Concrete Structures

- **Introduction to design methods in reinforced concrete**
- **Sustainable construction – is concrete “green”?**
- **Possibilities in concrete structure**

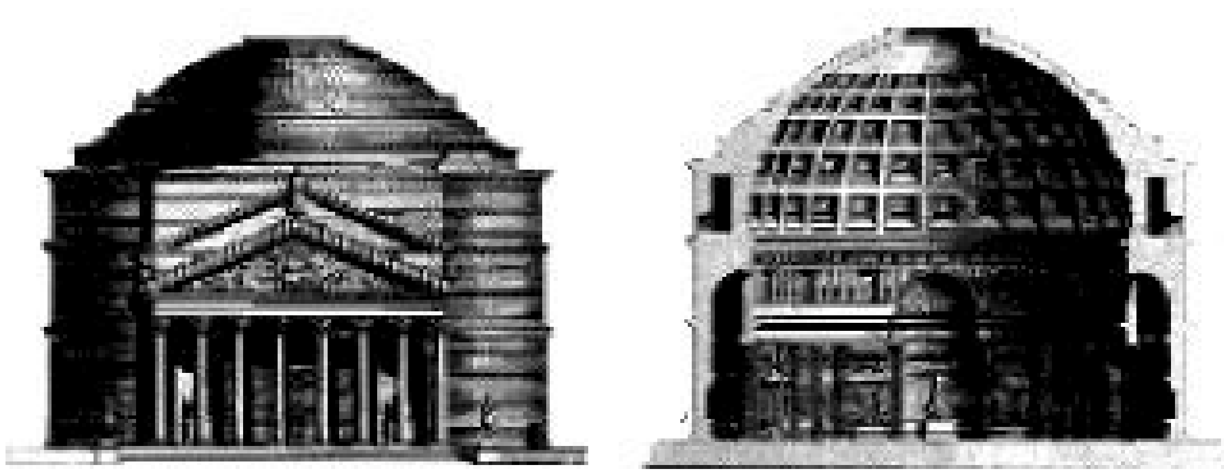
- **Technical concepts:**
  - **Bending moment diagrams**
  - **Reinforced vs. prestressed concrete**
  - **Strut and tie method of design**

Outline

- Introduction to concrete as a material
- Stresses in bending
- Reinforced concrete vs. prestressed concrete
- Design methods
- Environmental issues
- Design possibilities
- Conclusions

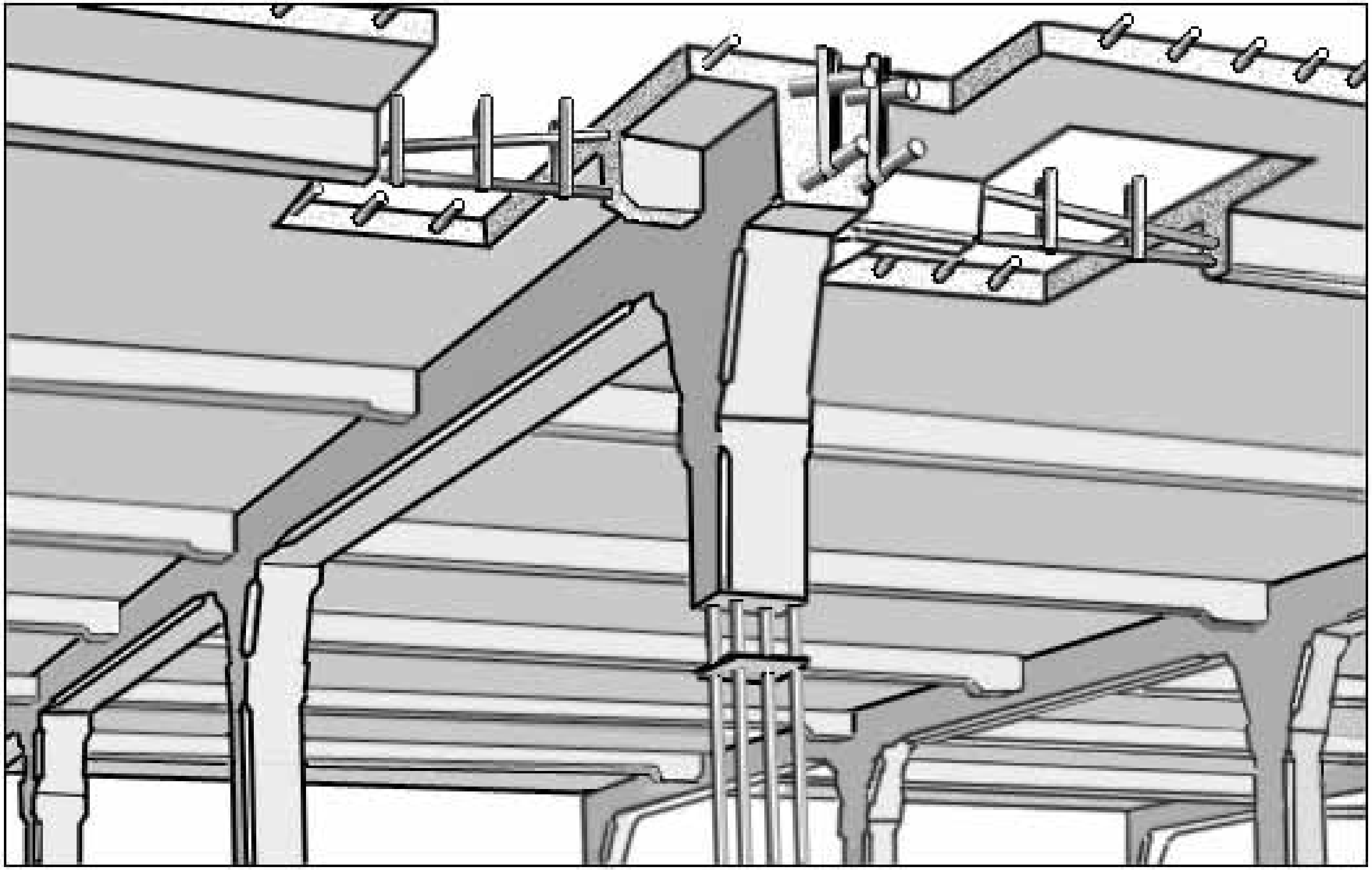
Unreinforced Concrete

- Same as masonry: it must act in compression (no resistance to tension)



