Previous Conclusions

- Concrete will continue to be a dominant construction material
- Reinforced concrete must crack in order for reinforcing to work → lower durability because steel can corrode
- Prestressed concrete prevents cracking
- Two powerful design methods: moment diagrams or strut and tie models
- Environmental impact can be reduced through design: minimize material and recycle waste

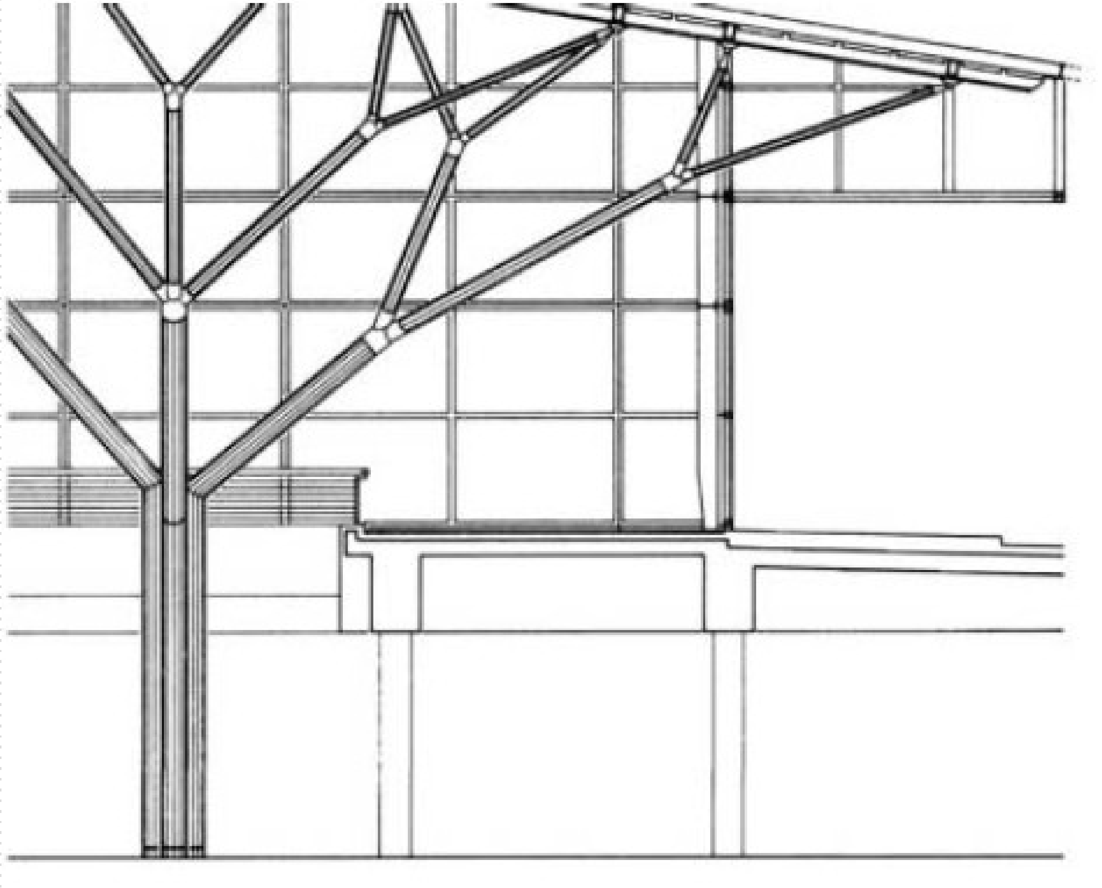
Steel Structures

- **Technical concepts:**
  - Structural failure
  - Ductility
  - Buckling
  - Shear diagrams

Steel Structures

- Recent structures in steel
- Material properties – definitions
- Structural failure
- Environmental issues
- Conclusions

Stuttgart Airport, 1991, Germany



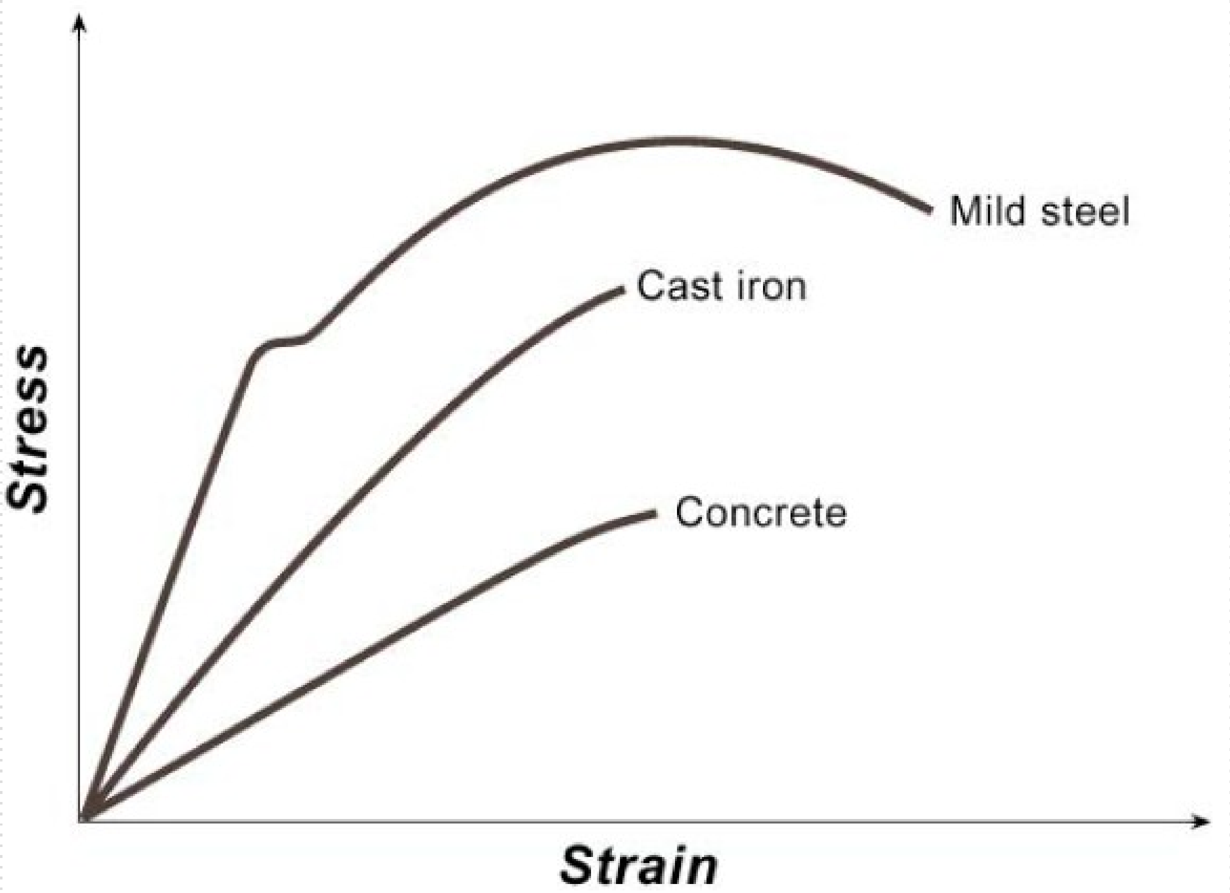
Structural Design in Steel

- Can resist tension and compression
- Slender elements in compression may buckle
- Very lightweight structures, so vibrations are a problem
- Follow moment diagram to minimize material use

