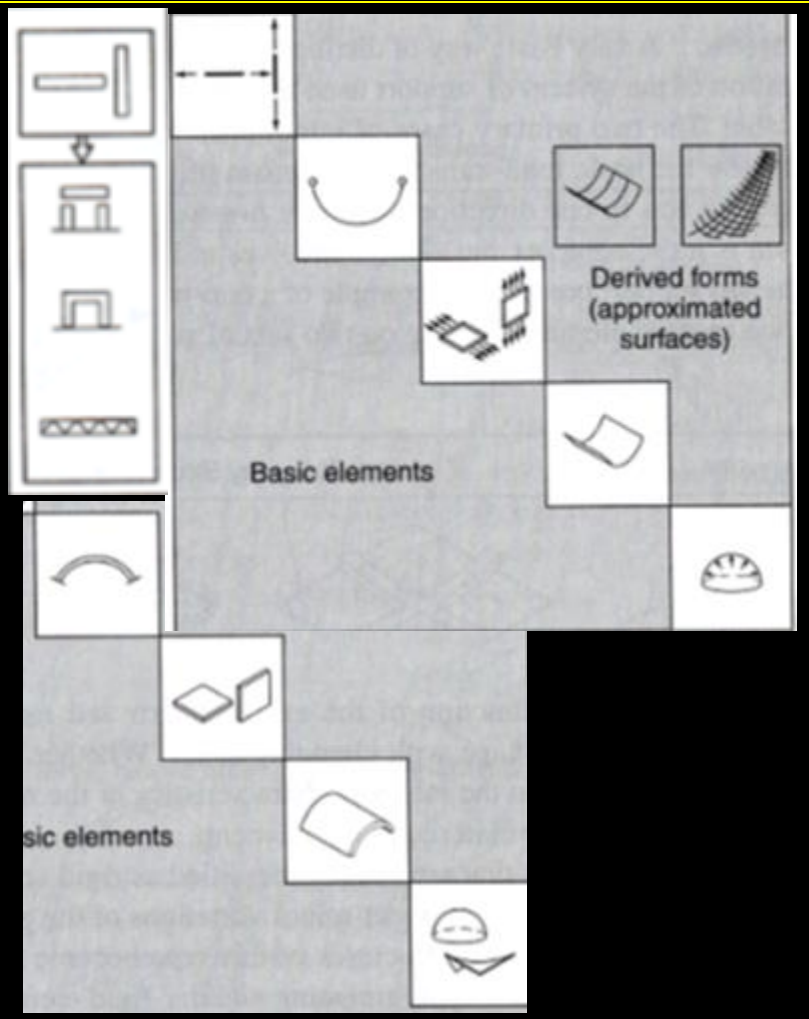
http:// nisee.berkeley.edu/godden

Concrete

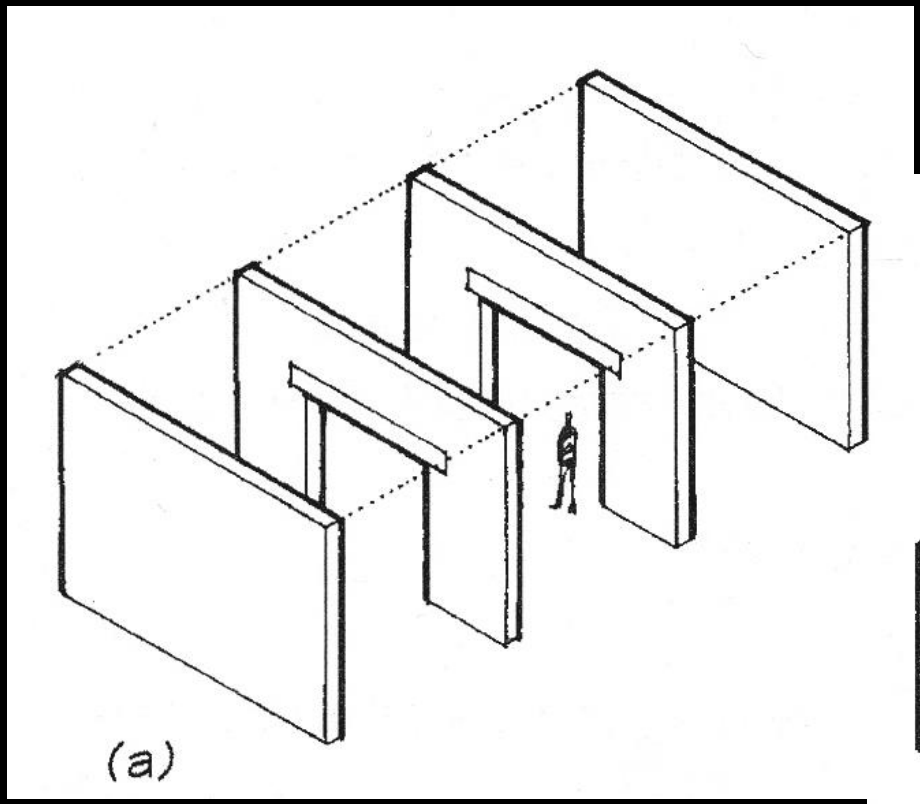
- *columns*
- *beams*
- *slabs*
- *domes*