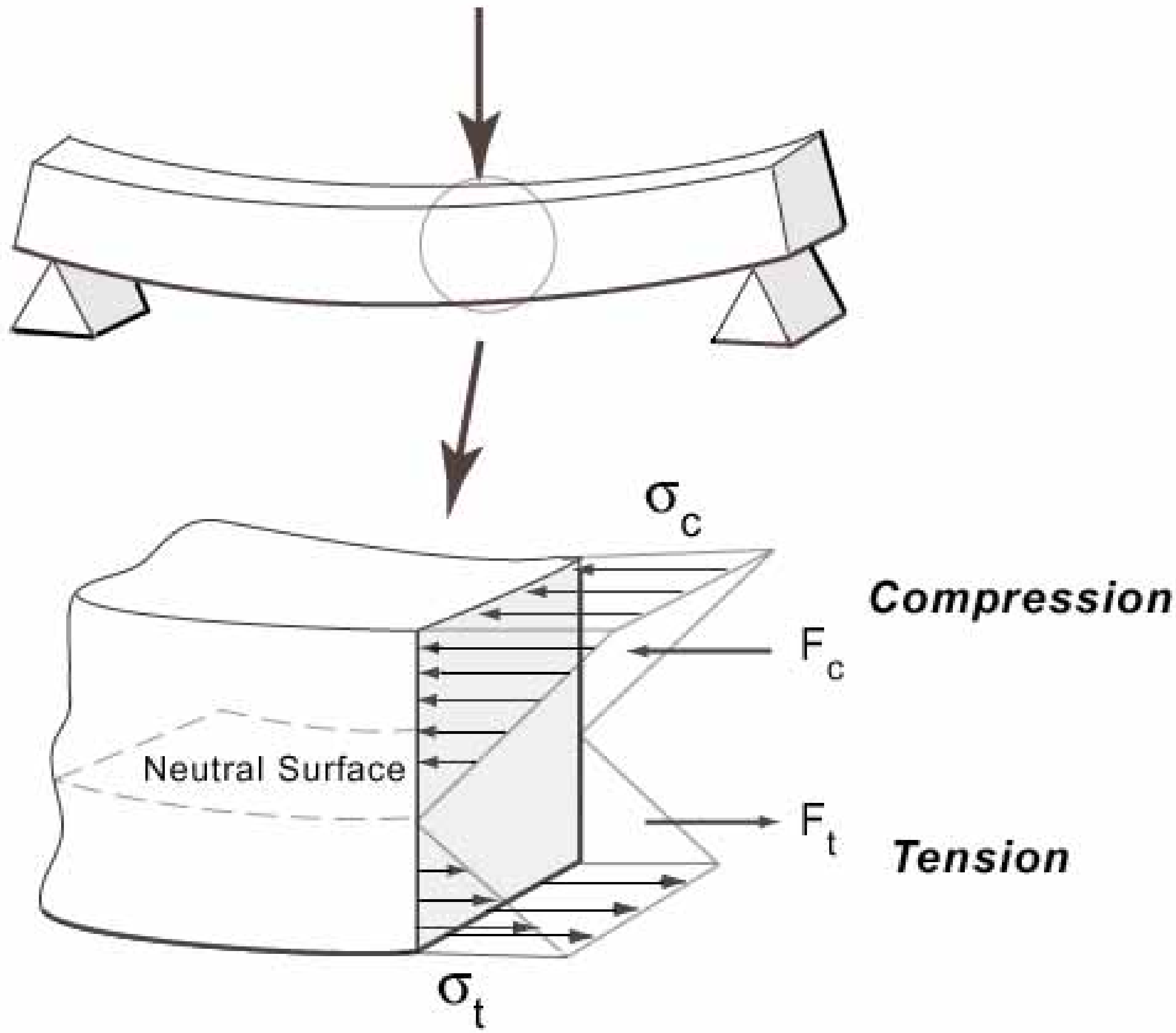
  – Roman Pantheon, 126 AD

Beginnings of Reinforced Concrete

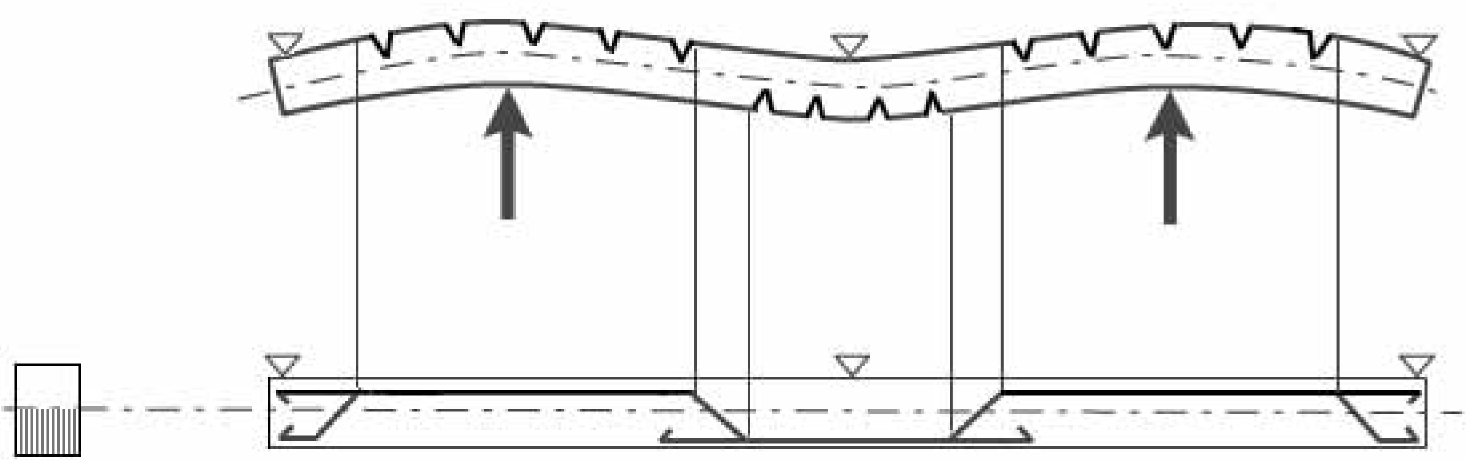


Hennebique system patented in France

Bending Stresses in a Beam

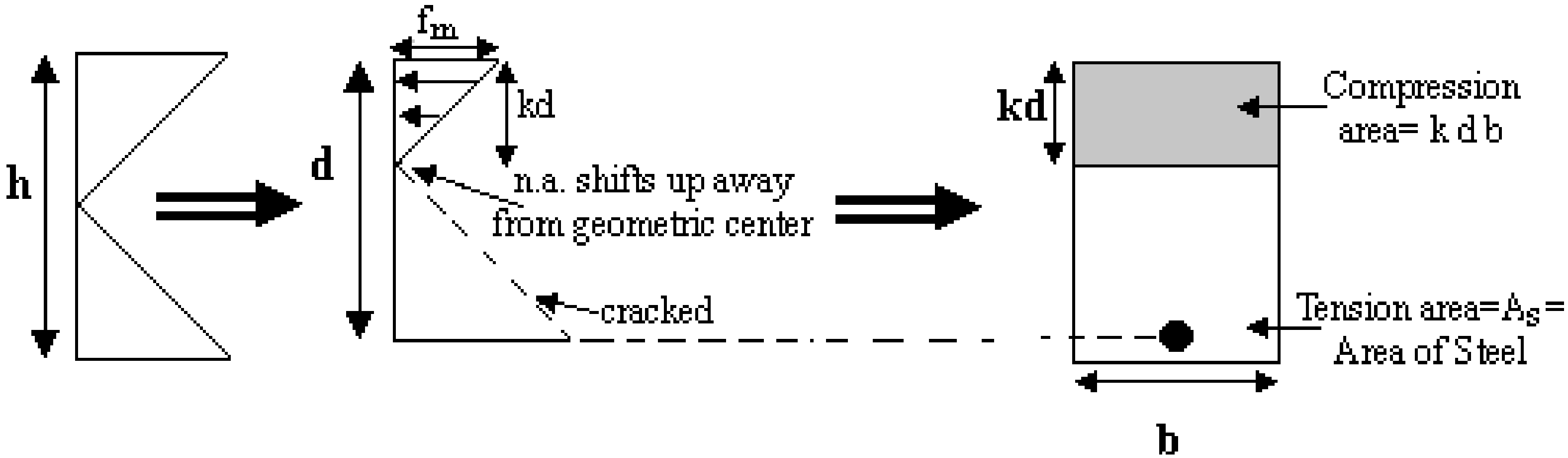


Steel Reinforcing in Concrete



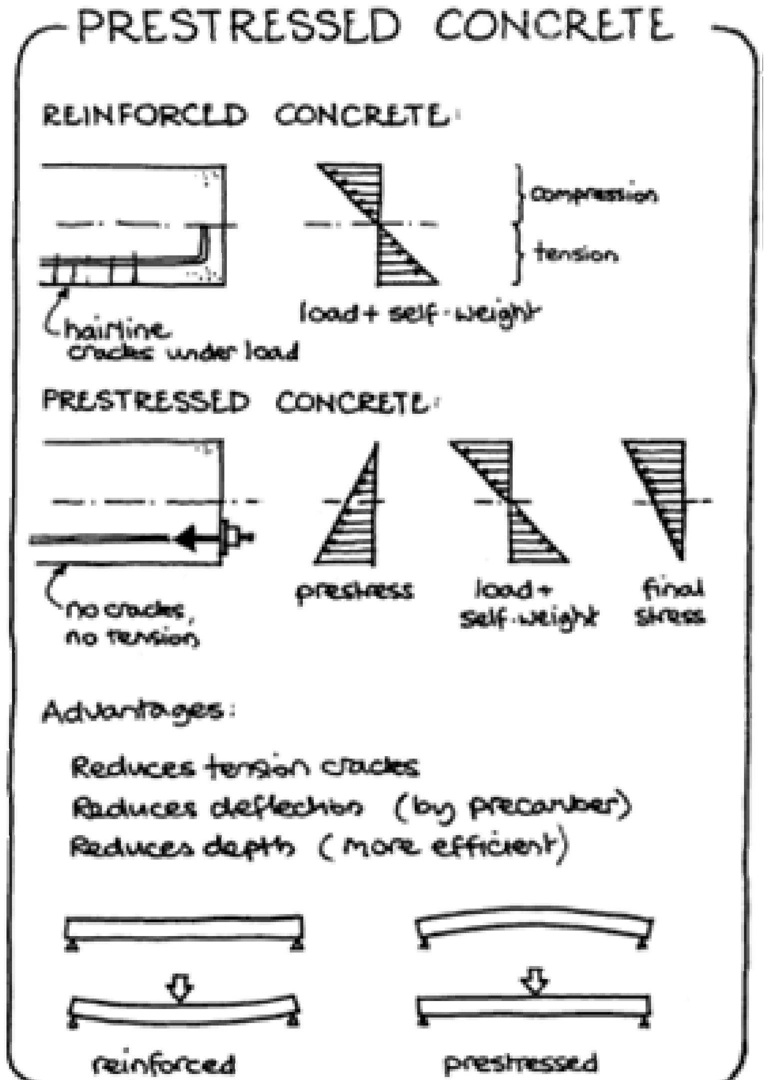
19th Century invention