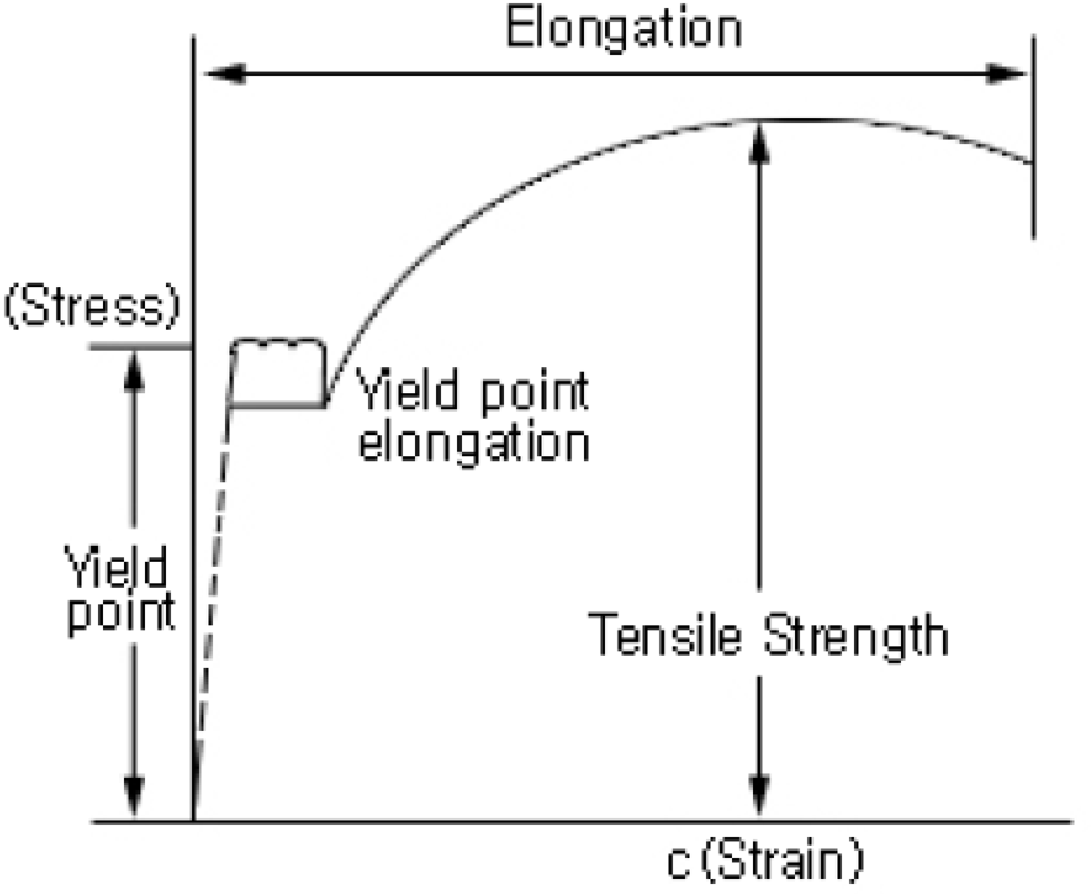
Why is steel a good structural material?

- High strength
- Ductile material

Ductility of Steel



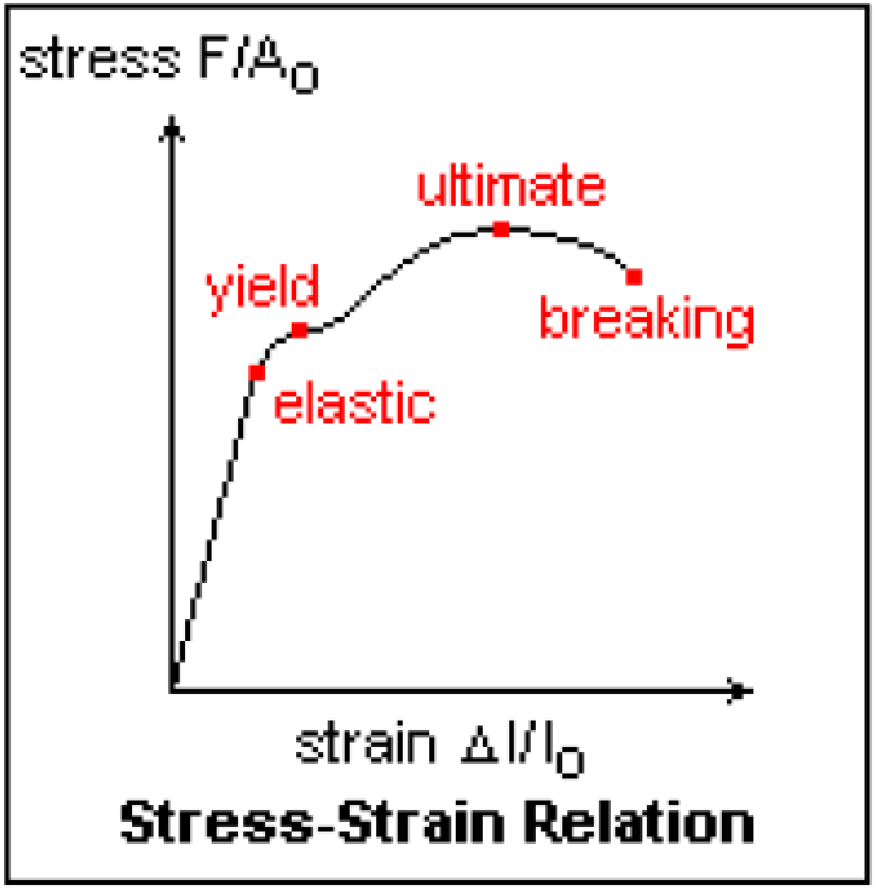
Ductility of Steel



Importance of Ductility

- **Large displacements before collapse (as opposed to a *brittle* material, which fails suddenly)**
- **Energy dissipation as the steel yields (important for resisting earthquakes and other overloading)**

Yield Stress of Steel



Yield Stress of Steel

Steel Type	Yield Stress	Ultimate Stress
A36	36 ksi (kips/in^2)	~50 ksi
A50	50 ksi	~67 ksi
High Strength	80 ksi	Up to 100 ksi

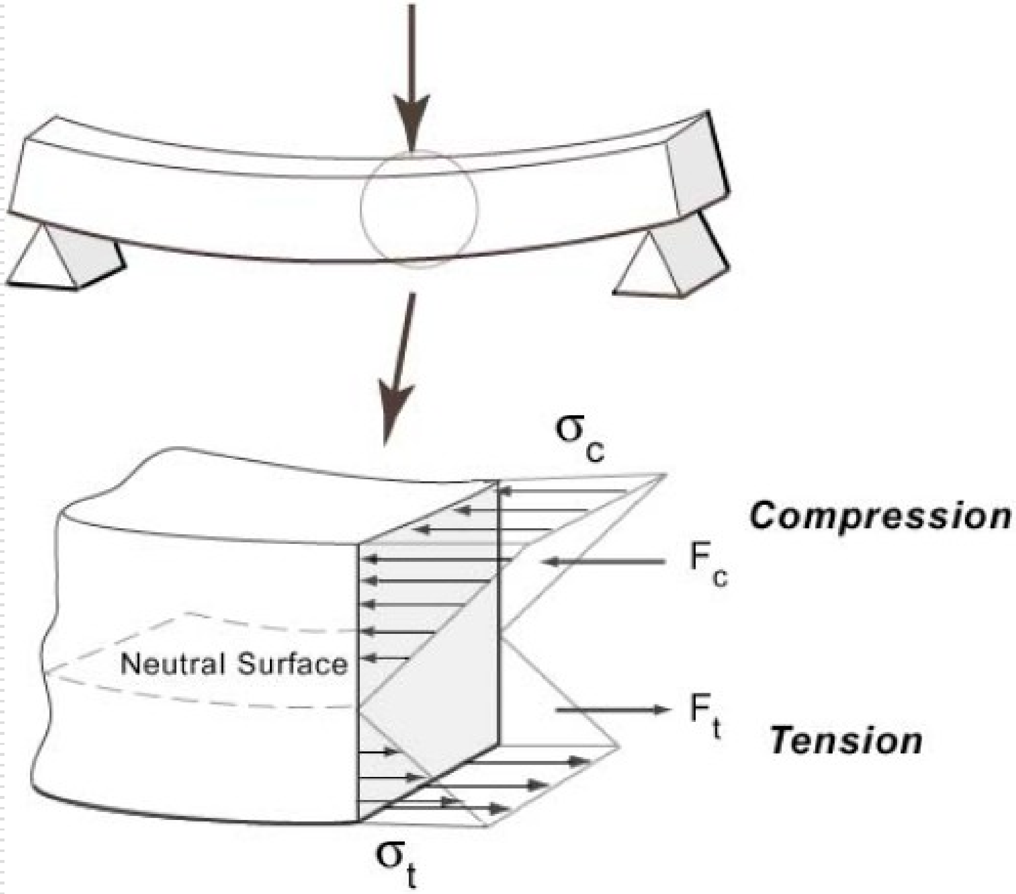
How far down can a steel cable hang under its own weight?