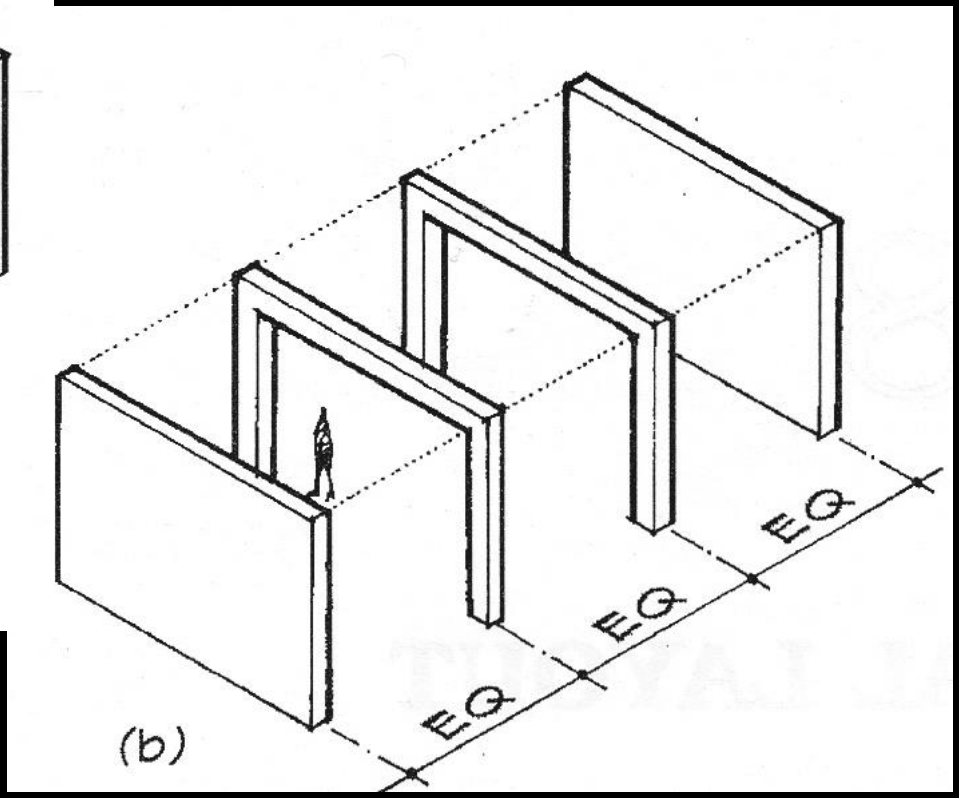
Structural Components

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



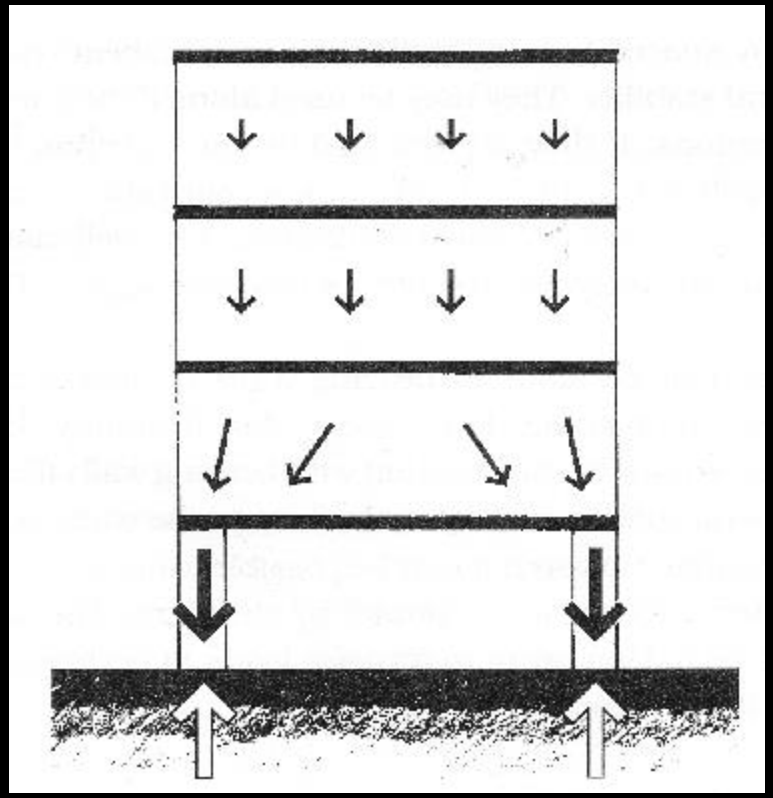
Bearing Walls



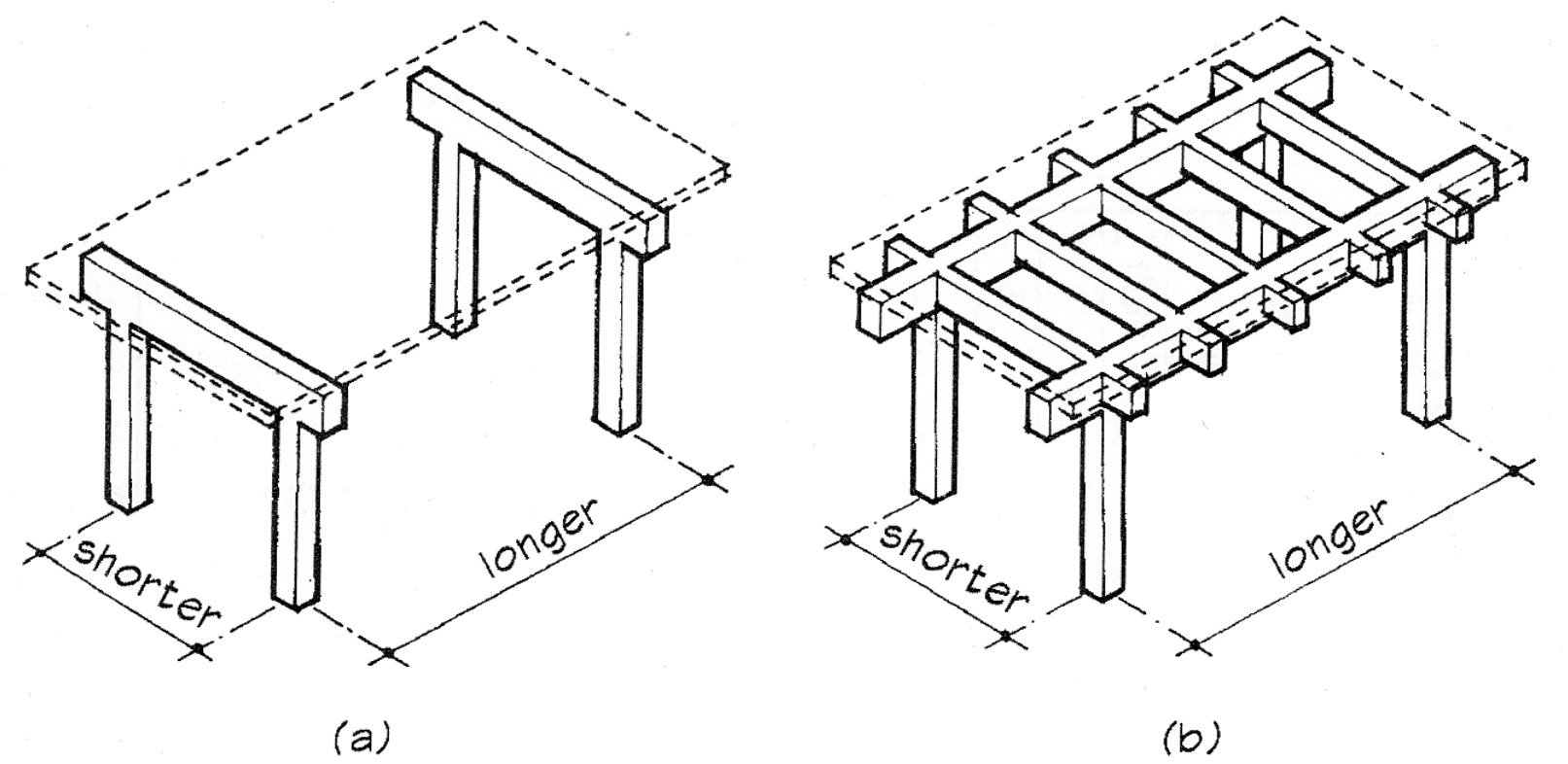


Bearing Walls

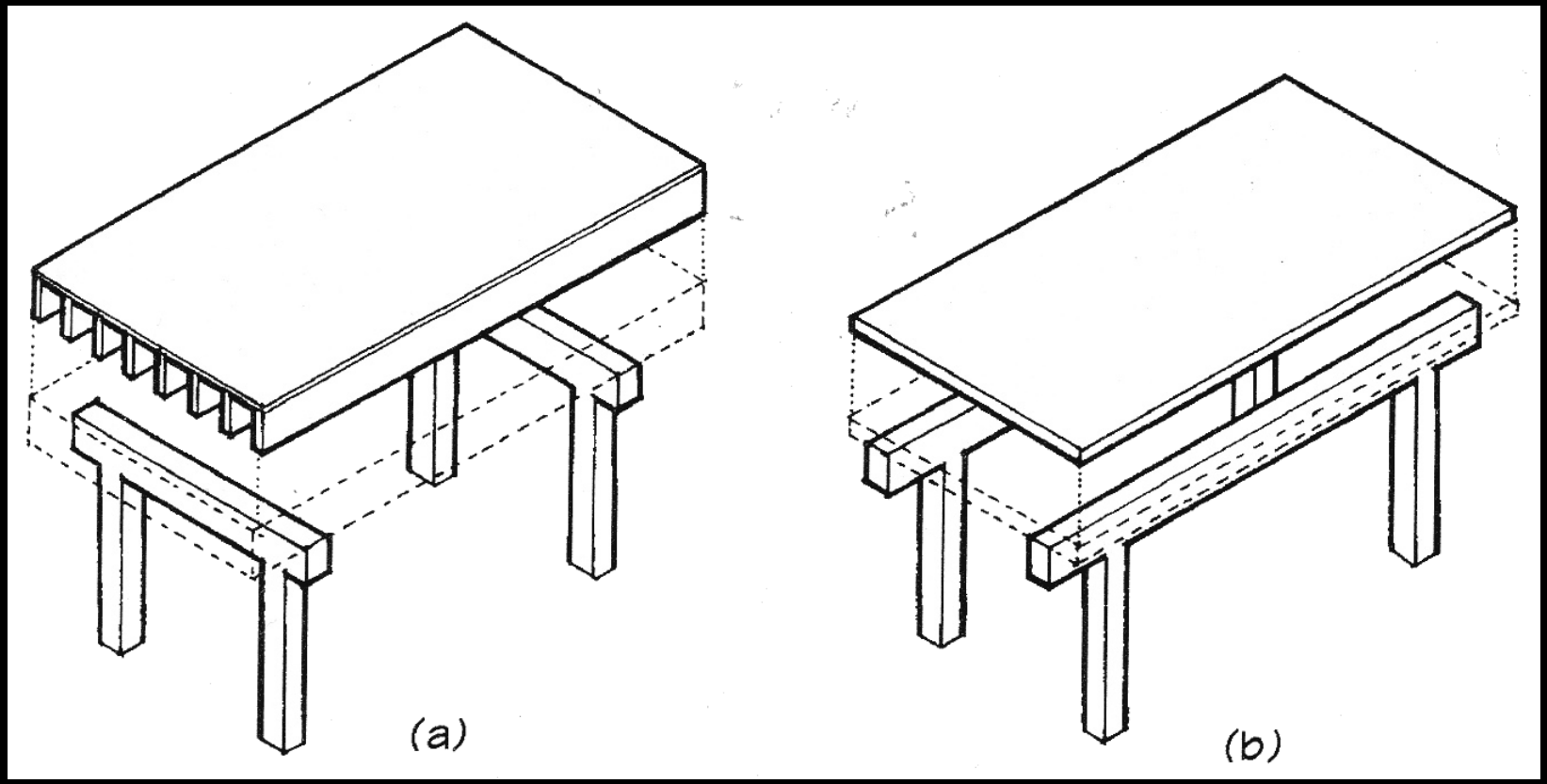
- *behavior as “deep beams”*



Beams & Plates

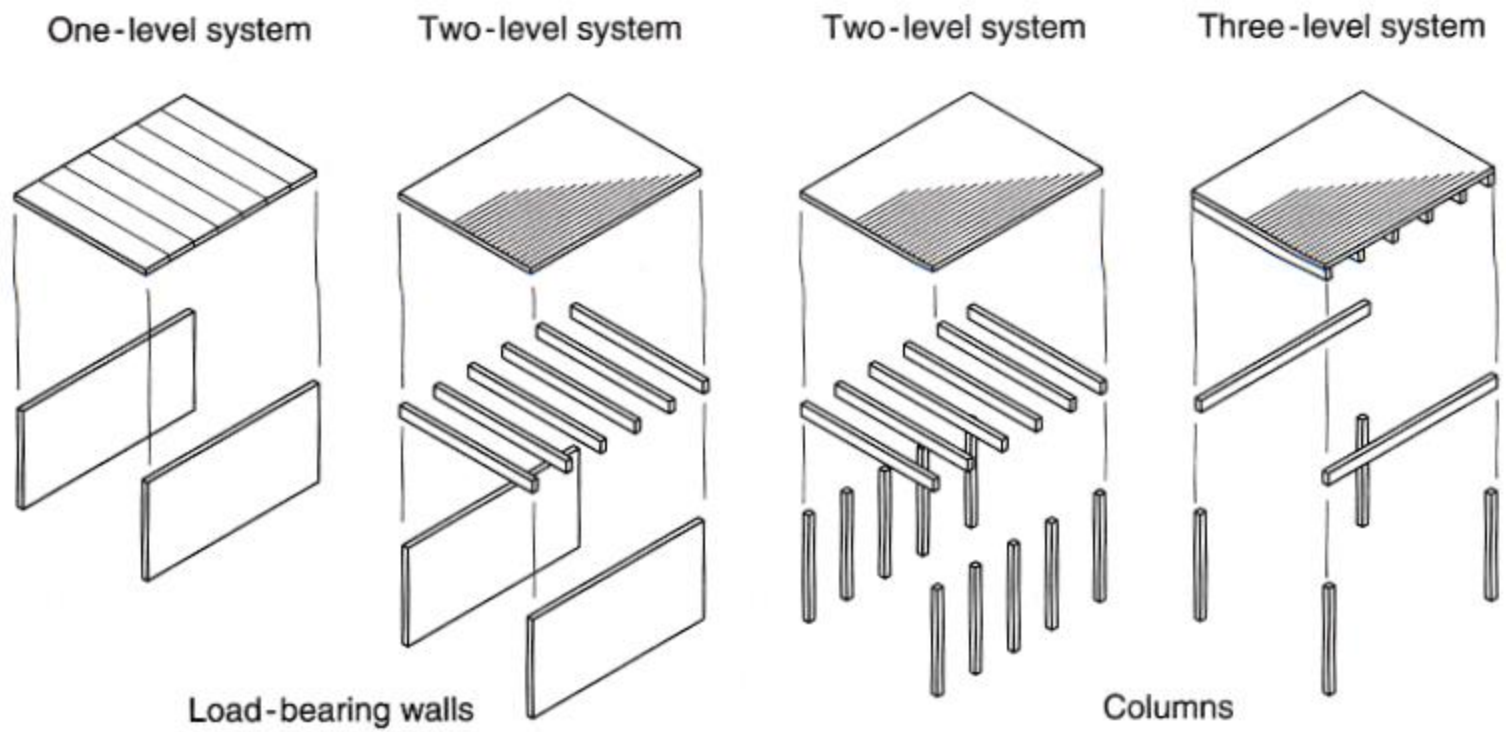


Beams & Plates



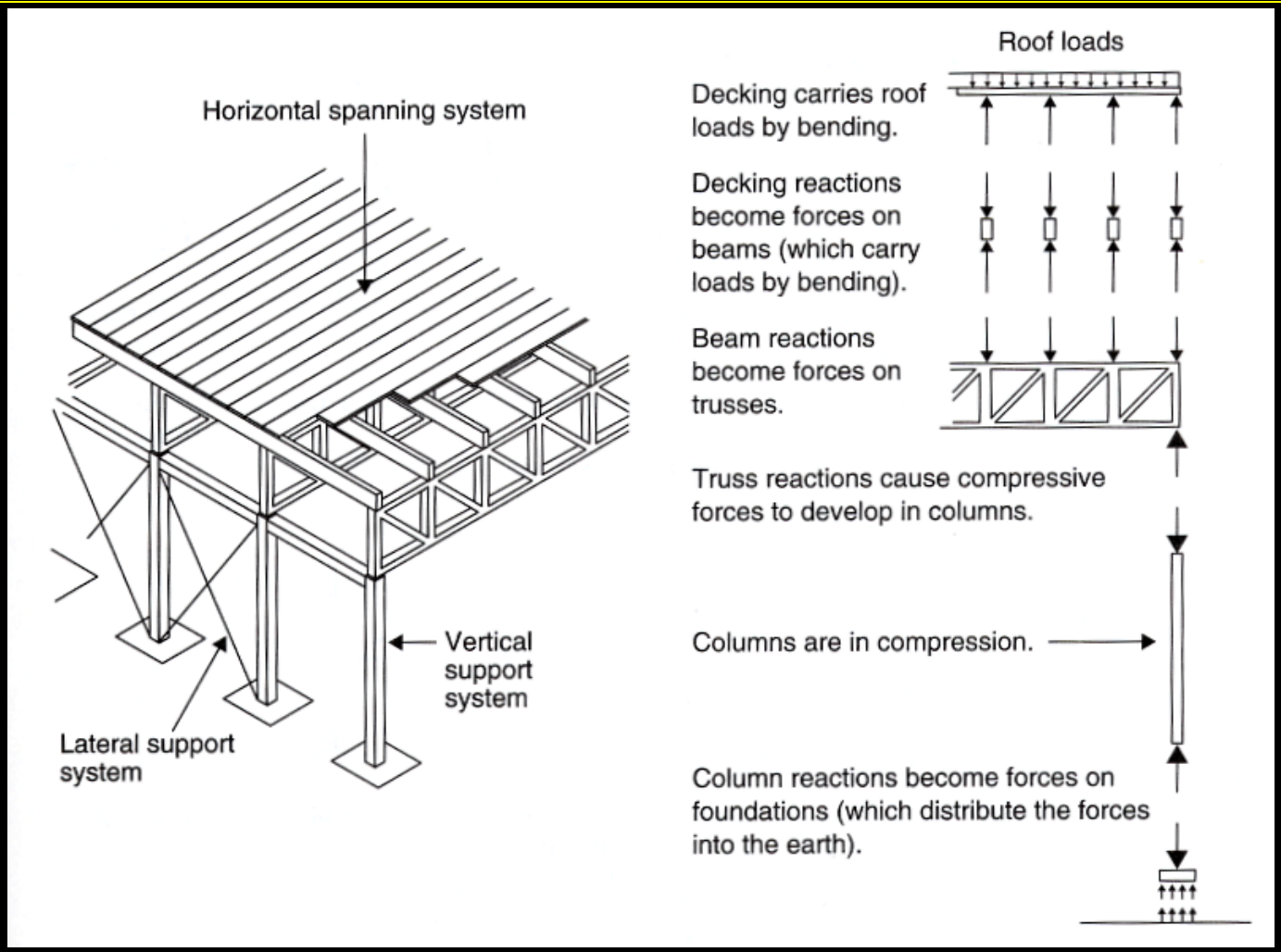
Building Framing

- Components or Assemblages



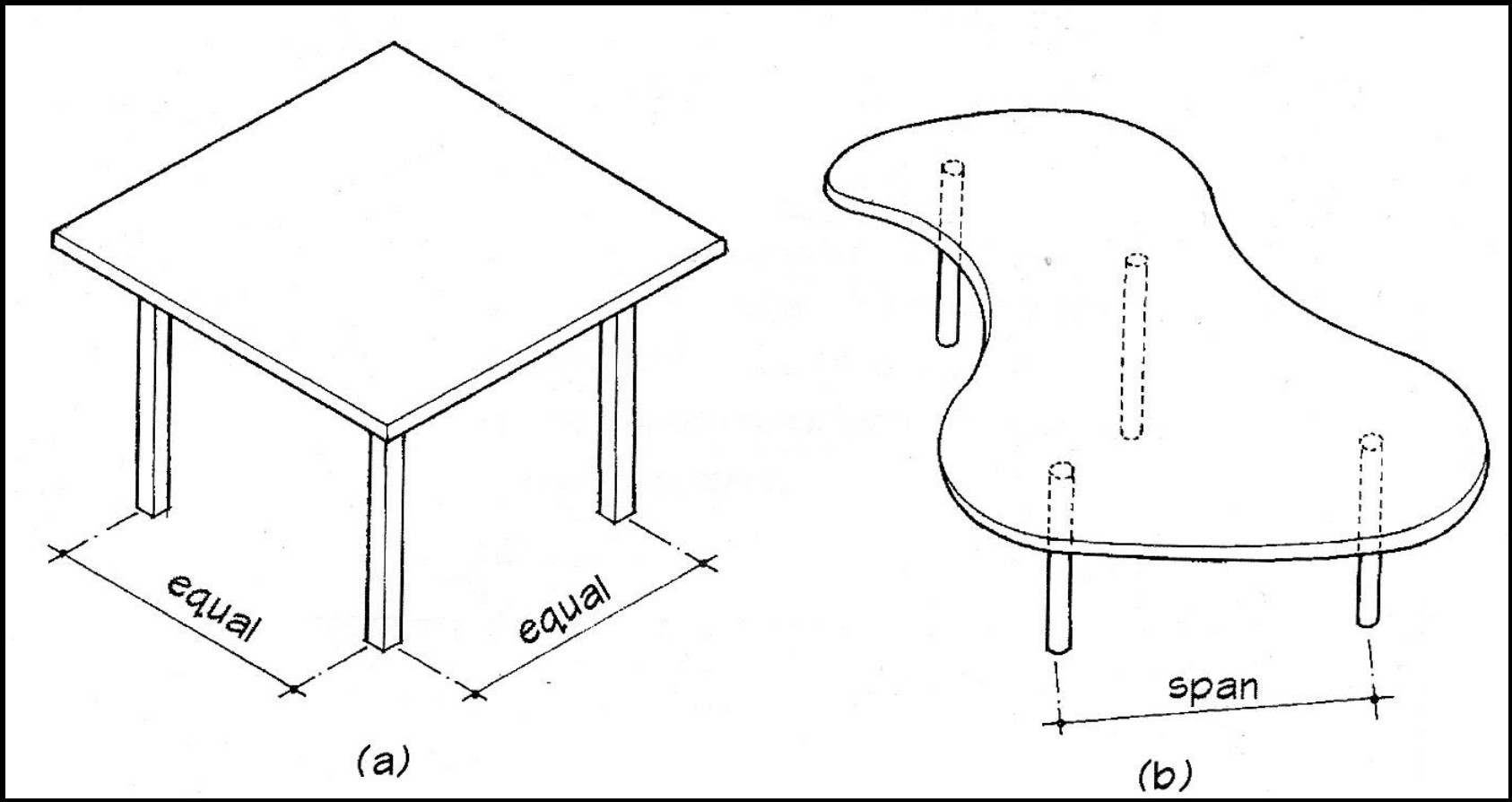
(a) Common types of horizontal spanning systems (one, two, and three level systems) used in relation to different types of load-bearing wall and columnar vertical support systems.

Building Framing



System Selection

- *evaluation of alternatives*



DESIGN CRITERIA	Light-frame timber	Heavy-frame timber	Masonry bearing wall	Steel frame (hinge connections)	Steel frame (rigid connections)	Steel open-web joists	Steel space frame	Steel decking	Site-cast