Design Basis for Reinforced Concrete



Concrete must <u>crack</u> in order for the reinforcing steel to carry load

Reinforced vs. Prestressed Concrete



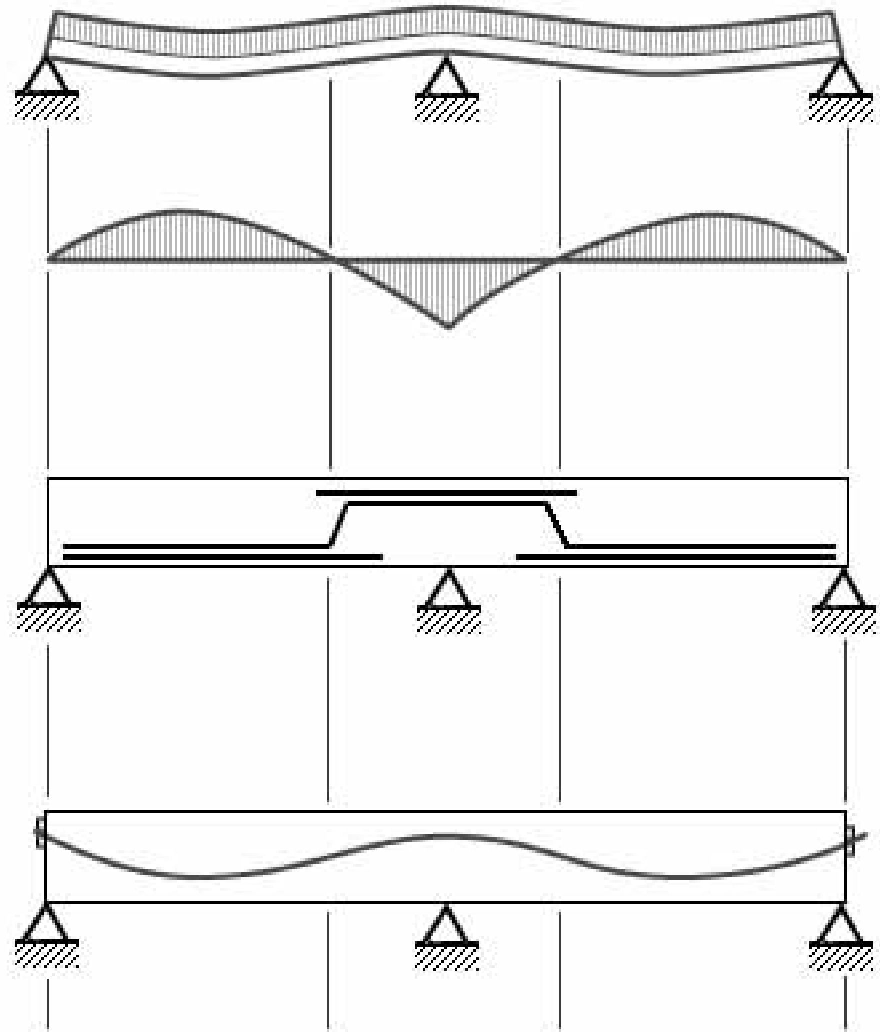
Principles of Reinforcing

(a) *Loading.*

(b) *Moment diagram.*

(c) *Reinforced concrete beam. Reinforcing steel is placed in tension regions.*

(d) *Post-tensioned beam. Cable is draped to reflect moments present.*