Specific weight of steel: 490 lbs/ft3

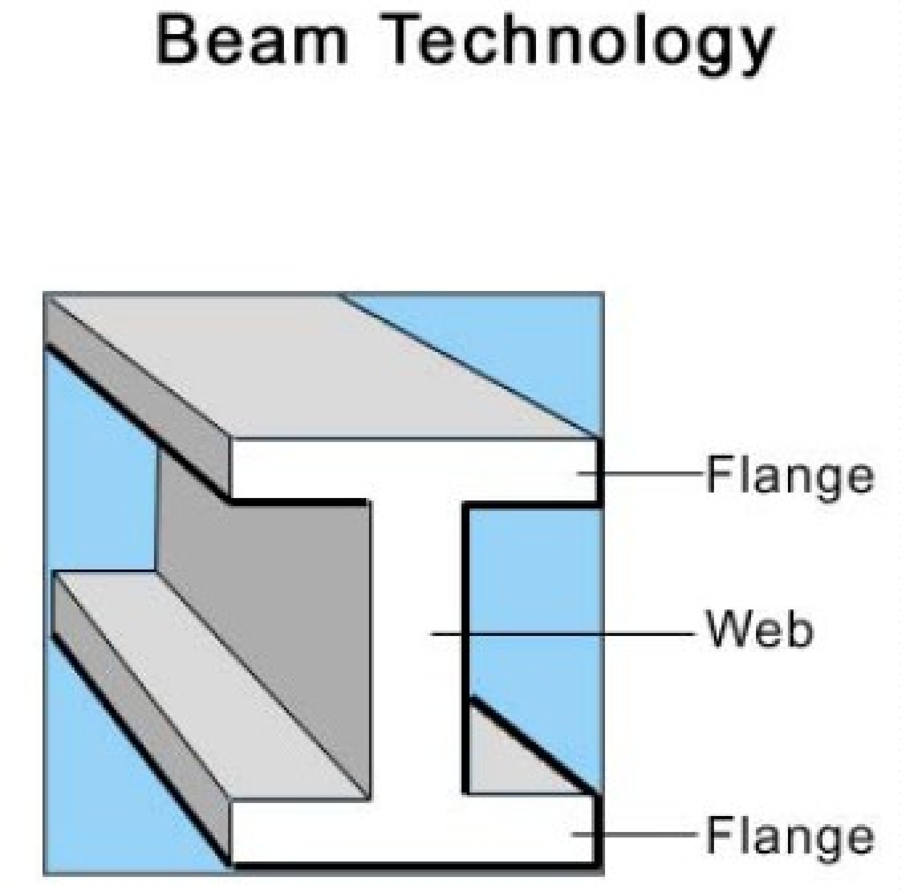
Stress = Force/area

Ultimate Stress	Length of cable before breaking
50 ksi	~15,000 feet (4.5 km)
67 ksi	~20,000 feet (6 km)
100 ksi	~35,000 feet (11 km)