concrete: one-way slab	Site-cast concrete: two-way plate	Site-cast concrete: two-way slab	Site-cast concrete: one-way joists	Site-cast concrete: waffle slab	Precast concrete: solid slab	Precast concrete: hollow-core slab	Precast concrete: single tee	Precast concrete: double tee	RATIONALE
Exposed, fire-resiant construction		■	■						■	■	■	■	■	■	■	■	■	Inherently fire-resistive construction
Irregular building form	■		■						■	■	■							Simple, site-fabricated systems
Irregular column placement										■	■		■					Systems without beams in roof or floors
Minimize floor thickness									■	■				■	■			Precast-concrete systems without ribs
Allow for future renovations	■	■	■	■	■	■	■	■	■			■		■	■			Short-span, one-way, easily modified
Permit construction in poor weather	■	■		■	■	■	■	■						■	■	■	■	Quickly erected; avoid site-cast concrete
Minimize off-site fabrication time	■		■						■	■	■	■	■					Easily formed or built on site
Minimize on-site erection time		■		■	■	■		■						■	■	■	■	Highly prefabricated; modular components
Minimize low-rise construction time	■	■		■	■	■		■										Lightweight, easily formed or prefabricated
Minimize medium-rise construction time				■	■	■		■	■	■	■	■	■	■	■	■	■	Precast, site-cast concrete; steel frames
Minimize high-rise construction time				■	■	■		■										Strong; prefabricated; lightweight
Minimize shear walls or diagonal bracing			■		■				■	■	■	■	■					Capable of forming rigid joints
Minimize dead load on foundations	■	■		■	■	■	■	■										Lightweight, short-span systems
Minimize damage due to foundation settlement	■	■		■		■		■						■	■	■	■	Systems without rigid joints
Minimize the number of separate trades on job	■		■															Multipurpose components
Provide concealed space for mech. services	■					■	■								■			Systems that inherently provide voids
Minimize the number of supports							■											Two-way, long-span systems
Long spans						■	■									■		Long-span systems