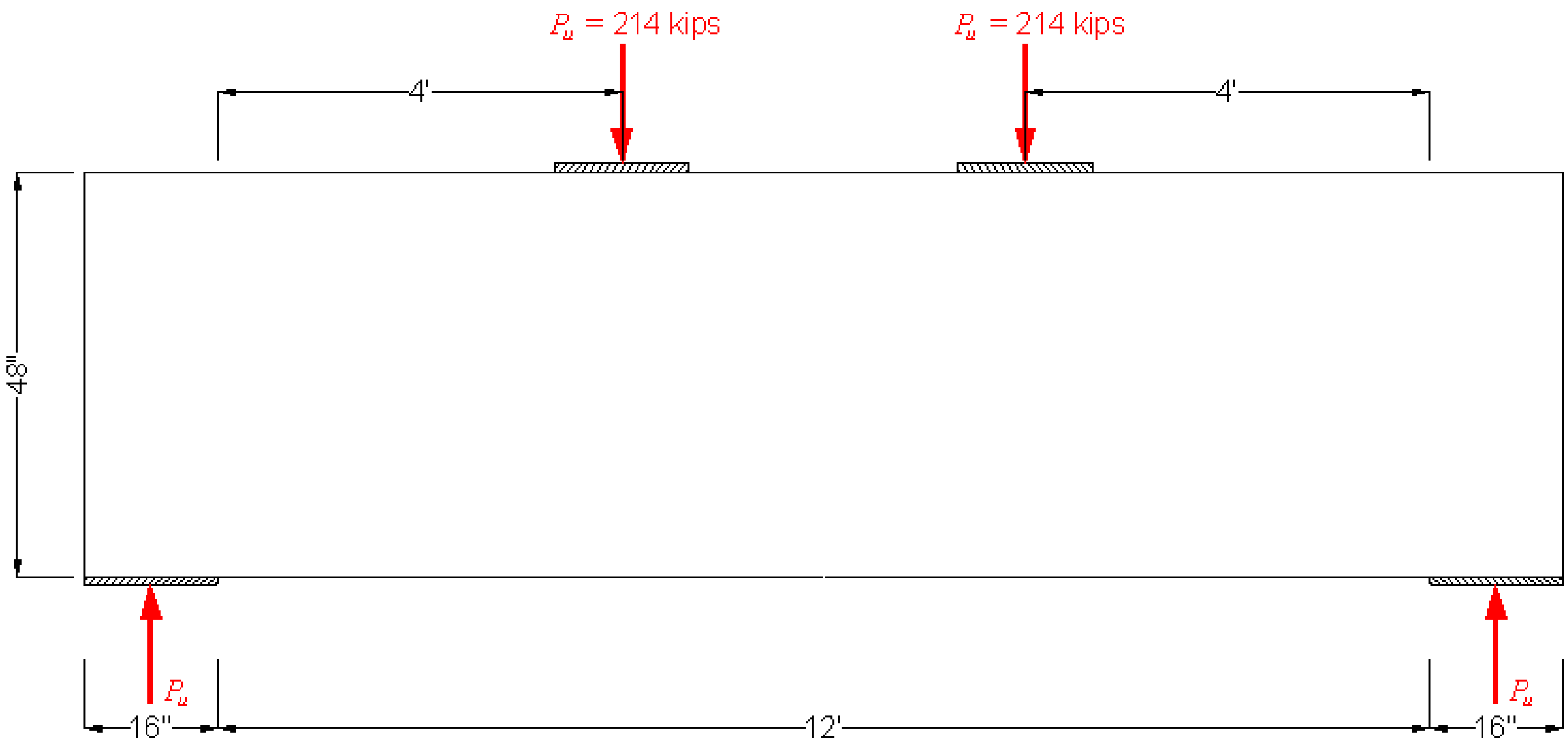


Two design methods for concrete

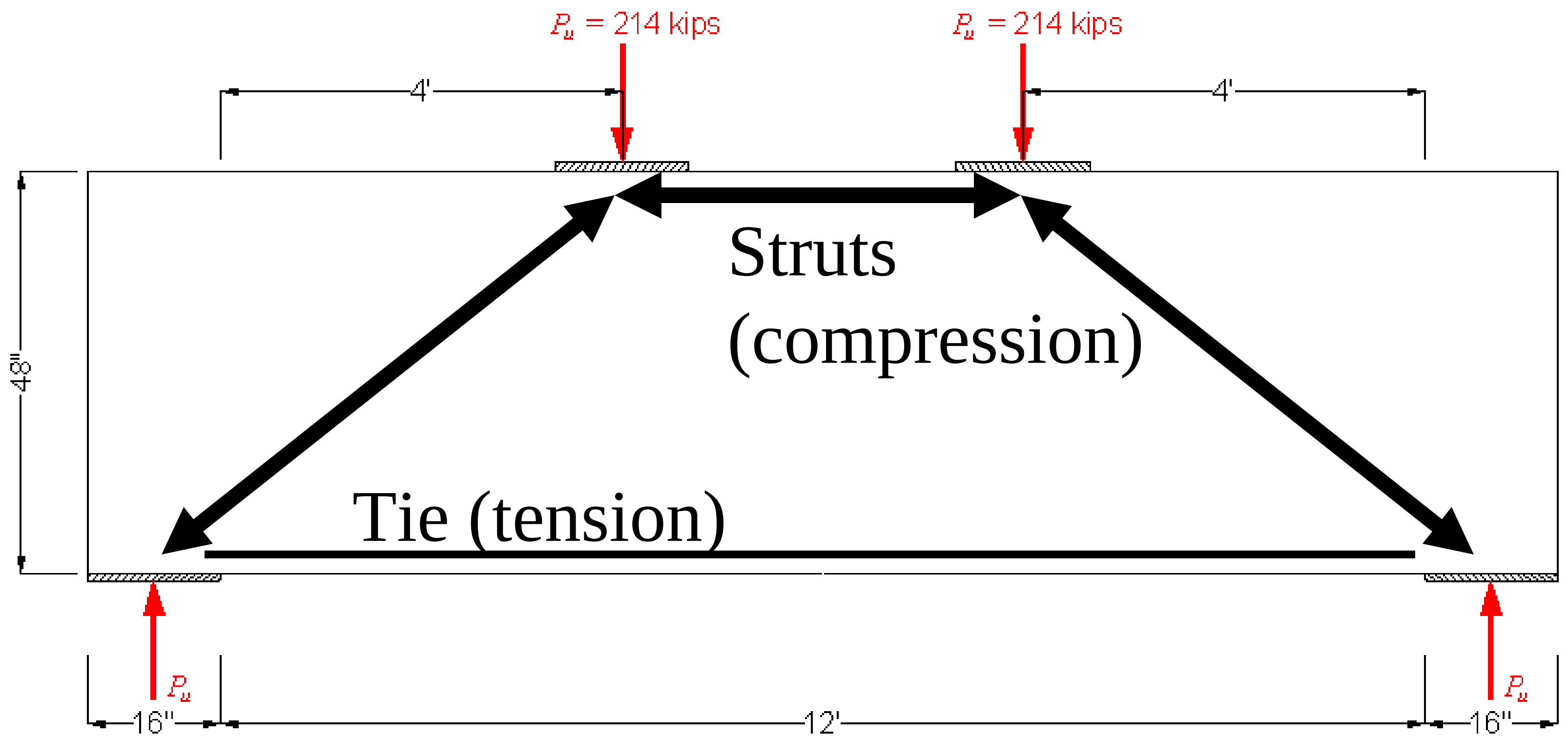
- **Conventional design:**
  - Determine moment diagram
  - Specify steel in areas of tension

- **Strut and tie models:**
  - Define internal forces in tension and compression (ties and struts)
  - Specify steel in areas of tension