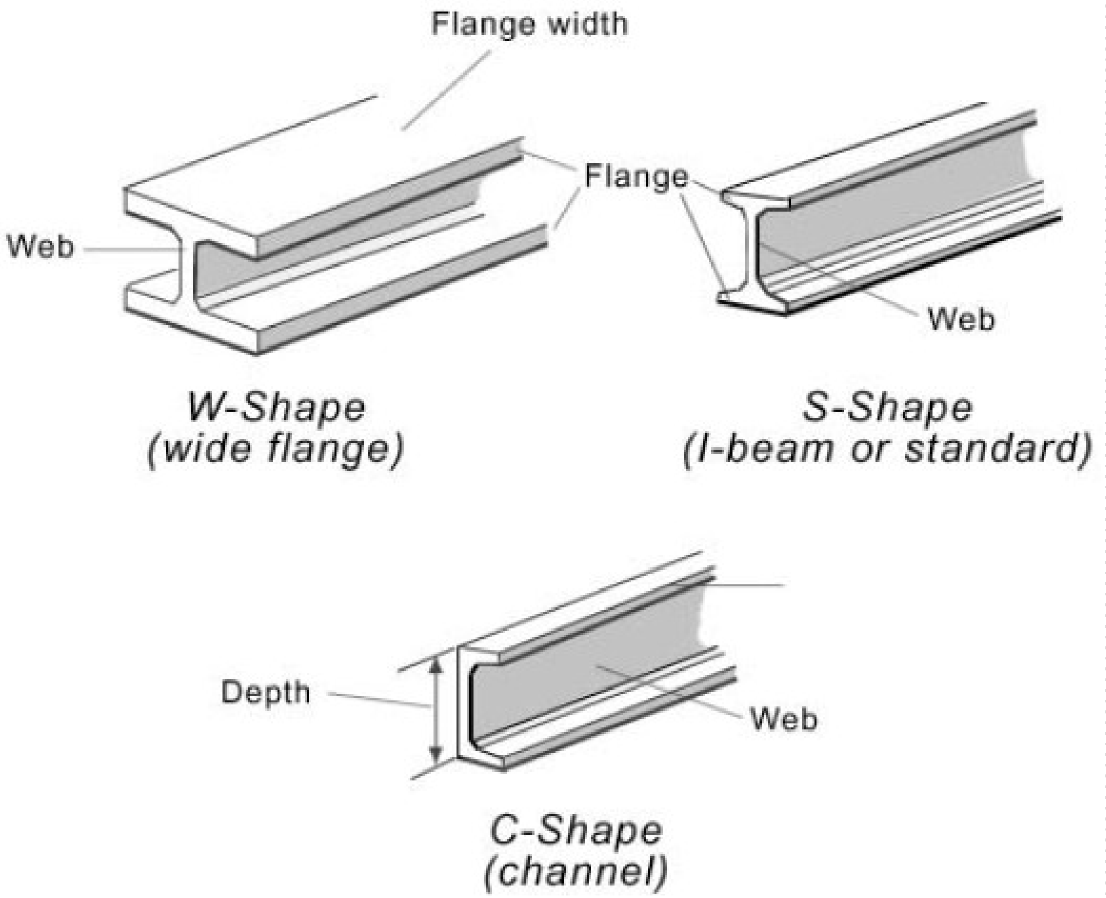
Bending Stresses in a Beam



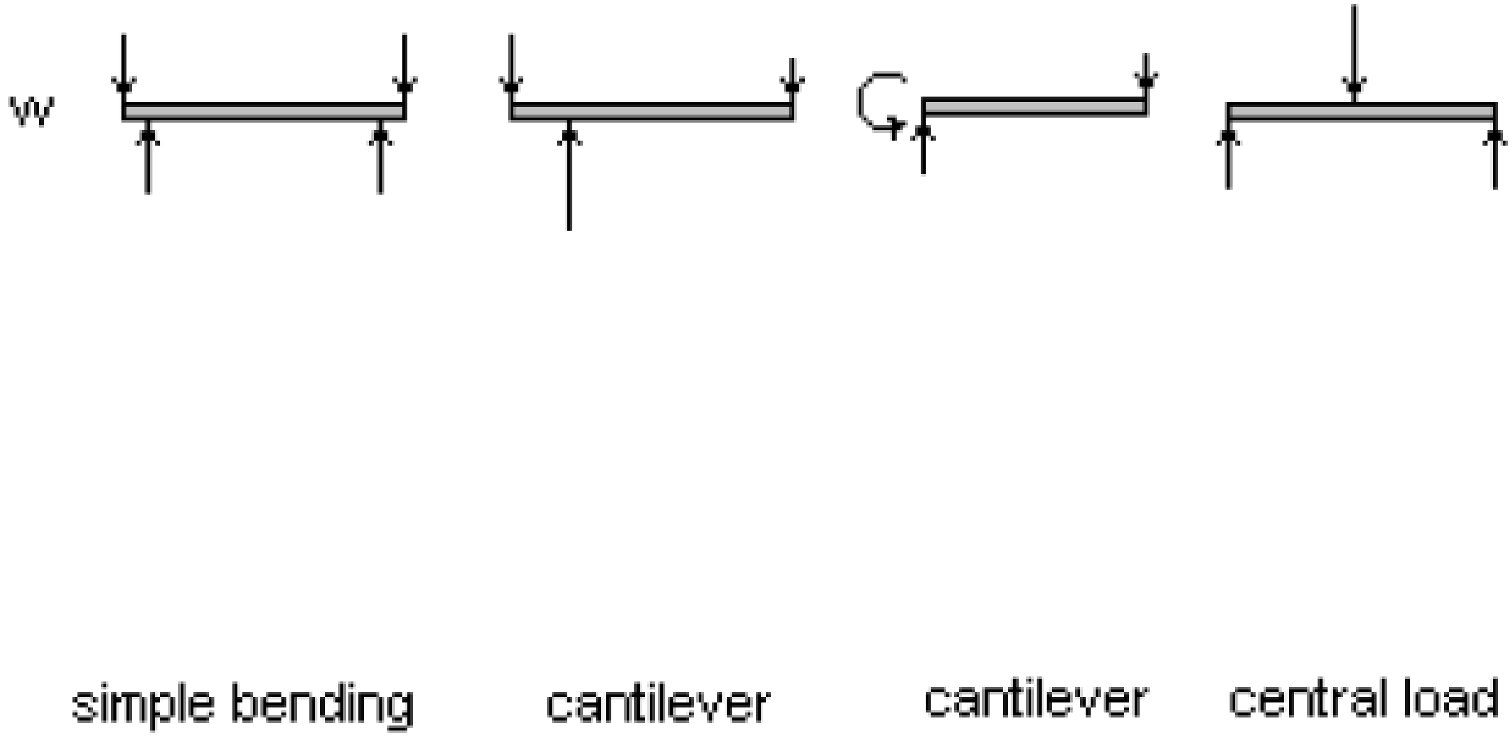
Steel Section Terminology



Steel Section Terminology

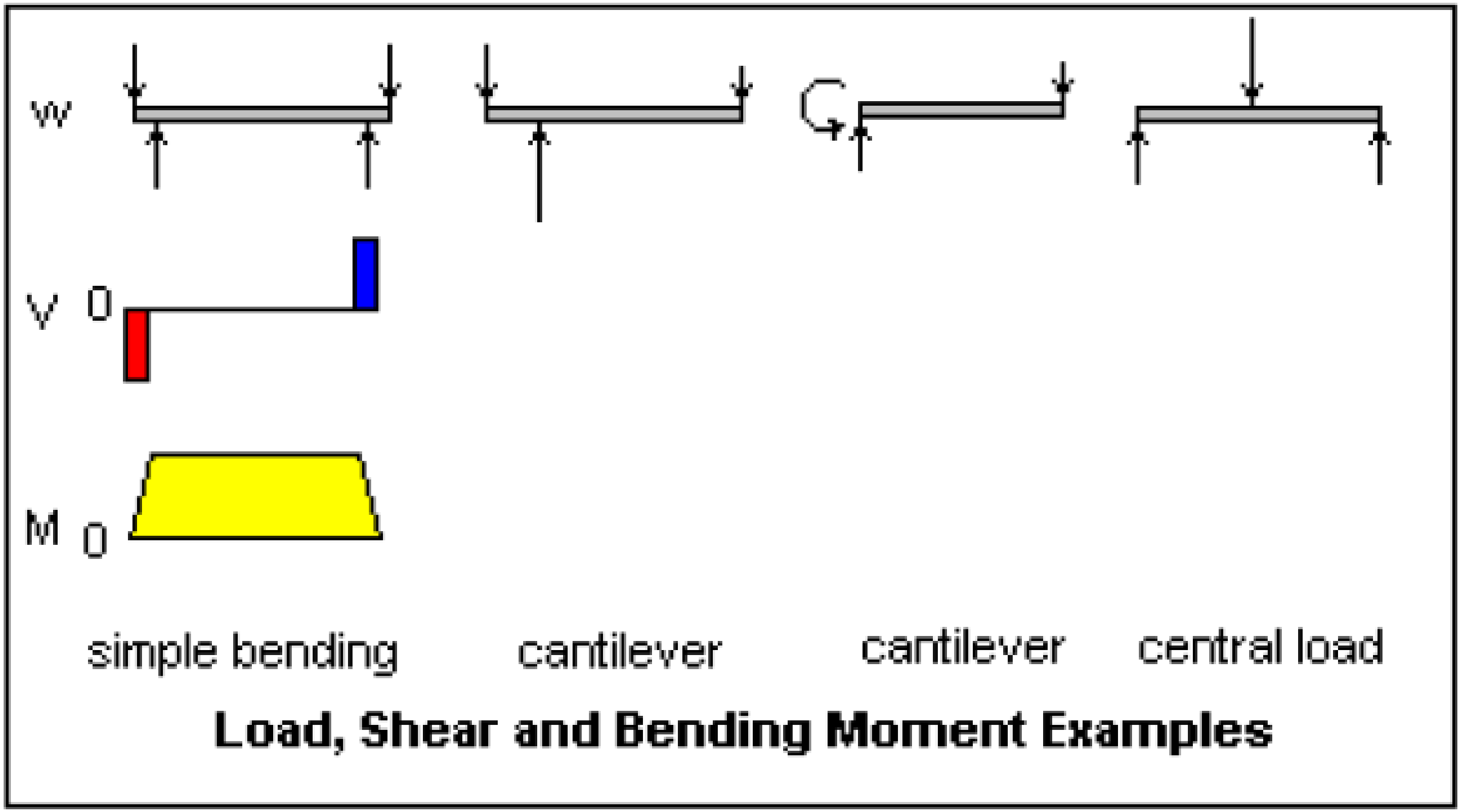


Shear Diagrams

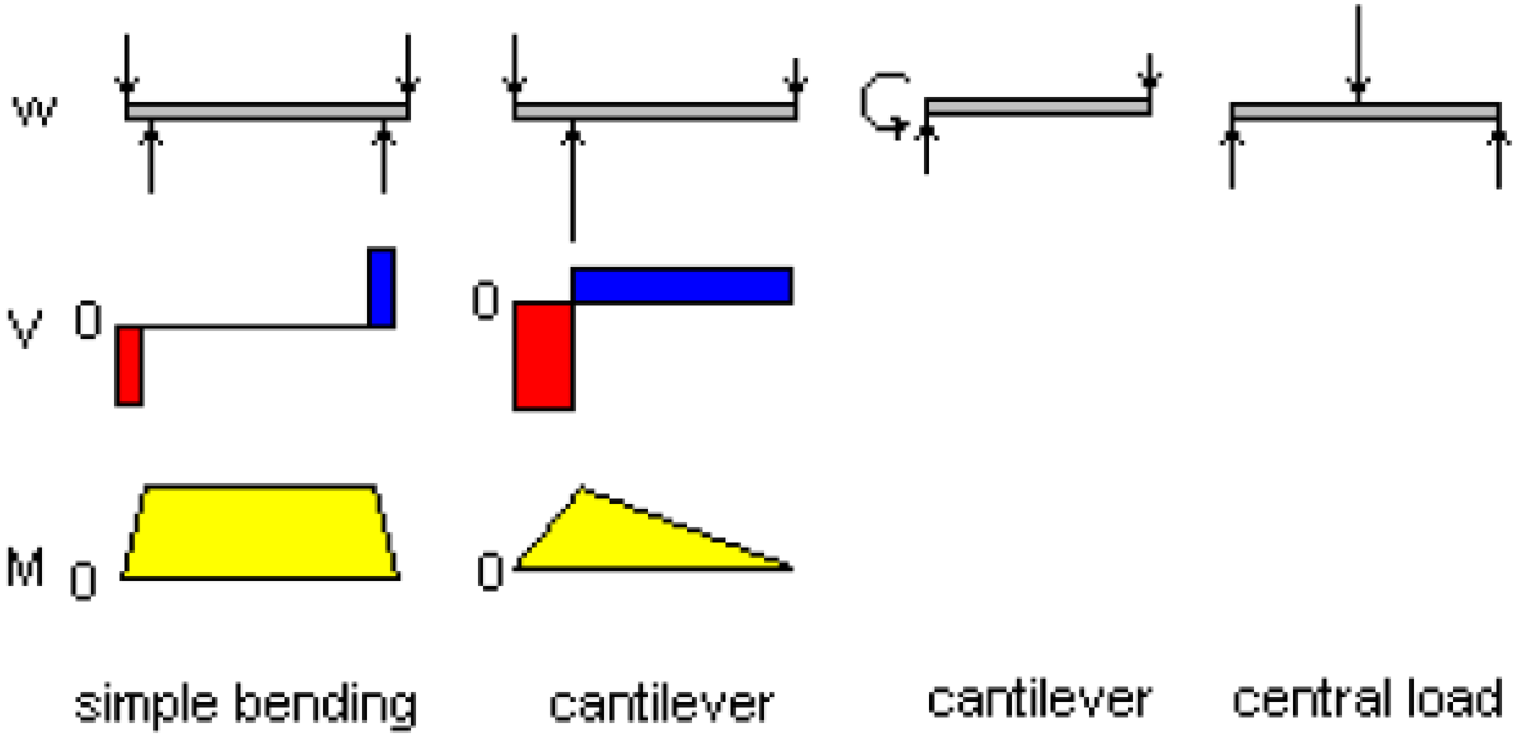


Load, Shear and Bending Moment Examples

Shear Diagrams

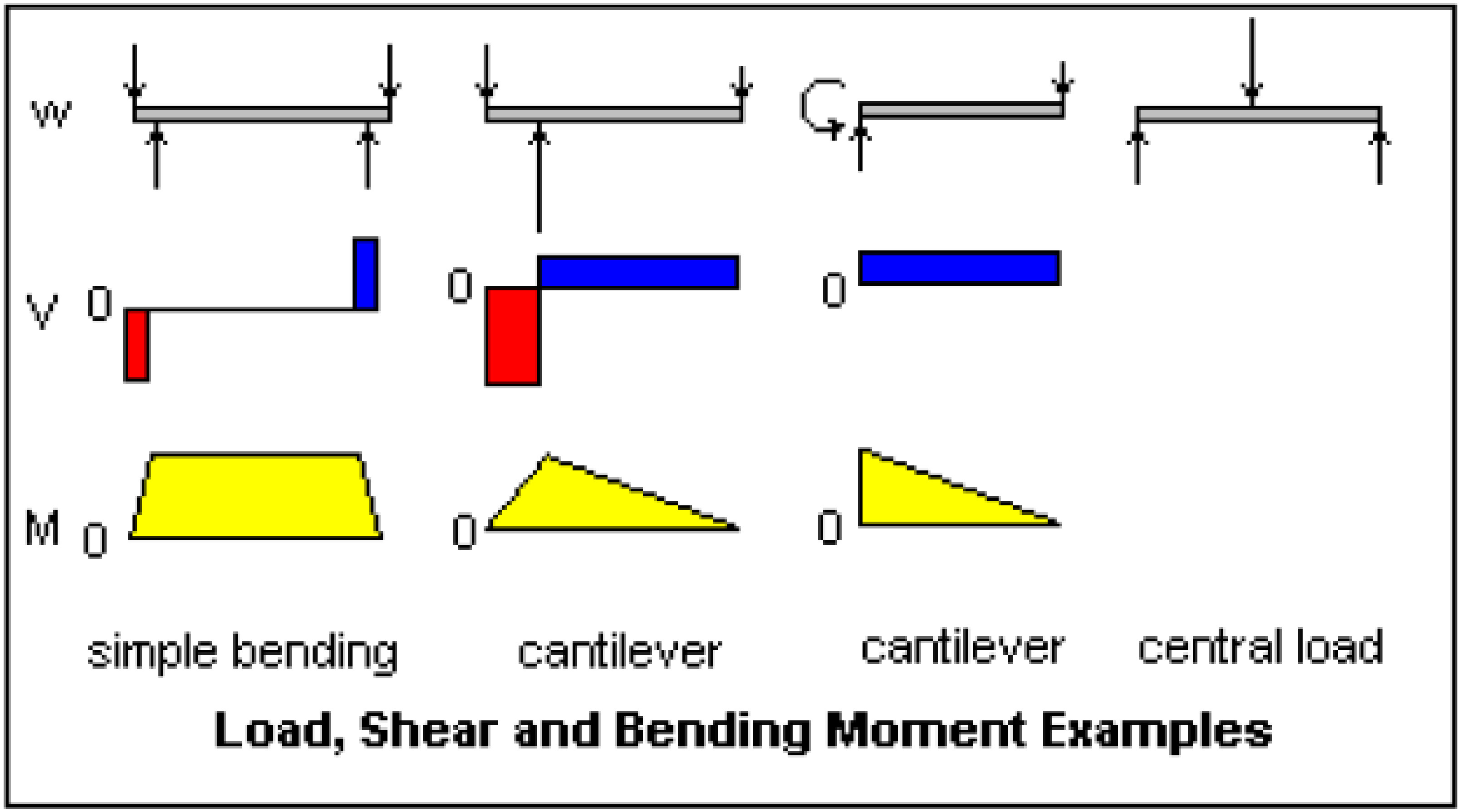


Shear Diagrams