Structural Math

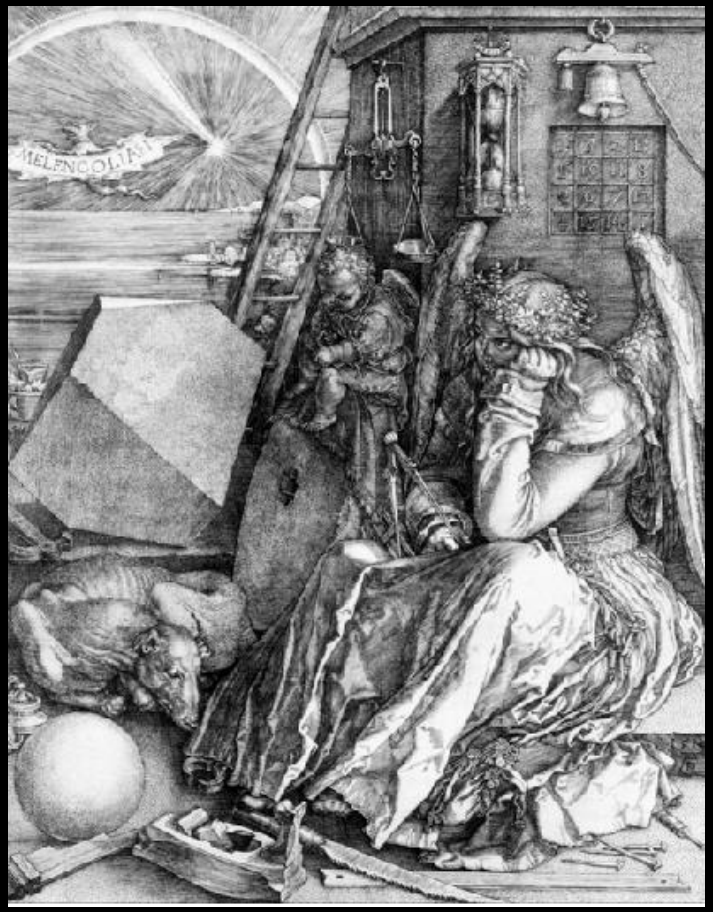
- *quantify environmental loads*
  - *how big is it?*
- *evaluate geometry and angles*
  - *where is it?*
  - *what is the scale?*
  - *what is the size in a particular direction?*
- *quantify what happens in the structure*
  - *how big are the internal forces?*
  - *how big should the beam be?*

Physical Math

- *physics takes observable phenomena and relates the measurement with rules: <u>mathematical relationships</u>*
- *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*



Melancholia - Albrecht Dürer

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 <u>both sides</u> of equality*

$$\frac{2}{5}\times\frac{5}{6}=\frac{2}{6}=\frac{2}{2\times 3}=\frac{1}{3}$$

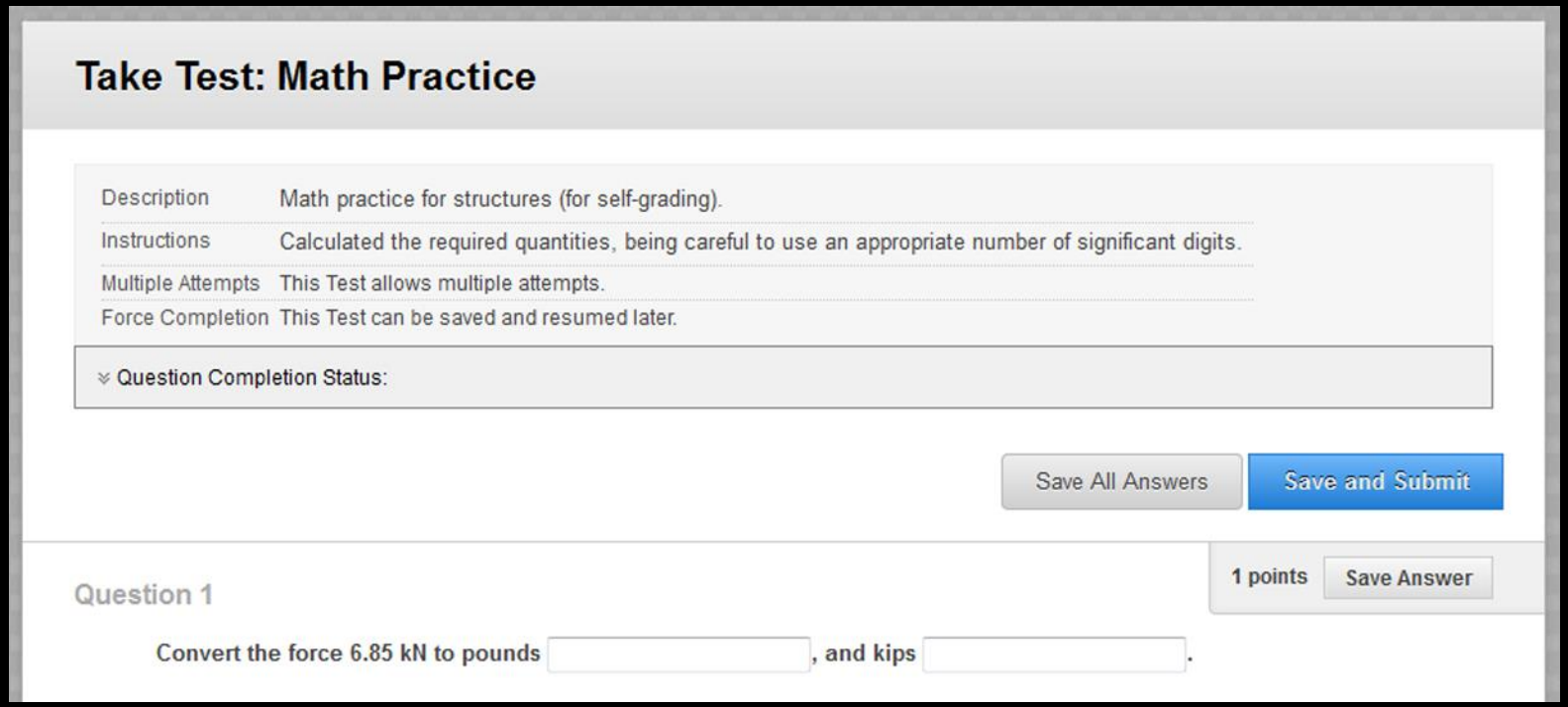
$$\frac{x}{6}=\frac{1}{3}$$

$$10^3=1000$$

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

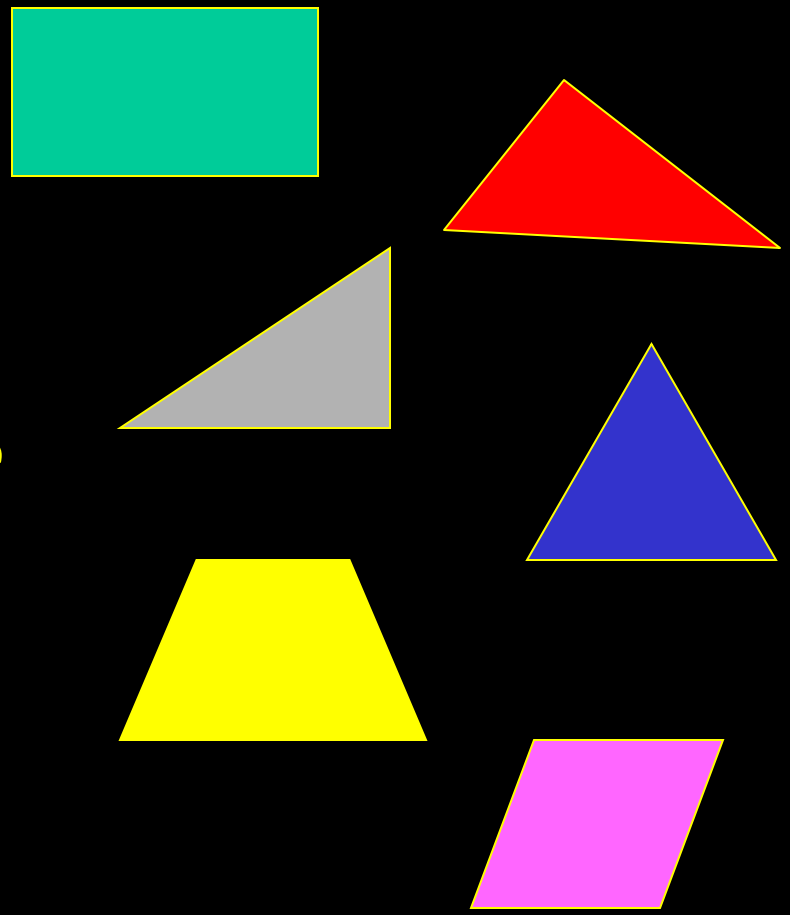
On-line Practice

- *eCampus / Study Aids*



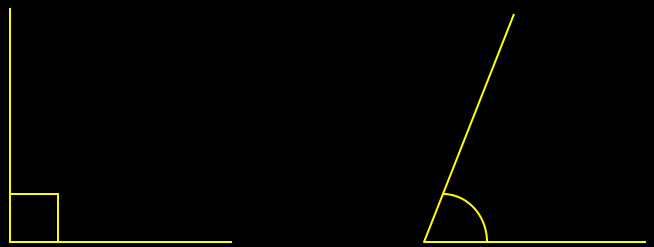
Geometry

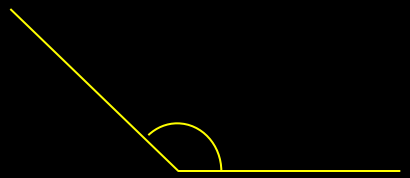
- *shapes*
  - *rectangle*
  - *triangle*
  - *right triangle*
  - *equilateral triangle*
  - *rhomboid*
  - *parallelogram*



