Lecture 31, Nov 30, 2021

Concrete

- Concrete has the advantage of being able to be cast into any shape
- Cement is to concrete as flour is to cake: concrete is made of a combination of materials, including cement, water, sand, aggregate (rocks), and admixtures (additives to change the concrete's properties)
  - Cement is the expensive part, made of limestone, heated to remove carbon dioxide, and ground into a powder
  - Adding water to this basically gives you artificial stone
- Concrete can be made inexpensively and locally but produces a lot of carbon dioxide
- When concrete cures, it does not dry, instead it undergoes a chemical reaction that consumes the water and produces heat
- Concrete is either cast or placed, not poured; it is gently laid down so that the aggregate doesn't all sink to one place

Material Properties of Concrete

- Concrete exhibits linear elasticity in compression until about 40% of its ultimate compressive stress, and is fully linear elastic in tension until it fails by cracking
  - The full stress-strain curve in compression for concrete looks like a parabola
  - Stone usually does not have the curve (only concrete does)
  - The yield strain of steel and concrete are similar
- The notation for stresses in concrete are different, with f representing axial stresses and v representing shear stresses (instead of σ and τ)
- The compressive strength of concrete is denoted f_c'
  - Compressive strengths higher than 40MPa is high strength concrete (as opposed to normal strength); high strength concrete can have compressive strengths exceeding 100MPa
  - The prime denotes the testing method (size, age, machine, etc)
- Since performing tensile tests on stone-like materials is difficult, often cracking stresses are obtained using empirical equations that relate compressive strength to these quantities
- The tensile/cracking strength of concrete is related to its compressive strength by $f_t' = 0.33\sqrt{f_c'}$
  - Note that f_c' *must* be in MPa, because the square root means that 0.33 has dimensions
- For normal strength concrete, the Young's modulus relates to compressive strength by $E_c = 4730\sqrt{f_c'}$
  - Again f_c' must be in MPa
  - Note that even though 4730 seems precise it's actually not

Reinforcing Steel

- Reinforcing steel bars or *rebar* are bent and tied together to form cages to strengthen the concrete; concrete without steel is called plain concrete and concrete with steel is reinforced concrete
- Deformed bars have ribs on the bar to mechanically connect to the concrete (so the concrete grabs onto the bar)
  - This allows us to assume that the steel strain is equal to the concrete strain
- Rebar is made of mild steel with $E_s = 200000$MPa and a yield strength of $f_y = 400$MPa in both tension and compression (note: different countries have different standards; most other places use $f_y = 500$MPa)
- Rebar has standard sizes with designations; the bar number roughly refers to the diameter
  - The M in the names mean metric
- We assume that rebar has a flat yield plateau with no strain hardening because to get strain hardening requires strains that are not realistic

Reinforced Concrete

- Concrete reinforced with steel behaves similarly in compression but is much better in tension

- Once the concrete cracks, the steel carries the tension and it yields, making the material much more ductile and able to carry much more tension
  - The shape of the stress-strain response after cracking is complex
- More steel leads to more cracks, which distributes the tension more evenly across more narrow cracks instead of one big crack