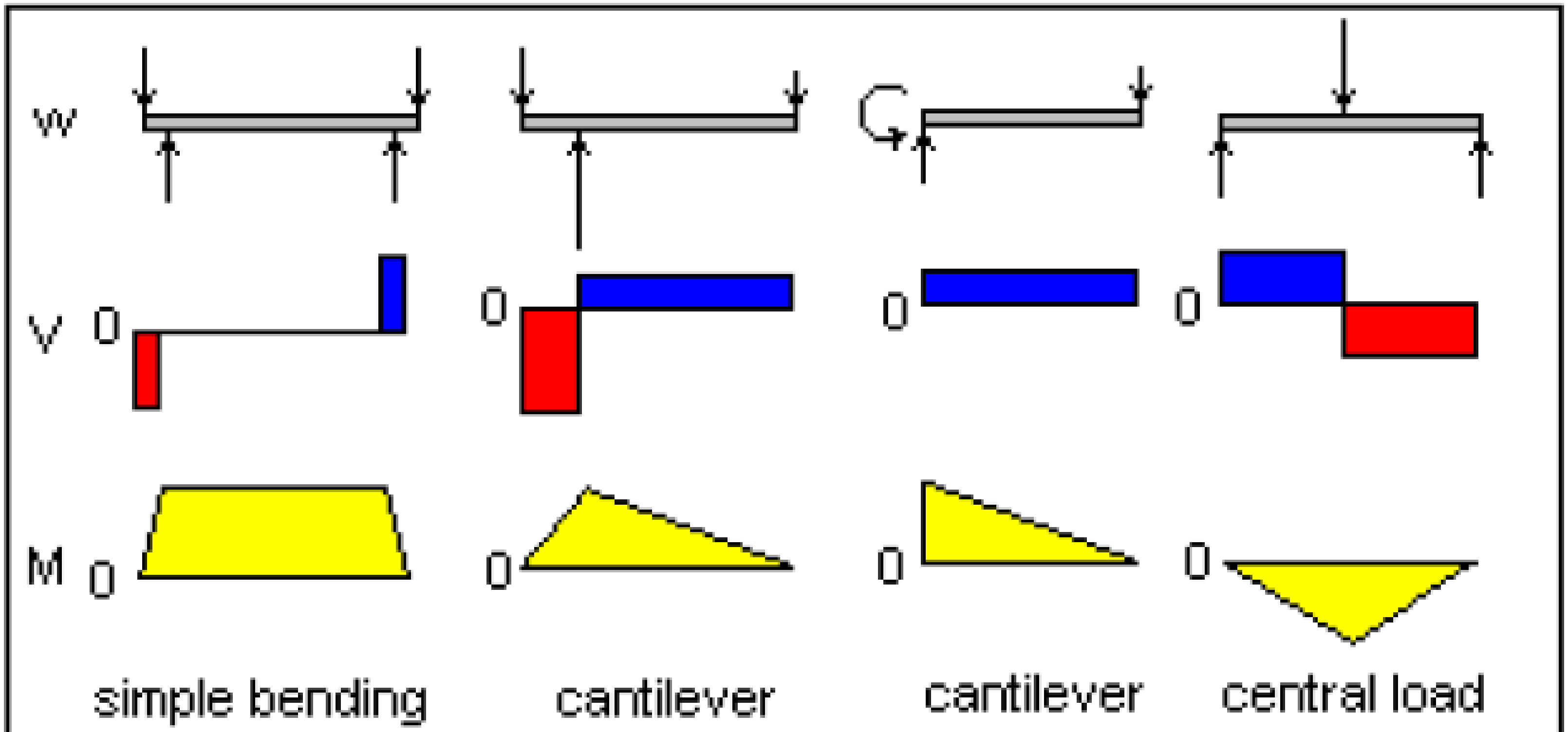


Load, Shear and Bending Moment Examples

Shear Diagrams



Shear Diagrams



Load, Shear and Bending Moment Examples

How to draw a shear diagram

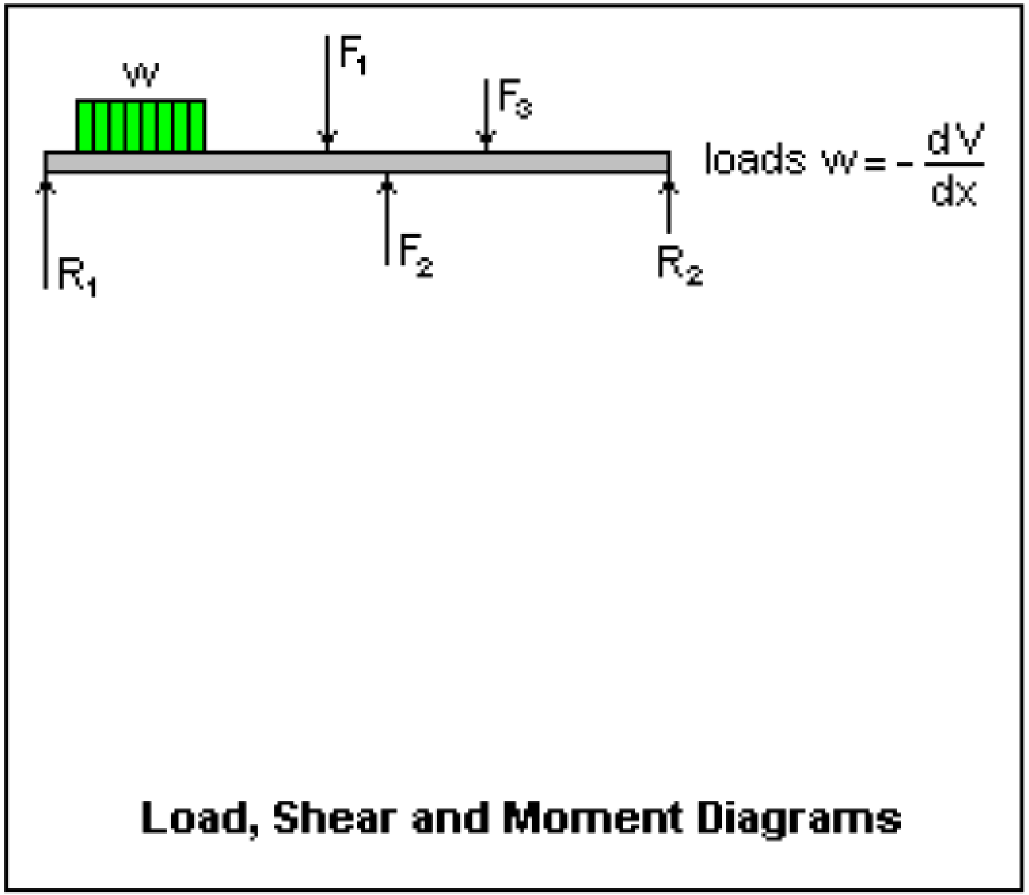
1) Determine external reactions on beam

2) “Walk” along beam with your pen

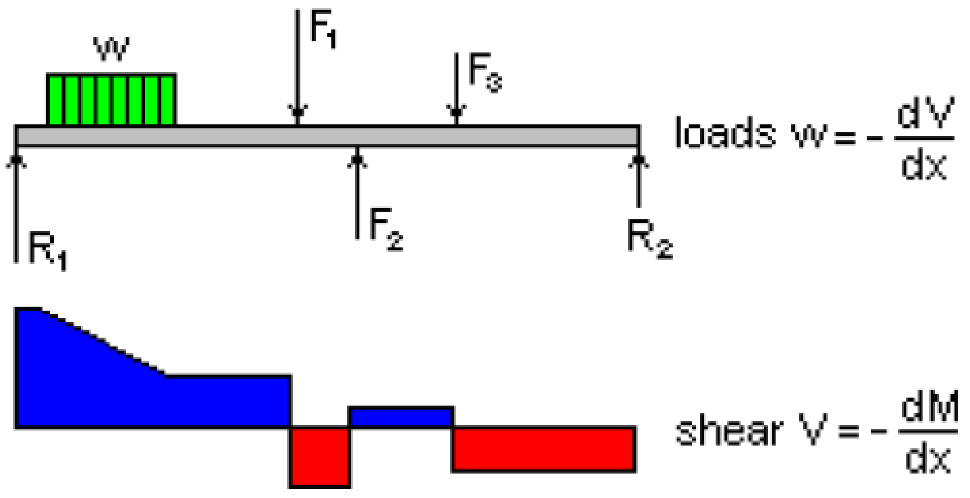
3) Pen goes up and down with the loads