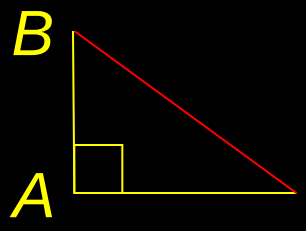
Geometry

- *angles*
  - *right* = 90º
  - *acute* < 90º
  - *obtuse* > 90º
  - π = 180º





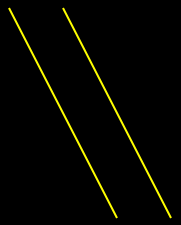
- *triangles*
  - *area* $= \frac{b \times h}{2}$
  - *hypotenuse*
  - *total of angles = 180º*



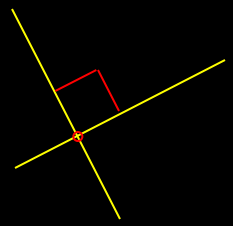
$$AB^2 + AC^2 = BC^2$$

Geometry

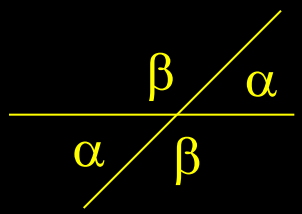
- *lines and relation to angles*
  - *parallel lines can't intersect*



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

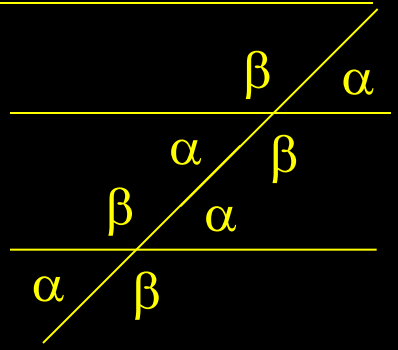


  - *opposite angles are equal when two lines cross*

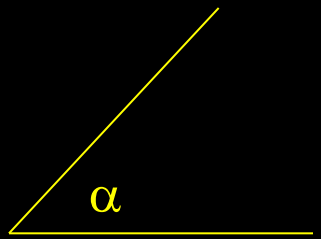


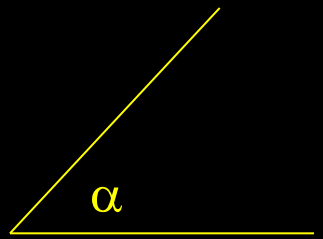
Geometry

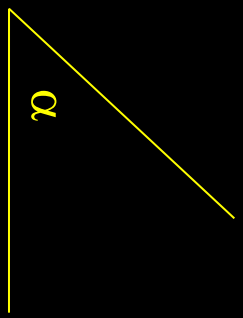
- *intersection of a line with parallel lines results in identical angles*



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

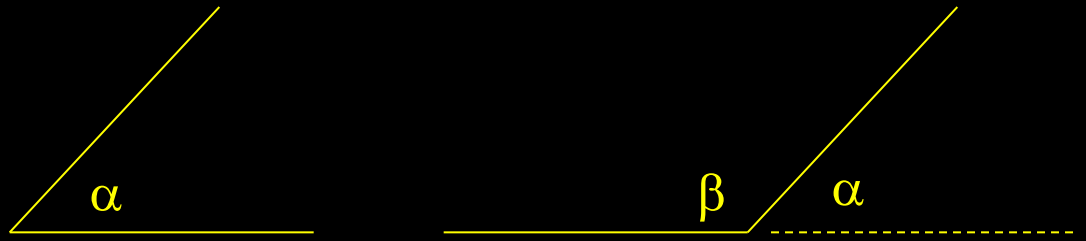






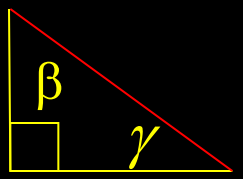
Geometry

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



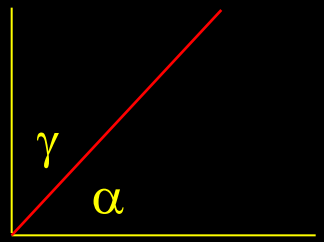
- *two angles that sum to 90° are said to be <u>complimentary</u>*

