Chapter 11

Designing Structural Systems

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Structural Systems

- Structure
  - Body that supports a load
  - Withstands external forces without changing shape
- Natural structure
  - Human endoskeleton

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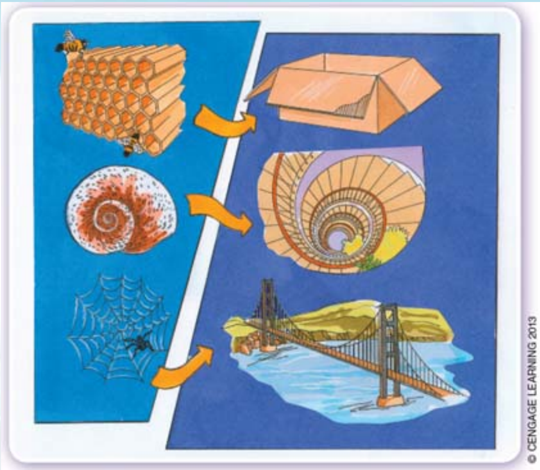

Figure 11-7: Examples of natural and technological structures.

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Technological Structures

- Purposes of technological structures
  - Provide housing
  - Provide containment
  - Transportation
- Structures must support loads caused by internal and external forces
- Structures must not fail prematurely

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Structural Failure

- All well-designed technological structures:
  - Have a defined useful life
  - Will fail at some point due to natural forces or misuse
- Bridges
  - 590,000 bridges in the National Bridge Inventory
    - Many are almost at their 50 year useful life

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Structural Failure (cont'd.)

- Planned obsolescence
  - Decision that a product will become obsolete in a predefined time frame
  - May be functional or aesthetic
- Durable goods
  - Intended to last more than three years
- Nondurable goods
  - Useful for less than three years

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Structural Failure (cont'd.)

- Example of early structural failure
  - Tacoma Narrows Bridge
  - Failed in 1940 due to resonant oscillation caused by wind
  - Today, oscillations are better understood
  - Bridge design rules have been updated

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Structural Failure (cont'd.)

- Causes of failure
  - Something unexpected
  - Poor design choice of materials, components, or processes
  - Expected external forces
  - Overloading beyond the maximum rating

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Safety Factor

- Determines how much a product or element is overbuilt
- Ratio of ultimate stress and maximum expected load
- Safety factors should be greater than 1.0

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Newtonian Mechanics

- Newton's laws of motion
  - Provide relationships between forces acting on a body and the motion of the body
  - Formulated by Sir Isaac Newton
  - Published in 1687

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First law: An object at rest remains at rest and an object in motion continues to move in a straight line with a constant speed unless and until acted upon by an external unbalanced force.

Second law: The rate of change of momentum of a body is directly proportional to the force acting upon it and is in the same direction.

Third law: For every force applied to an object, there is an equal, but opposite, reaction force.

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Structural Loads and Forces

- Live loads
  - Weight of all occupants in the building
  - Weight of movable things
    - Example: furniture
- Dead loads
  - Weight of materials in the structure itself

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Structural Loads and Forces (cont'd.)

- Static loads
  - Loads at rest
- Dynamic loads
  - Characterized by forces in motion

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Equilibrium

- When external forces are balanced by internal forces

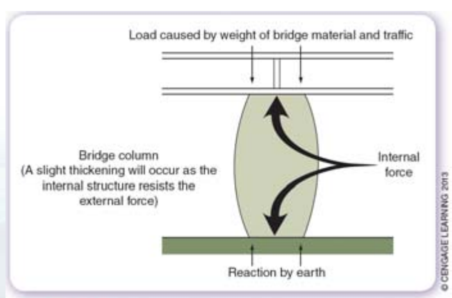

Figure 11-16: Internal forces must equal external loads in a structure in equilibrium.

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Stress

- Ability of a material to distribute internal forces when a load is applied
- Calculated by dividing force by area
- Represented by σ

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Strain

- Describes change in shape of a material caused by forces
- Expressed as percentage change in original length
- Represented by ϵ

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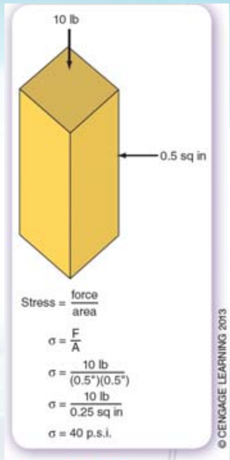

Figure 11-17: Stress formula with sample problem.