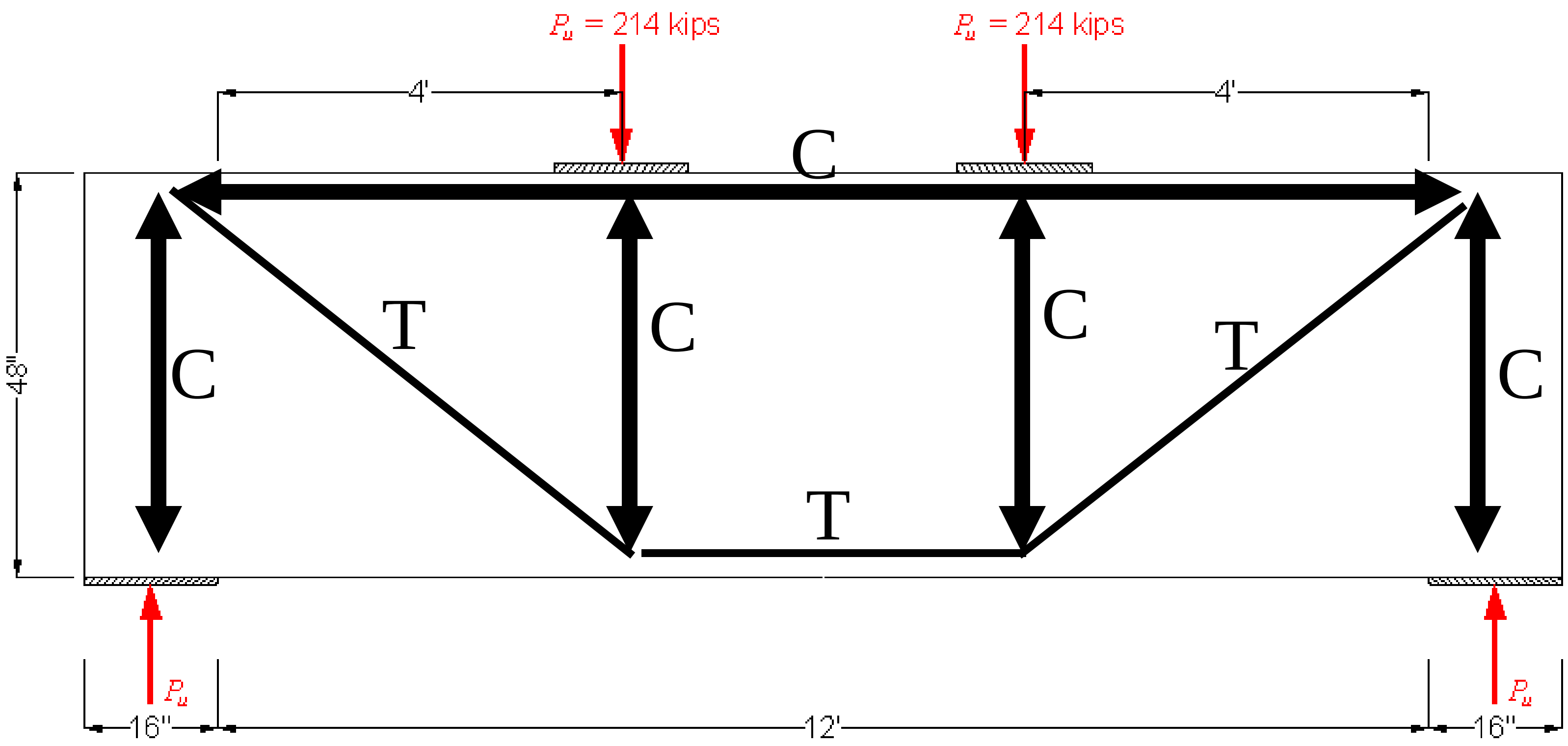
Strut and Tie Modeling



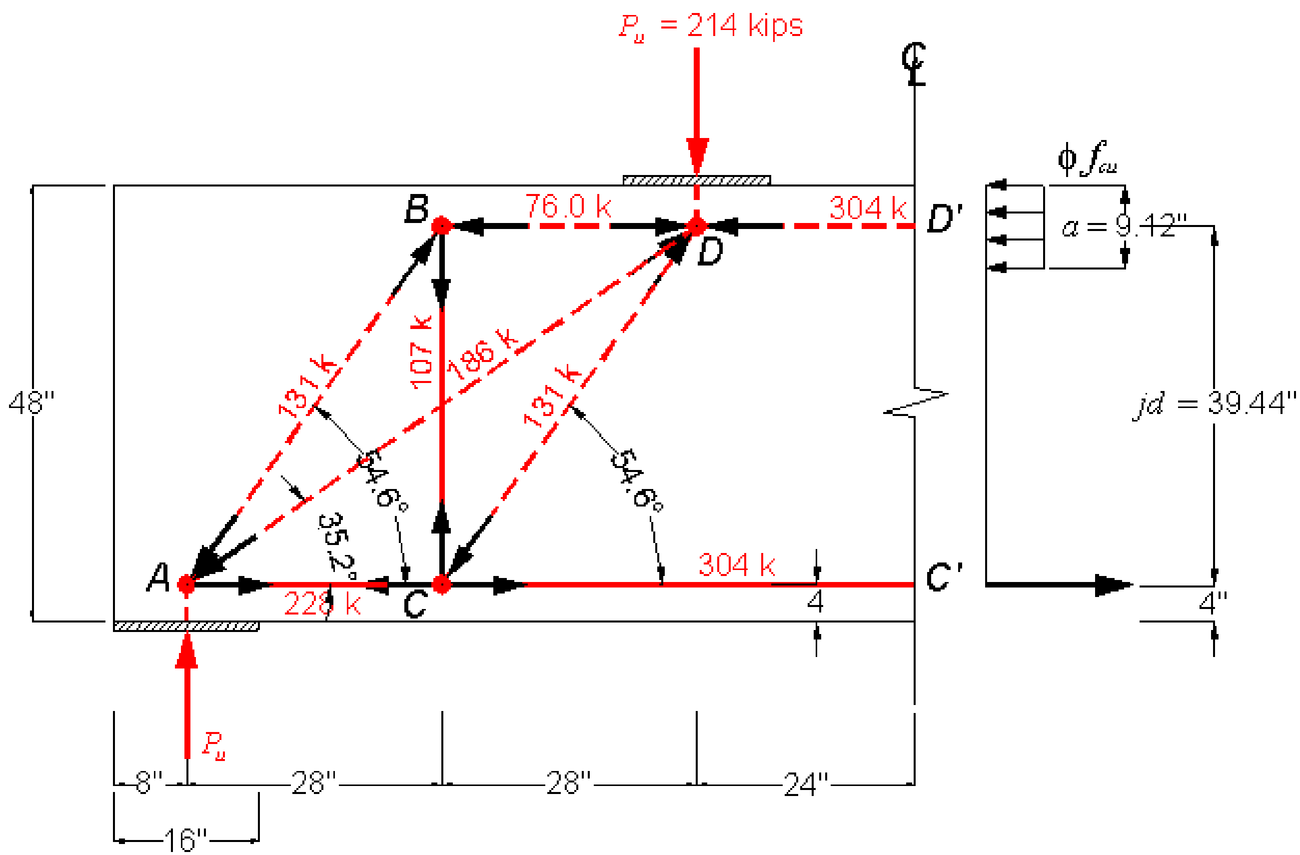
Strut and Tie Modeling



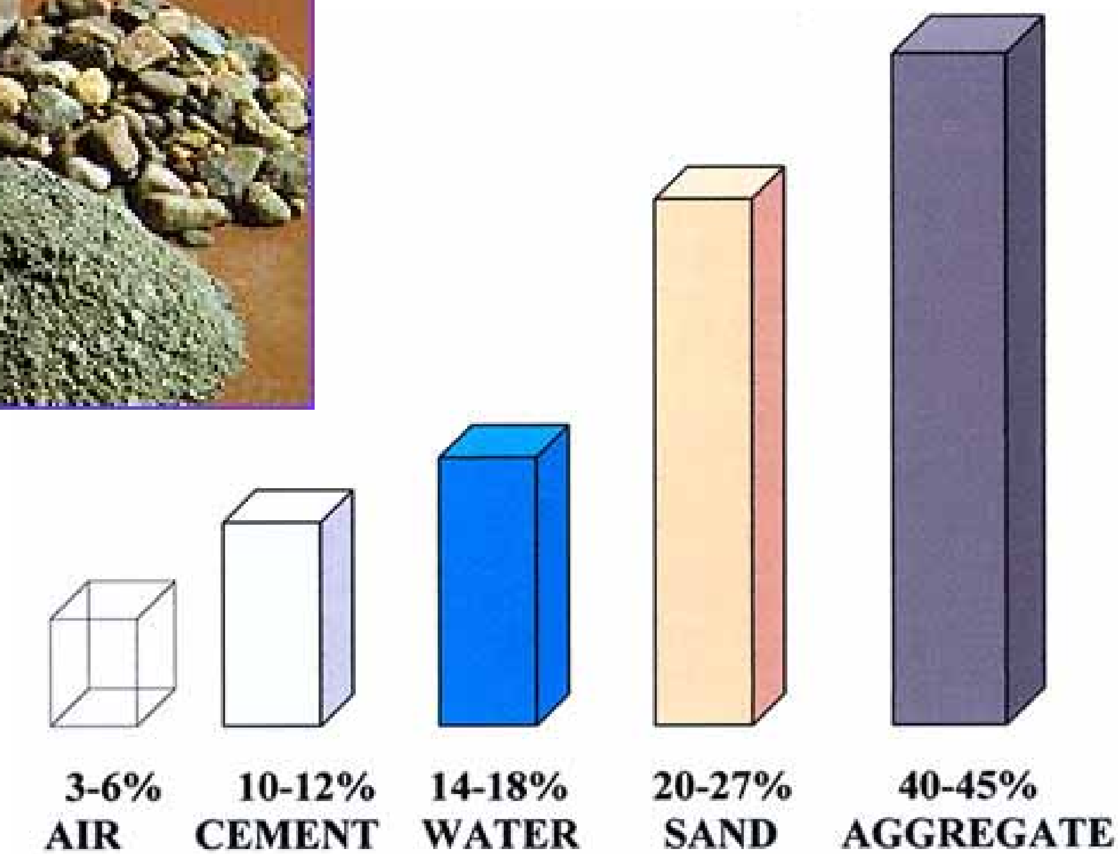
Strut and Tie Modeling



Strut and Tie Modeling



What is concrete?