4) Must “close” diagram at the ends of thebeam

Shear Diagrams

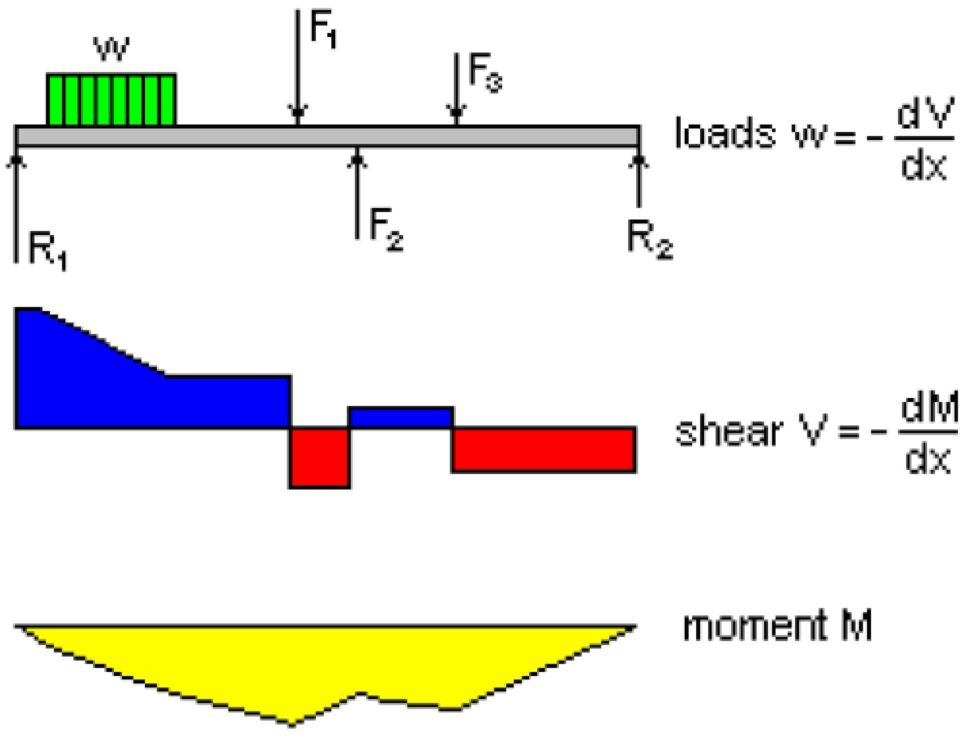


Shear Diagrams



Load, Shear and Moment Diagrams

Shear Diagrams



Load, Shear and Moment Diagrams

Structural Failure

- STRENGTH
  - Material failure
  - Buckling (due to instability of section)
- SERVICEABILITY
  - Excessive deflections or vibrations
  - Cracking (usually in concrete)