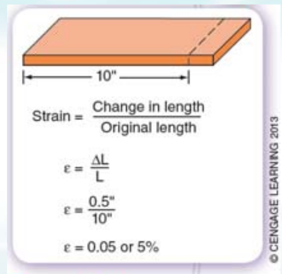

Figure 11-18: Strain formula with sample problem.

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Common Forces

- Five forces to consider when designing structures
  - Compression
  - Tension
  - Bending
  - Shear
  - Torsion

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Common Forces (cont'd.)

- Compression
  - Force that pushes against something
- Tension
  - Load is applied in a pulling action
- Bending
  - Force applied across the material
  - Example: books on a bookshelf
  - Location of supports is important

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Common Forces (cont'd.)

- Shear
  - Compression applied in opposite directions across a perpendicular plane

Figure 11-25: Material under shear.

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Common Forces (cont'd.)

- Torsion
  - Twisting force
  - Force that tries to twist or rotate the material apart
  - Also called torque

Figure 11-26: Material under torsion.

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Structural Components

- Beams
  - Horizontal structural components
  - Primarily designed to resist bending forces
  - Must also resist shear and torsion forces
- Engineered beams
  - Reduced weight
  - Increased strength

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Bridge Structures

- Beam bridge

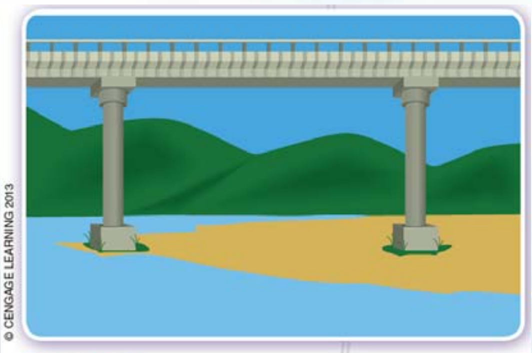

Figure 11-31: A beam bridge.

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Bridge Structures (cont'd.)

- Truss bridge

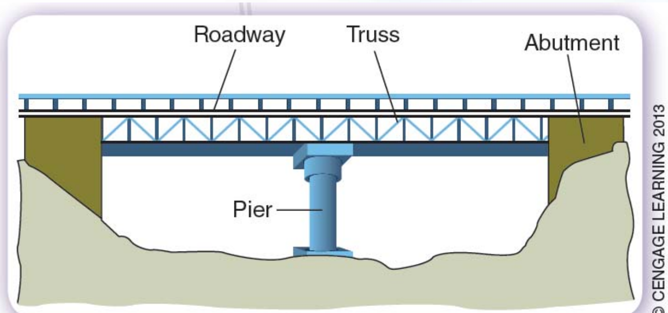

Figure 11-33: Basic components of a truss bridge.

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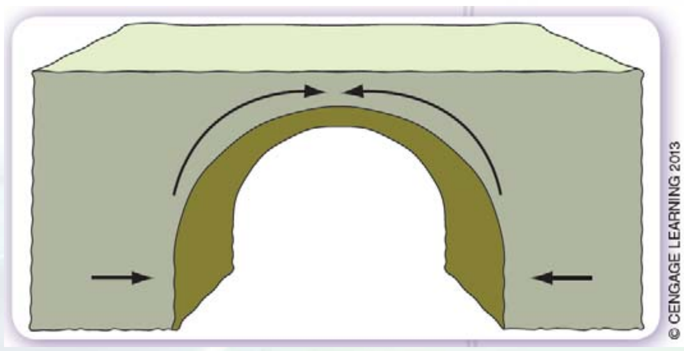
Bridge Structures (cont'd.)

- Arch bridge



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Bridge Structures (cont'd.)

- Suspension bridge

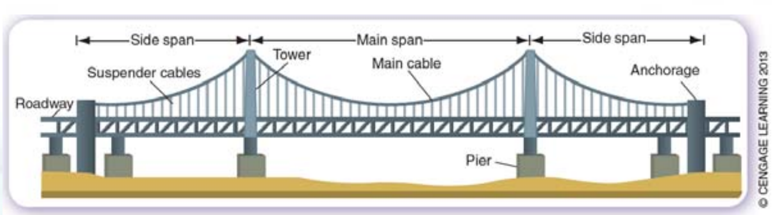

Figure 11-40: Structural elements of a typical suspension bridge.