Is concrete a green material?

Construction and the Environment

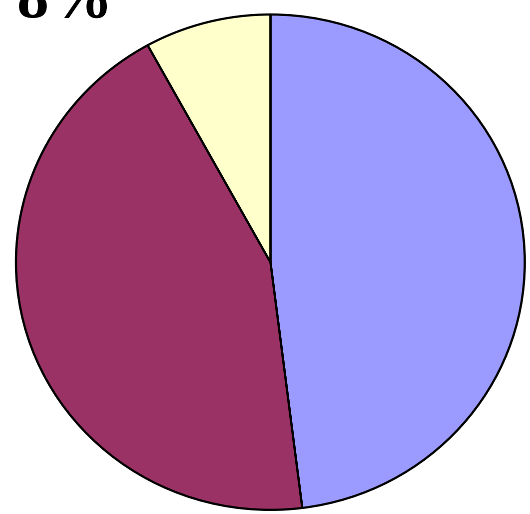
In the United States, buildings account for:

36% of total energy use
(65% of electricity consumption)
30% of greenhouse gas emissions
30% of raw materials use
30% of waste output (136 million tons/year)
12% of potable water consumption

-US Green Building Council (2001)

Construction Waste

- US Environmental Protection Agency (EPA) estimates that 136 million tons of waste is generated by construction each year
- Most results from demolition/renovation and nearly half the weight is concrete



Embodied Energy per Stiffness

Source: Biggs (1991)

Energy required for concrete

Component	Percent by weight	Energy %
Portland cement	12%	92%
Sand	34%	2%
Crushed stone	48%	6%
Water	6%	0%

Each ton of cement produces one ton of CO2

ENVIRONMENTAL COUNCIL of CONCRETE ORGANIZATIONS

- *Concrete is in tune with the environment. From an environmental standpoint, concrete has a lot to offer.*
- *The ingredients of concrete (water, aggregate, and cement) are abundant. Concrete can be made from local resources and processed near a jobsite.*
- *Concrete is an ideal medium for recycling waste or industrial byproducts. Many materials that would end up in landfills can be used instead to make concrete.*
- *Concrete is modest in its energy needs and generous in its payback. The only energy intensive demand is in the manufacture of portland cement, typically a 10-15% component of concrete.*
- *Concrete offers significant energy savings over the lifetime of a building or pavement. Concrete's high thermal mass moderates temperature swings by storing and releasing energy needed for heating and cooling. And concrete is a durable material that conserves resources by reducing maintenance and the need for reconstruction.*
- *A reliable and versatile product for centuries, concrete paves the way toward an environmentally secure future for successive generations.*

Corrosion of Reinforced Concrete

Reinforced Concrete Corrosion

Corrosion of RC

- **In the United States, the overall costs of reinforcing steel corrosion have been estimated at more than $150 billion per year.**
- **A particular problem for highway bridges due to de-icing salts**

Corrosion Prevention of RC

- Simplest method: Maintain concrete in compression and provide greater cover of concrete over rebar
- More complicated and more expensive:
  - Protect steel (with epoxy coating) or by using stainless steel rebar
  - Use non-metallic reinforcing, such as carbon or kevlar, but these materials are expensive and energy-intensive

Structural Design in RC

- Maintain concrete in compression as much as possible
- Follow moment diagram to minimize material use
- Detailed design
  - Prevent water infiltration
  - Protect steel
  - Specify use of fly ash
  - Recycle old concrete

"Fly Ash" in Concrete

- Fly ash is a byproduct of coal burning: 600 million tons are produced per year and over 80% goes to the landfill
- Up to 50% of cement (by volume) can be replaced with fly ash (15-35% is typical)
- Today only about 10% of available fly ash is used in concrete

Why use fly ash in concrete?

- Reduce environmental impact
- Improve workability (better finish)
- Increase corrosion resistance
- Improve long term concrete strength

Good practice in concrete design

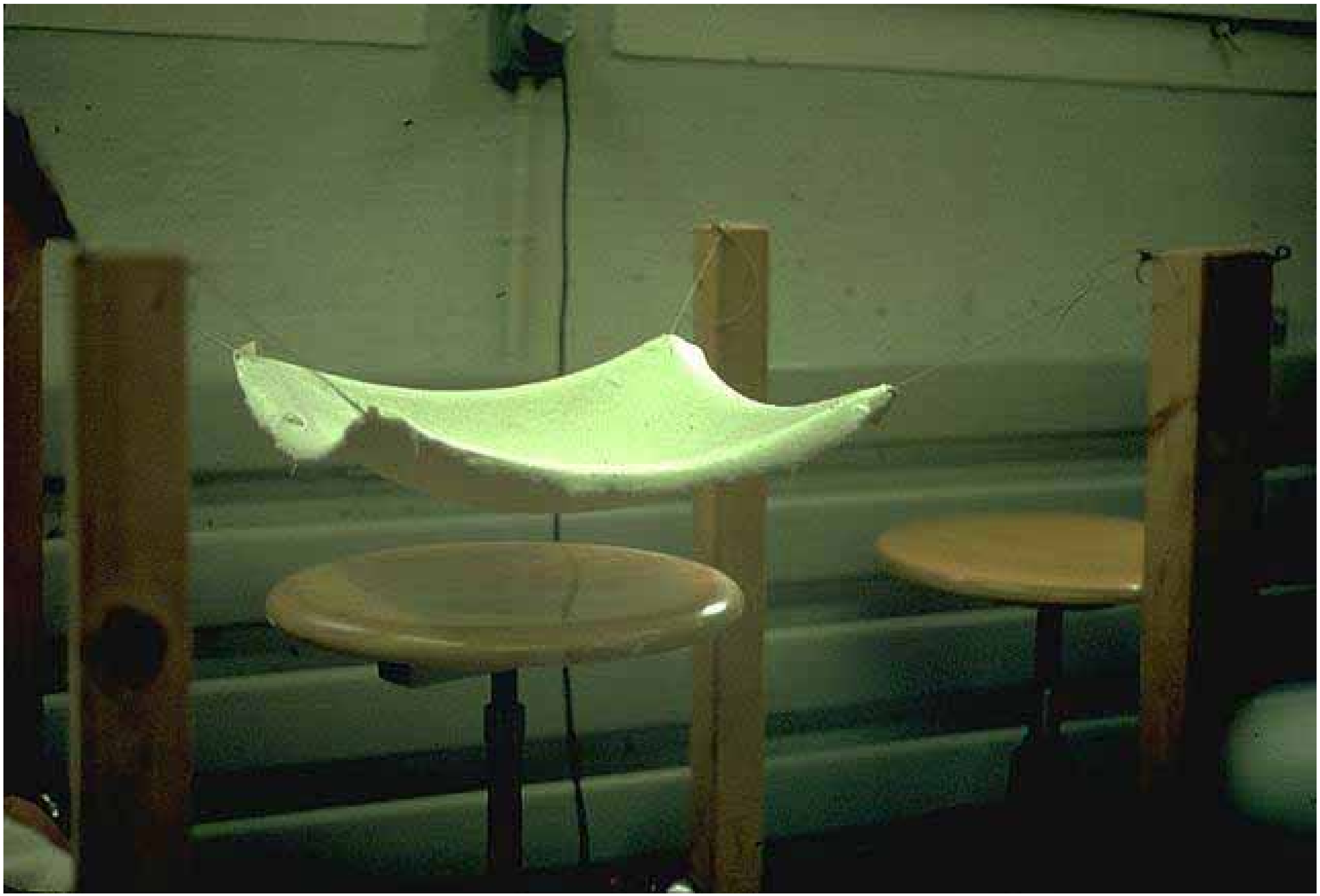
- Consider pre-cast concrete systems which can use considerably less concrete.
- Specify fly ash, which can improve workability and strength, as well as help to recycle waste.
- Use concrete waste as fill whenever possible around buildings or as aggregate under parking lots and driveways.
- Reduce waste through design by eliminating unnecessary concrete (i.e. use smaller transfer beams in the Stata Center)

