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

Compression

Tension

\( \sigma_c \)

\( \sigma_t \)

Neutral Surface

F

\( F_c \)

\( F_t \)
Steel Reinforcing in Concrete

19th Century invention
Concrete must crack in order for the reinforcing steel to carry load
Reinforced vs. Prestressed Concrete

**Prestressed Concrete**

**Reinforced Concrete:**
- Compression
- Tension
- Hairline cracks under load
- Load + self-weight

**Prestressed Concrete:**
- No cracks, no tension
- Prestress
- Load + self-weight
- Final stress

**Advantages:**
- Reduces tension cracks
- Reduces deflection (by precast)
- Reduces depth (more efficient)

![Diagram comparing reinforced and prestressed concrete](image-url)
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

$P_u = 214$ kips

4' 4'

16'' 16''

12'' 12''
Strut and Tie Modeling

**Diagram Description:**
- **Struts (compression):**
  - Arrows pointing to the center from both ends.
  - Length: 12'
- **Tie (tension):**
  - Arrows pointing outward from the center.
  - Length: 16''
- **Load:**
  - $P_u = 214$ kips at both ends of the struts.

**Dimensions:**
- Width: 48''
- Length: 12'
Strut and Tie Modeling

\[ P_u = 214 \text{ kips} \]
Strut and Tie Modeling

$P_u = 214$ kips

$\phi f_{cu}$

$\alpha = 9.42''$

$jd = 39.44''$

48''

$228$ k

$46^\circ$

$35.2$

$131$ k

$104$ k

$131$ k

$54.6^\circ$

$76.0$ k

$304$ k

$4$

$16''$

28''

28''

24''
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)
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

<table>
<thead>
<tr>
<th>Component</th>
<th>Percent by weight</th>
<th>Energy %</th>
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</thead>
<tbody>
<tr>
<td>Portland cement</td>
<td>12%</td>
<td>92%</td>
</tr>
<tr>
<td>Sand</td>
<td>34%</td>
<td>2%</td>
</tr>
<tr>
<td>Crushed stone</td>
<td>48%</td>
<td>6%</td>
</tr>
<tr>
<td>Water</td>
<td>6%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Each ton of cement produces one ton of CO2
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

- Post-tensioning tendons
- Typical box girder segment
- Deviation saddles
Greater Depth Gives Greater Stiffness
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
Ecological Profile of Materials

- **Steel**
- **Brickwork**
- **Reinforced concrete**
- **Wood**

\[ \sigma = \text{tensile or flexural strength} \]

**Cost** (Fl/m³N/mm²-\( \sigma \))

**Energy** (MJ/m³N/mm²-\( \sigma \))

**Water** (m³/m³N/mm²-\( \sigma \))

**Deforestation**

**Desoiling** (m³/m³N/mm²-\( \sigma \))

**Labor** (hours/m³N/mm²-\( \sigma \))

**Dust** (Kg/m³N/mm²-\( \sigma \))

Ecological profile of various material properties expressed per unit strength.

*The Institution of Structural Engineering*
<table>
<thead>
<tr>
<th>Material</th>
<th>Stiffness MN/m²</th>
<th>Density kg/m³</th>
<th>Energy kJ/kg</th>
<th>Energy/stiffness</th>
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<tbody>
<tr>
<td>Wood</td>
<td>11000</td>
<td>500</td>
<td>1170</td>
<td>53</td>
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<tr>
<td>Brick</td>
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<tr>
<td>Concrete</td>
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<td>8300</td>
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<tr>
<td>Al</td>
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<td>238000</td>
<td>9180</td>
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# Material Properties

<table>
<thead>
<tr>
<th>Material</th>
<th>Stiffness ksi</th>
<th>Density lb/ft³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood</td>
<td>11000</td>
<td>30</td>
</tr>
<tr>
<td>Brick</td>
<td>3100</td>
<td>130</td>
</tr>
<tr>
<td>Concrete</td>
<td>3000</td>
<td>150</td>
</tr>
<tr>
<td>Steel</td>
<td>29000</td>
<td>490</td>
</tr>
<tr>
<td>Al</td>
<td>10000</td>
<td>170</td>
</tr>
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