$$\beta + \gamma = 90°$$



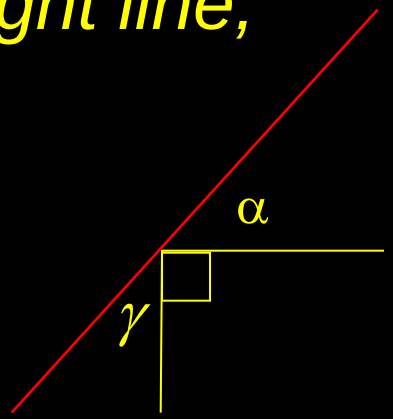
Geometry

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



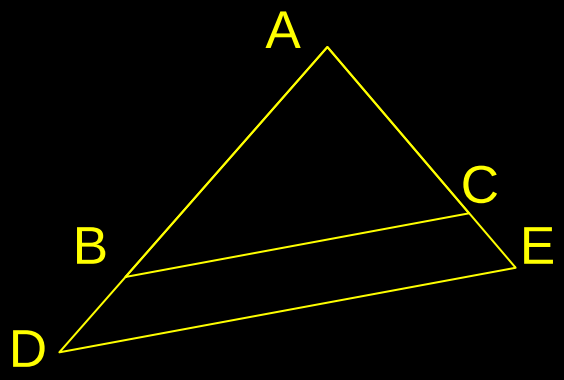
$$\alpha + \gamma = 90°$$

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

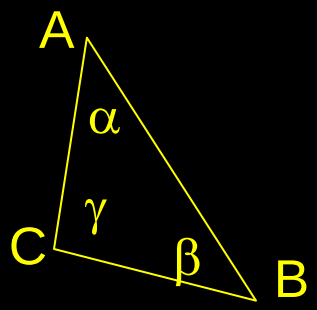


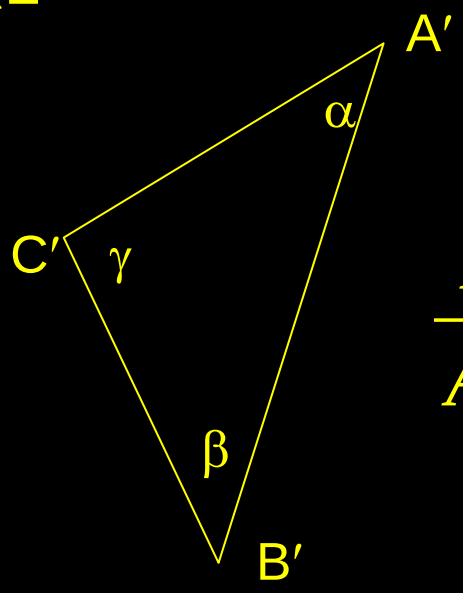
Geometry

– similar triangles have proportional sides



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





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

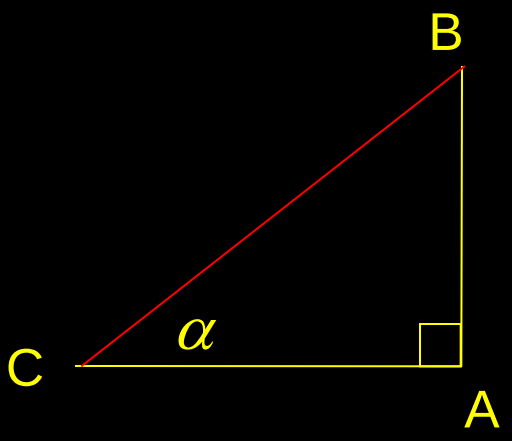
Trigonometry

- *for right triangles*

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

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

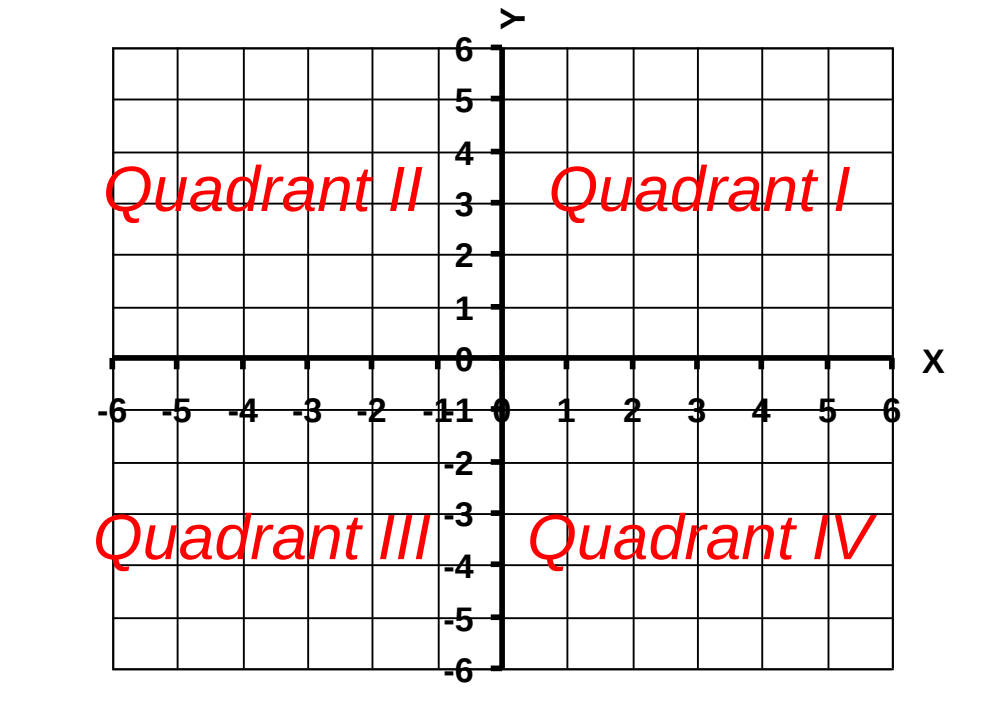
$$\tan = \frac{opposite\ side}{adjacent\ side} = \tan\alpha = \frac{AB}{AC}$$



SOHCAHTOA

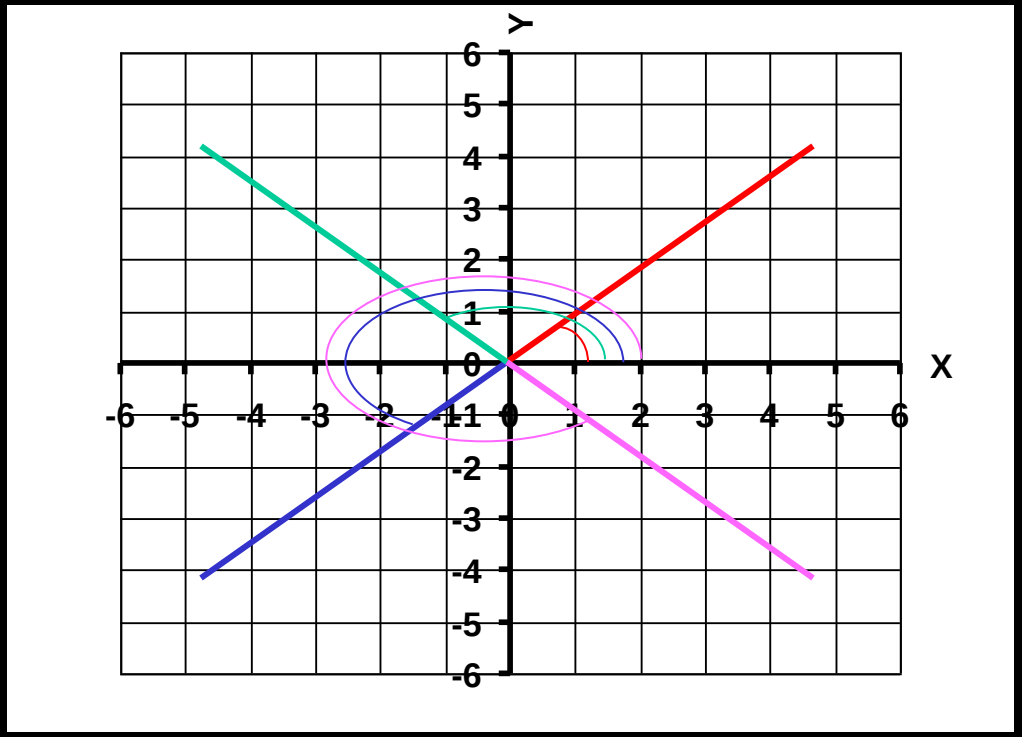
Trigonometry

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



Trigonometry

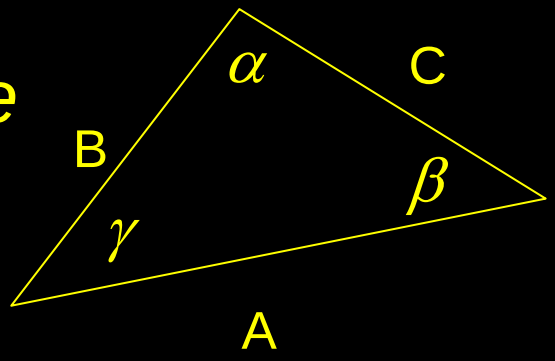
- *for angles starting at positive x*
  - sin *is y side*
  - cos *is x side*



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 α, β & γ*



  - *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:*
    - *add to both sides*
    - *divide both sides*
    - *get x by itself on a side*

$$2x - 1 = 0$$

$$2x - 1 + 1 = 0 + 1$$

$$2x = 1$$

$$\frac{2x}{2} = \frac{1}{2}$$

$$x = \tfrac{1}{2}$$

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*

$$\frac{-6}{2}=\frac{-3\cdot\cancel{2}}{\cancel{2}}=\frac{2x}{\cancel{2}}$$

    - *get x by itself on a side*

$$x=-3$$

Algebra

- *solving two equation*
  - *only works with two variables*
  - *ex:*
    - *look for term similarity*
    - *can we add or subtract to eliminate one term?*

$$2x + 3y = 8$$
$$12x - 3y = 6$$

- *add*

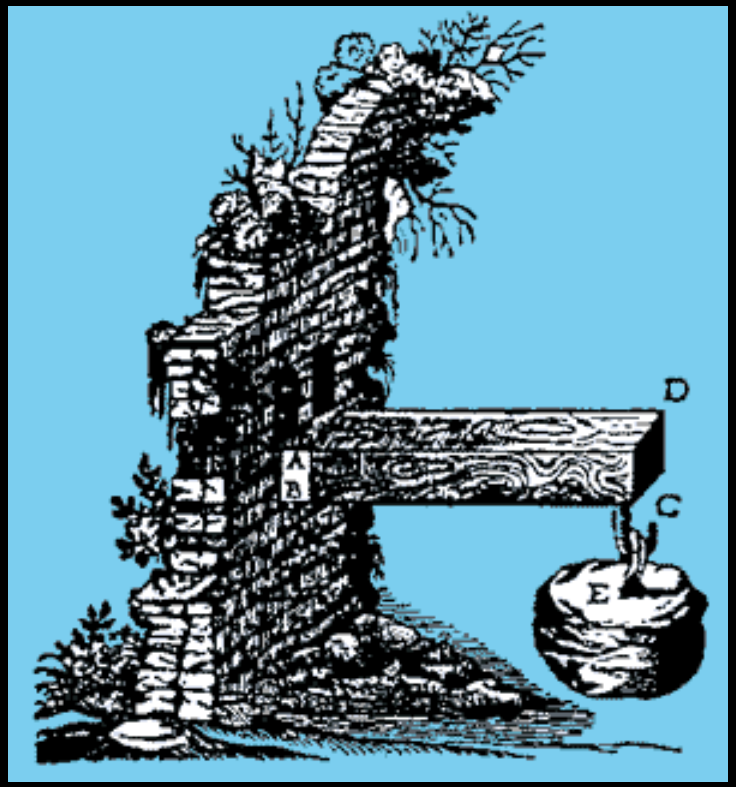
$$2x + 3y + 12x - 3y = 8 + 6$$
$$14x = 14$$