Precast Planks in Concrete

Tilt-Up Concrete Construction

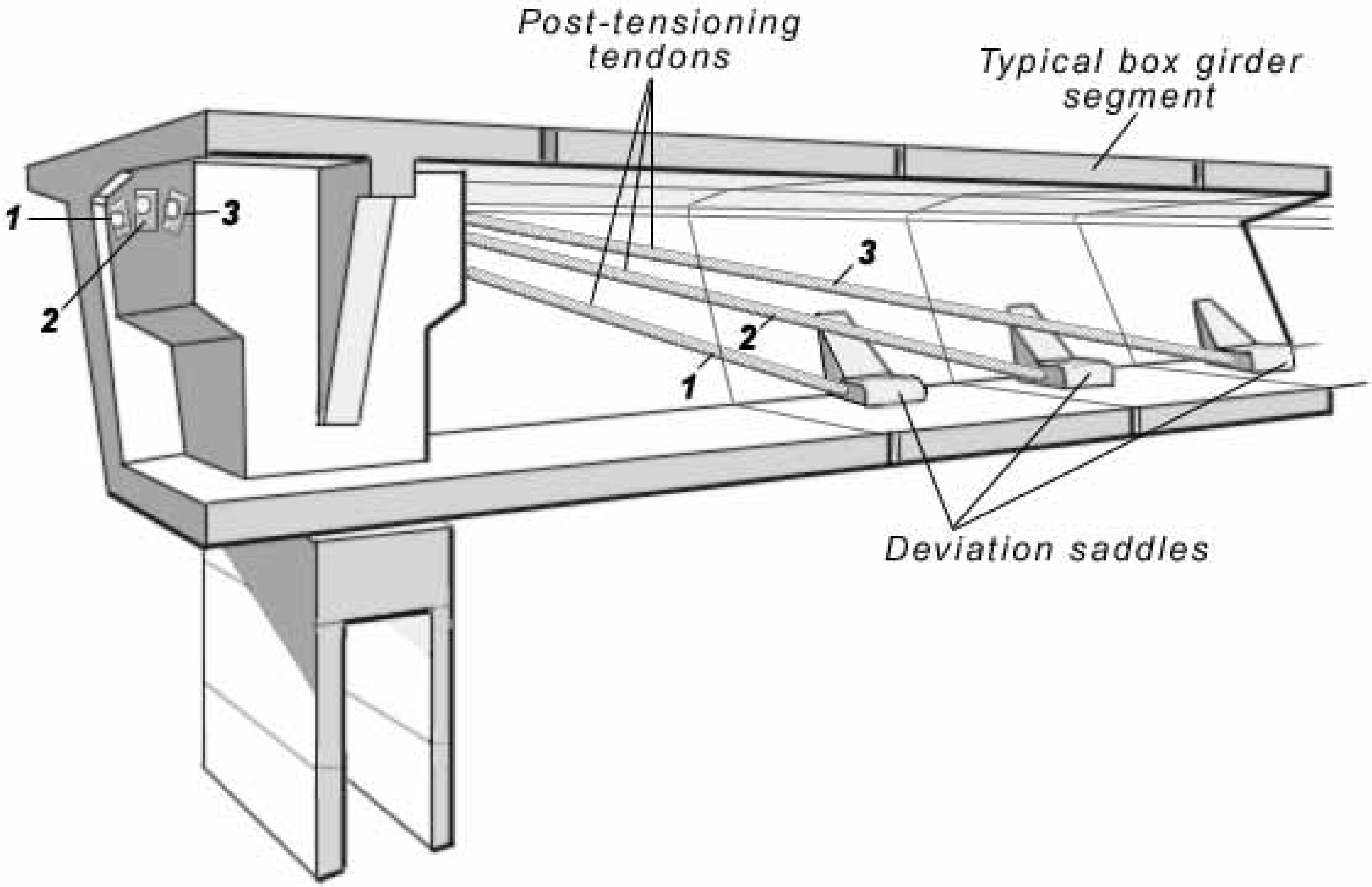
Hanging Model by Heinz Isler

Tension Model by Heinz Isler

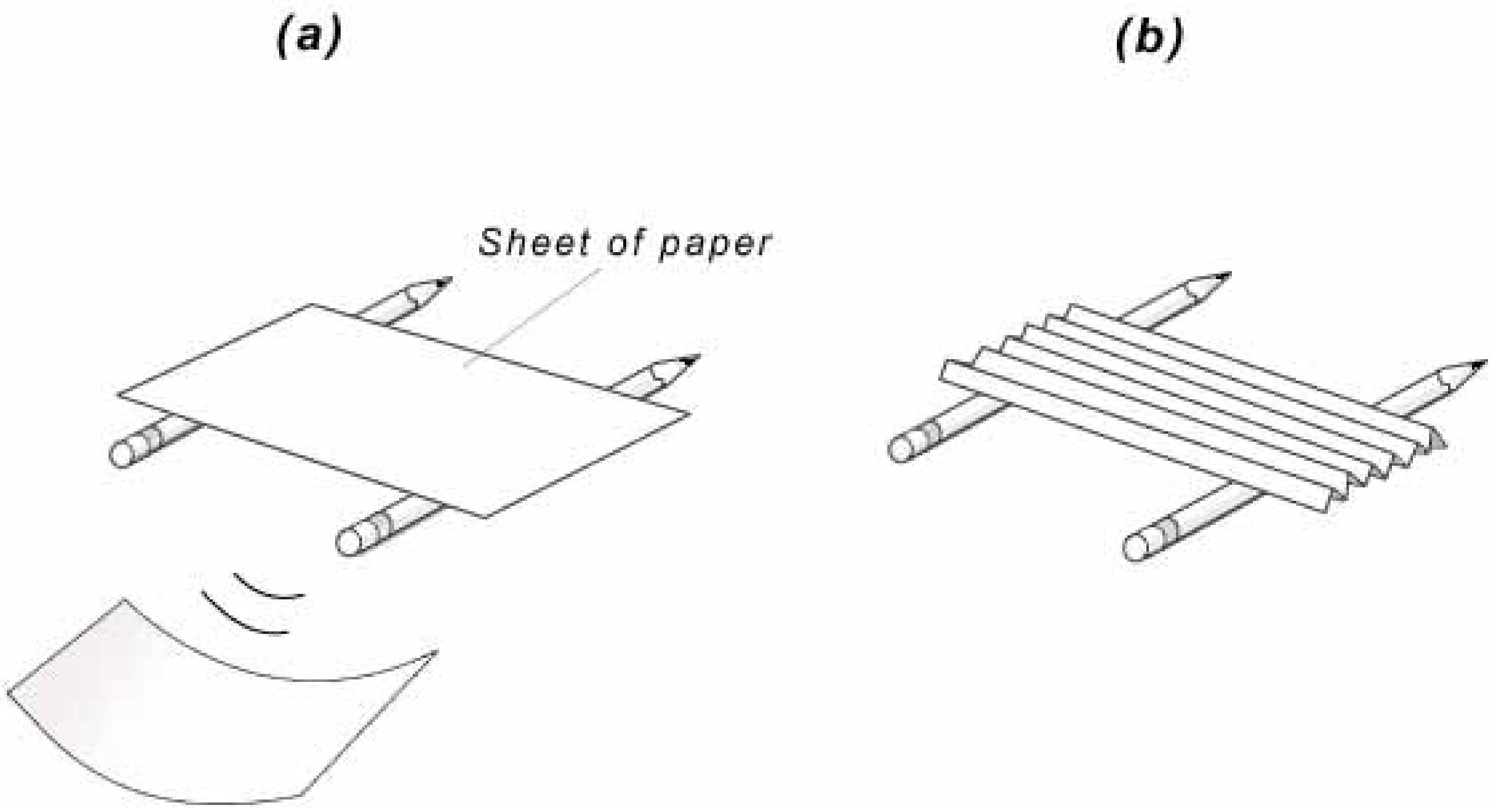


Compression Model by Heinz Isler

Post-tensioned Box Girder

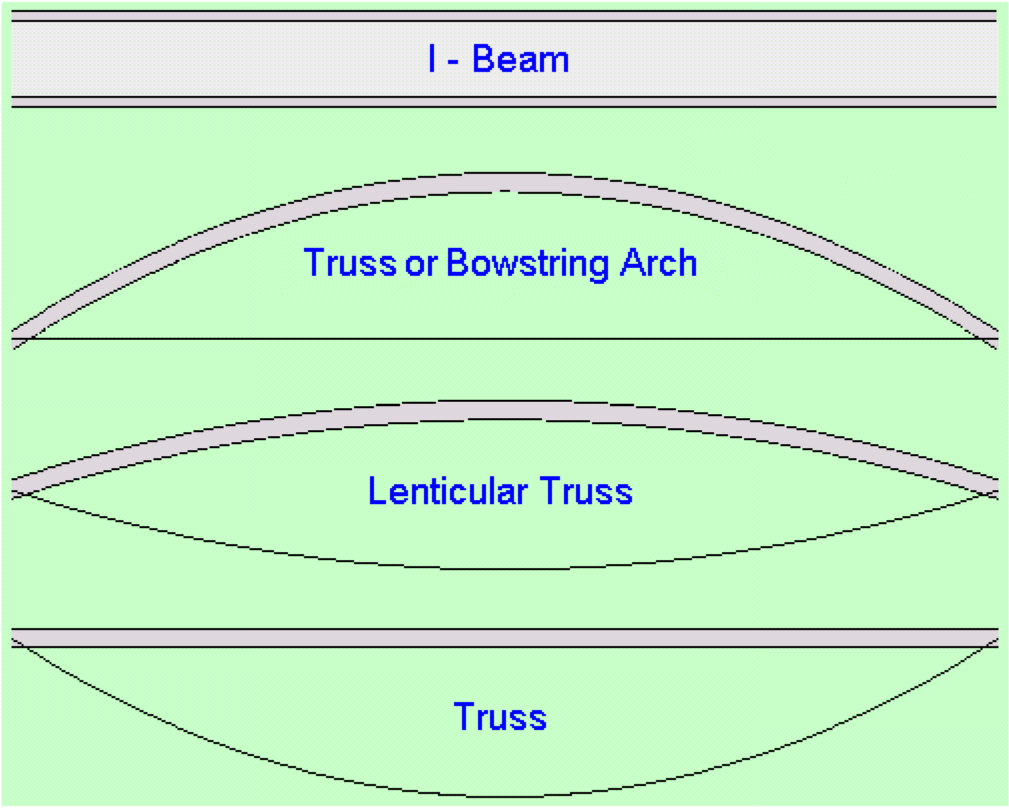


Greater Depth Gives Greater Stiffness

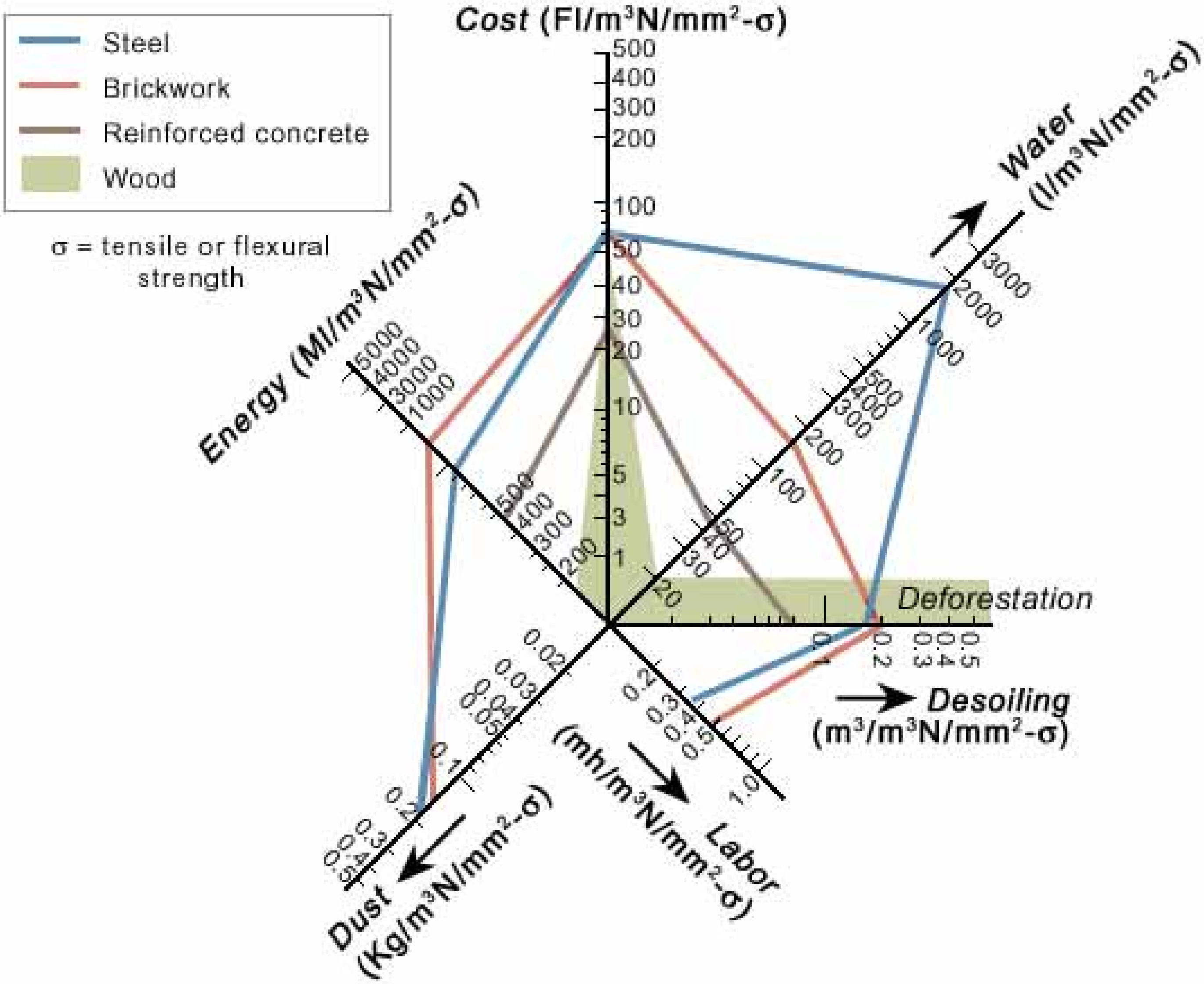


Conclusions

- **Concrete will continue to be a dominant construction material**
- **Reinforced concrete <u>must</u> 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**


I - Beam
Truss or Bowstring Arch
Lenticular Truss
Truss

Ecological Profile of Materials



Ecological profile of various material properties expressed per unit strength.

The Institution of Structural Engineering

Material Properties

	Stiffness MN/m2	Density kg/m3	Energy kJ/kg	Energy/stiffness	
Wood	11000	500	1170	53	22
Brick	30000	1800	2800	168	17
Concrete	27000	2400	8300	738	11
Steel	210000	7800	43000	1597	27
Al	70000	2700	238000	9180	26

Material Properties

	Stiffness ksi	Density lb/ft3
Wood	11000	30
Brick	3100	130
Concrete	3000	150
Steel	29000	490
Al	10000	170