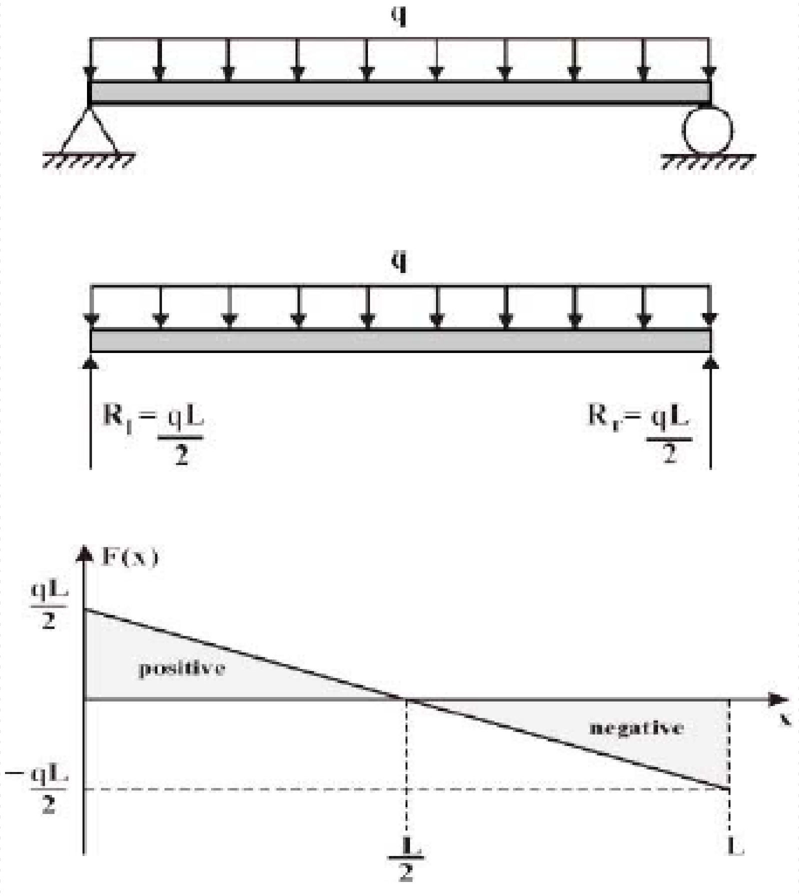
Stiffness of Steel

- STRENGTH
  - Higher yield stress allows smaller sections

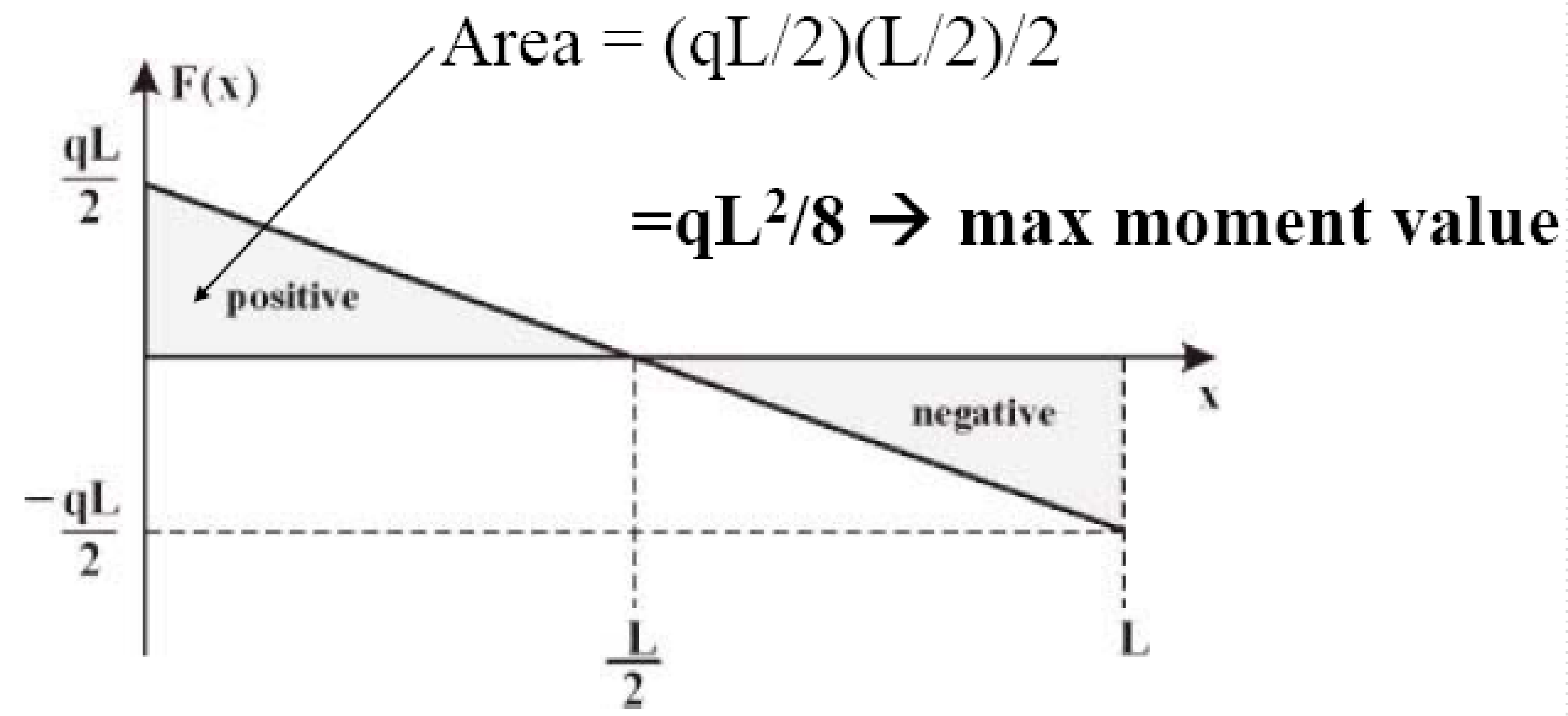
…but…

- SERVICEABILITY
  - Stiffness of steel is constant (modulus of elasticity, E)
  - Deflections, vibrations, and buckling become more common