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Calculating Loads on Structures

- Simple testing of loads
  - Use spring scale to estimate loads
- Physical modeling techniques
  - Use string and cardboard

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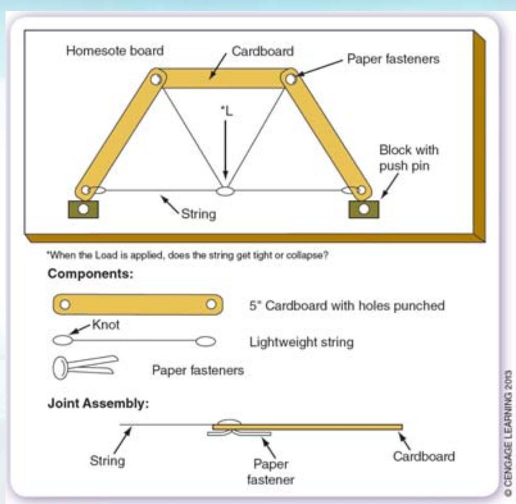

Figure 11-43: Determining compression and tension forces by modeling with string and cardboard.

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Using Mathematics to Calculate Loads

- Moment calculation
  - Point load
- Weight of the material
  - Can be estimated as uniform distributed load
- Vector analysis used to determine load

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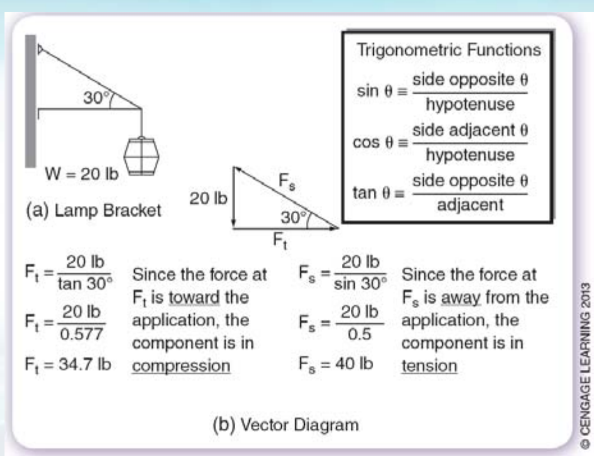

Figure 11-45: Determining force vectors using trigonometric functions.

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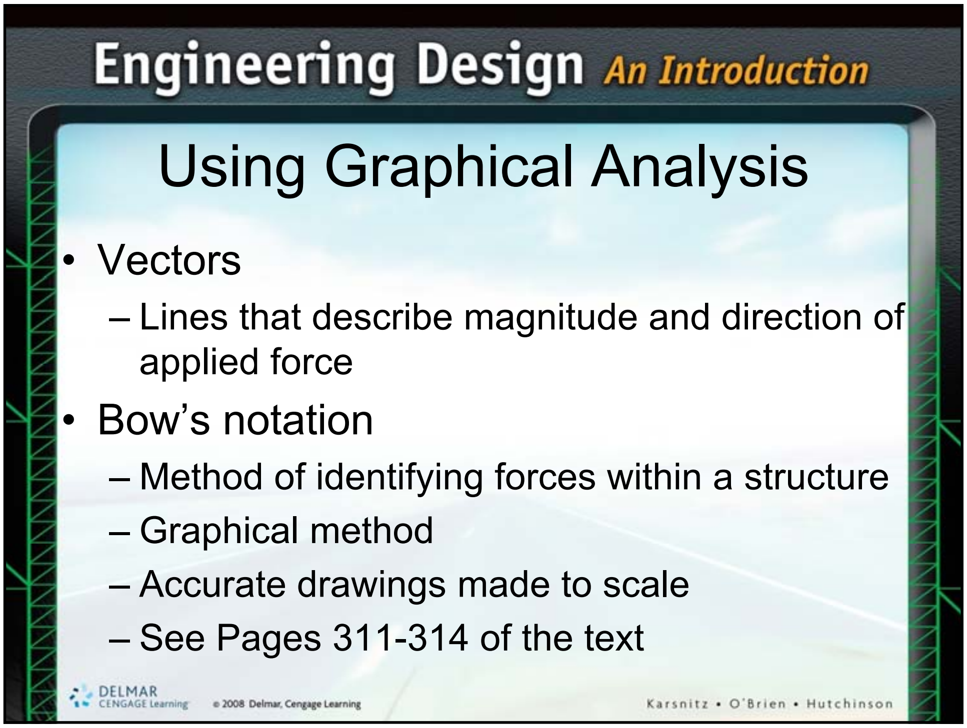
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Using Graphical Analysis
• Vectors
– Lines that describe magnitude and direction of applied force
• Bow's notation
– Method of identifying forces within a structure
– Graphical method
– Accurate drawings made to scale
– See Pages 311-314 of the text
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