- *get x by itself on a side*

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

Physics for Structures

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



Galileo Galilei

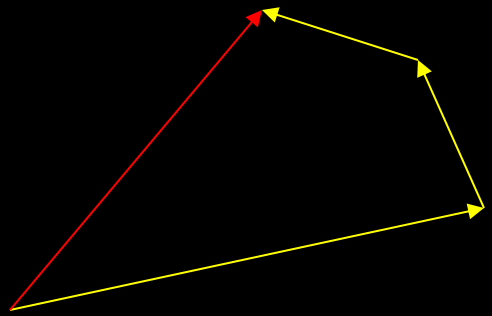
Physics for Structures

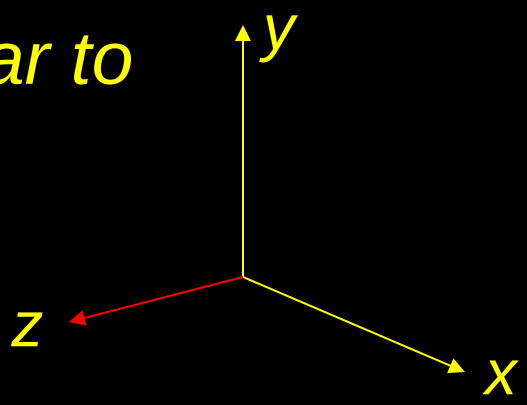
- *measures*
  - *US customary & SI*

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*
  - *<u>normal</u> 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*

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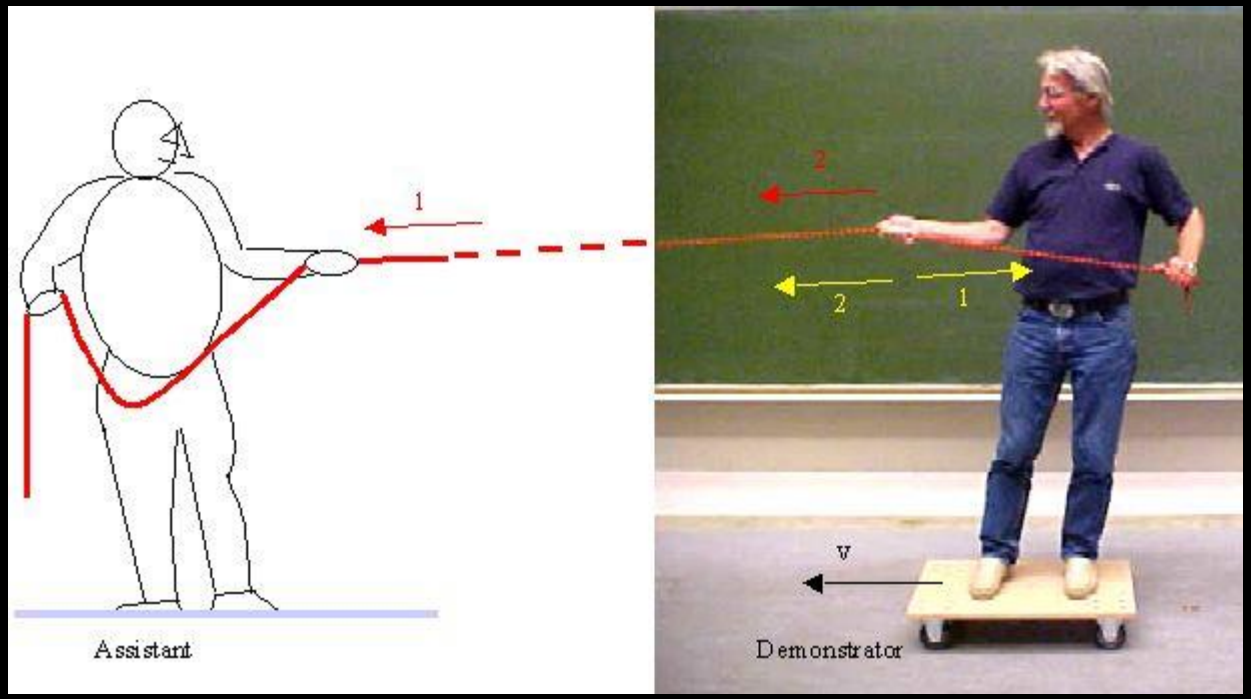
Physics for Structures

- *equilibrium of particles – no movement*



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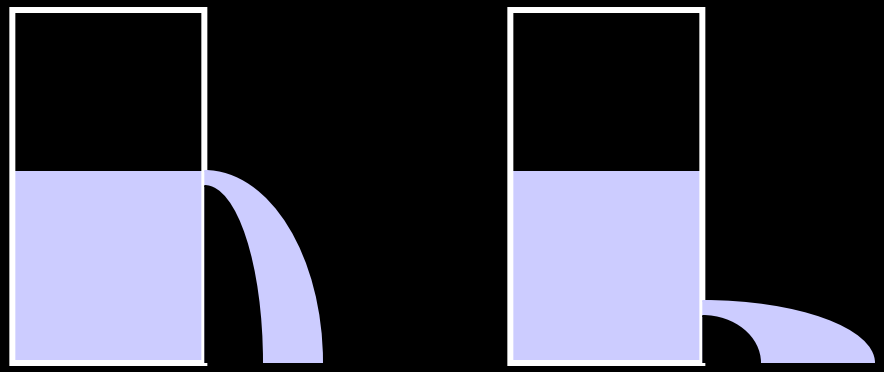
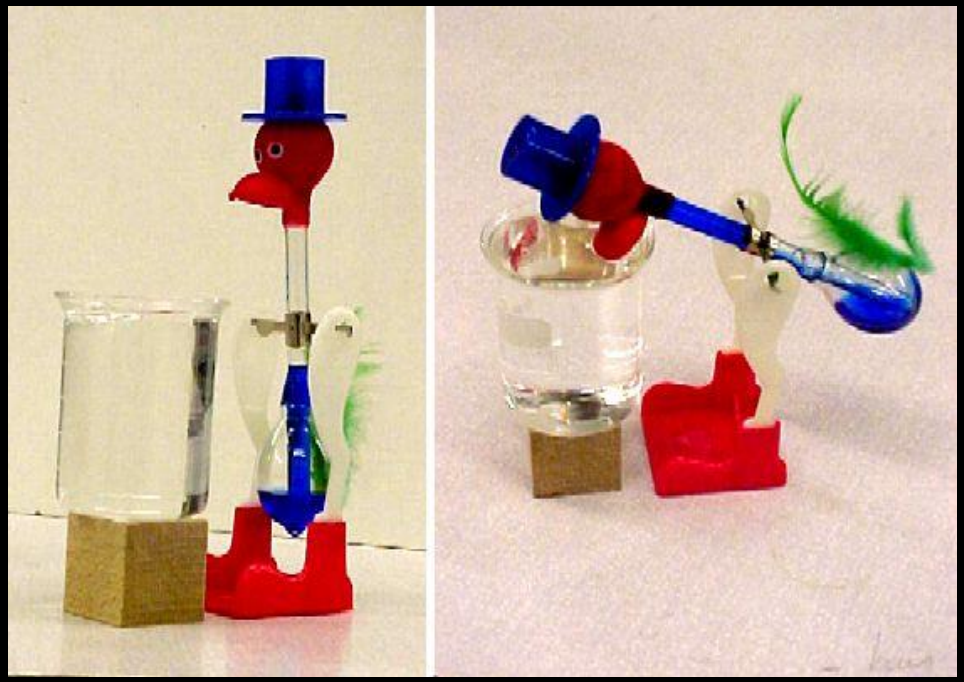
Physics for Structures

- *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*



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