Shear Diagram for Uniform Load

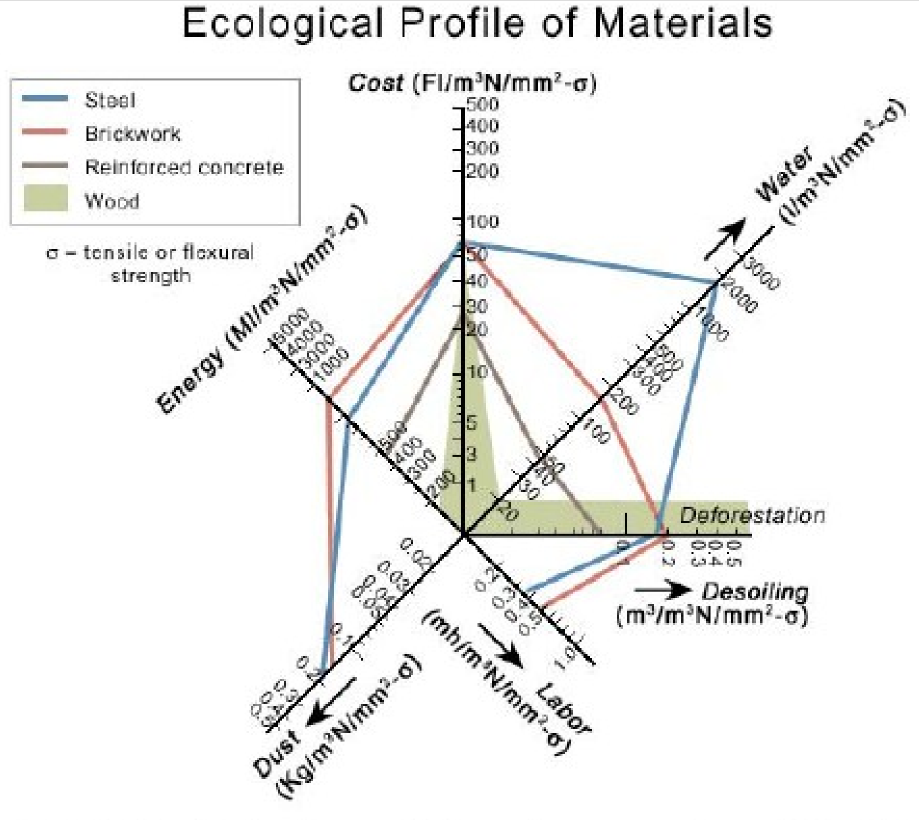


Shear Diagrams



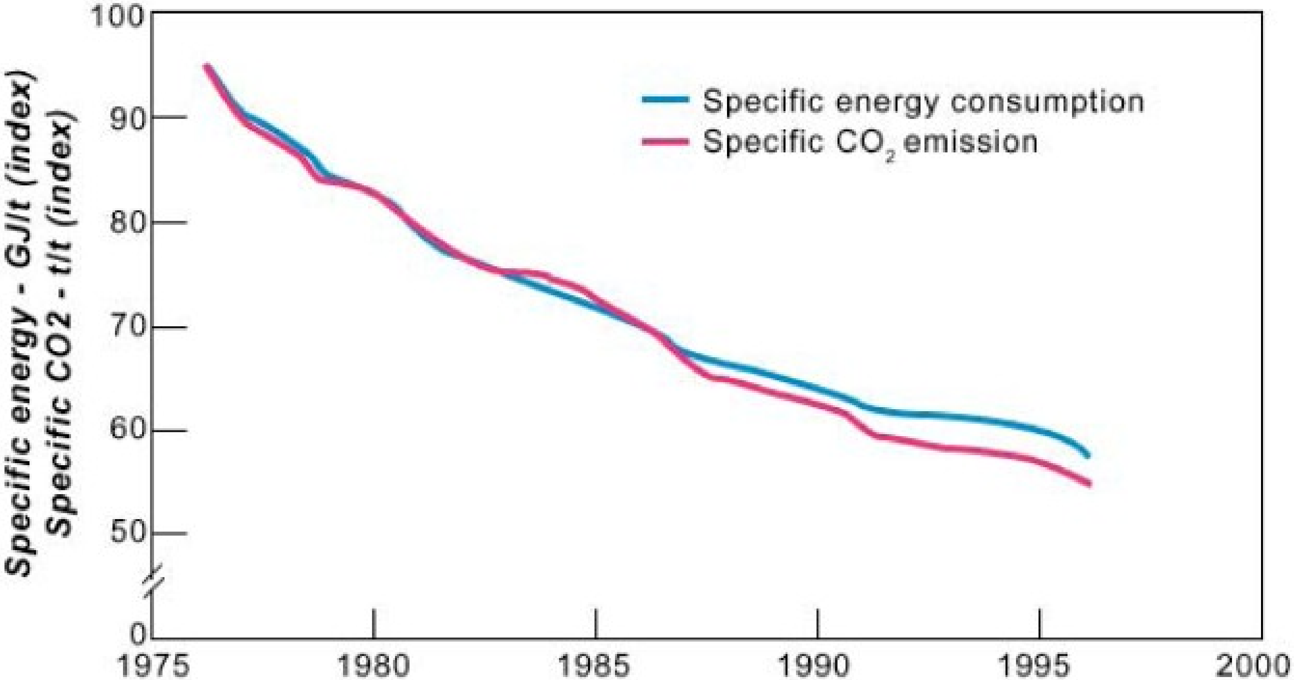
Shear diagram equals the slope of moment diagram

Is steel a green material?



Ecological profile of various material properties expressed per unit strength.
The Institution of Structural Engineering

CO_2 Emissions for Steel



EU steel industry consumption per tonne of hot-rolled steel
EU Steel Industry CO_2 emission per tonne of hot-rolled steel
(3 year moving averages)

Recycled content for steel

Type of steel	Percent recycled
Structural steel	90%
Light gauge steel	30%

Each ton of recycled steel saves 1200 pounds of coal

Environmental Advantages of Steel

- **Lower weight reduces foundation requirements**
- **Highly recycled and can continue to be recycled indefinitely**
- **Durable, if protected from corrosion**

Environmental Disadvantages of Steel

- Very high energy use, predominantly from burning coal → produces pollution
- Lightweight, so lower thermal mass compared to concrete → requires more insulation
- Is susceptible to corrosion

Corrosion of Steel

Corrosion costs around 4% of GDP

Every 90 seconds, across the world, one ton of steel turns to rust; of every two tons of steel made, one is to replace rust.

How to avoid corrosion?

- Careful detailing to protect from water
- Use stainless steel
- Protect steel with galvanizing (zinc coating) or other protective coating

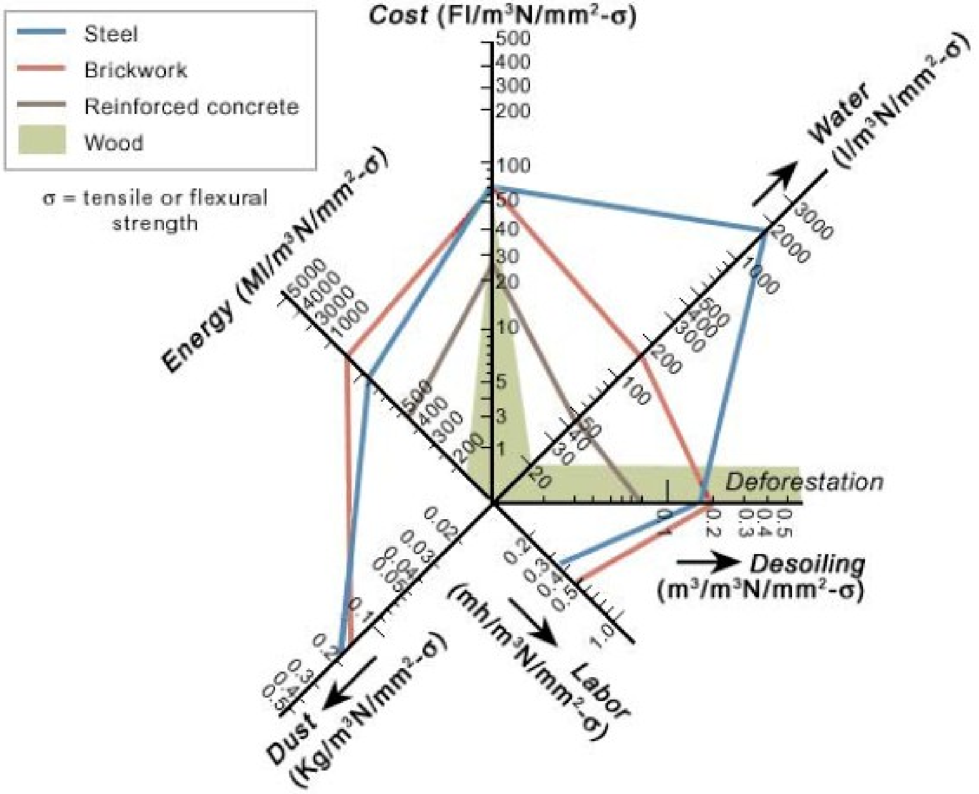
Stainless Steel Disadvantages

- High initial cost
- Difficulty in fabricating can often result in costly waste
- Difficulty in welding
- High cost of final polishing and finishing

Conclusions

- **Steel offers many advantages, primarily high strength and ductility**
- **Shear diagrams can be used to determine locations of high stresses (and are helpful in drawing moment diagrams)**
- **Lightweight structures are susceptible to vibrations and excessive deflections**
- **Environmental impact can be reduced through design**

Ecological Profile of Materials



Ecological profile of various material properties expressed per unit strength.
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Ecological Footprints

COUNTRY	POPULATION 1997	FOOTPRINT (ha/cap)	AVAILABLE CAPACITY (ha/cap)	DEFICIT (ha/cap)	TOTAL FOOTPRINT (km2)	TOTAL CAPACITY (km2)
India	970,230,000	0.8	0.5	-0.3	7,761,840	4,851,150
China	1,247,315,000	1.2	0.8	-0.4	14,967,780	9,978,520
Peru	24,691,000	1.6	7.7	6.1	395,056	1,901,207
France	58,433,000	4.1	4.2	0.1	2,395,753	2,454,186
Germany	81,845,000	5.3	1.9	-3.4	4,337,785	1,555,055
Canada	30,101,000	7.7	9.6	1.9	2,317,777	2,889,696
United States	268,198,000	10.3	6.7	-3.6	27,623,467	17,968,663
WORLD	5,892,480,000	2.8	2.1	-0.7		

Ecological Footprints for Selected Countries
[Data Source: Wackernagel, Mathis, Larry Onisto, et. al. Ecological Footprints of Nations: Rio+5 Forum Study, March 10, 1997.]