Concrete

10 Things Every Structural Engineer Should Know

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01 Concrete is a significant contributor to climate change.

The concrete industry is responsible for approximately 7% of global greenhouse gas (GHG) emissions and 1.5% of domestic GHG emissions. Vast quantities of concrete are required to build and maintain our built environment. For many structural components, especially foundations, it is difficult to replicate its inherent benefits, including durability, stiffness, strength, and flexibility in placement.

02 Most of the emissions from concrete come from cement production.

Approximately 88% of the emissions from concrete are associated with cement production, with the remainder coming from the production of other constituent materials and transportation. Production of portland cement involves first manufacturing clinker from limestone and clay in a kiln heated to extremely high temperatures (>2500°F). The limestone undergoes a process called calcination that releases carbon dioxide as a byproduct . The resulting clinker is ground to a fine powder and mixed with other components to create different cement types. Approximately 50% of cement's GHG emissions come from "process emissions" associated with calcination of limestone, 40% from thermal (energy) emissions from burning fuel to heat the kiln, and 10% from other sources, such as transport of materials and the grinding processes.

03 Specifiers should allow all cement types to be utilized including ASTM C150, ASTM C595, and ASTM C1157.

Traditionally, cement has been synonymous with Ordinary Portland Cement (OPC) conforming to ASTM C150. As the industry targets reductions in GHG emissions, alternate cement types will become increasingly common. Portland-Limestone Cement (PLC) is one of these alternatives, specified as Type IL under ASTM C595. PLC introduces limestone to replace a portion of the clinker leading to an average of 8% reduction in GHG emissions compared to OPC. A ready-mix supplier will often switch from OPC to PLC all at once as they typically do not have infrastructure available (silos) for storing numerous cement types. In recent history, entire markets or states have made this change. ASTM C595 also contains specifications for blended cements containing pozzolans, slag, and ternary blends, which may become more widely available in the future. ASTM C1157 is a performance-based standard for hydraulic cement.

04 Aggregate, water, and admixtures are also important components of a concrete mix that can have a significant impact on embodied carbon.

Aggregate quality has a significant impact on the performance of a mix. High-quality aggregate reduces the amount of cement required to achieve a specified strength. Water-cement ratio is also a key variable to the performance of a mix, influencing the amount of cement required. ASTM C1602 does not require water to be potable; freshwater usage is a parallel sustainability issue along with GHG emissions. Admixtures allow mixes to use less water, use less than ideal aggregate, improve early strength gain, improve placement and finishing characteristics, and improve performance when utilizing new and innovative materials. Aggregate quality and availability is regionally dependent and some markets may import aggregate from other areas to improve mix performance.

05 Performance-based specifications support embodied carbon reductions.

Specifications should only dictate the required performance of the concrete without prescriptive requirements for materials and mixture proportions. Prescriptive specification requirements such as minimum cement contents, maximum supplementary cementitious material (SCM) contents, or maximum w/cm can lead to overdesigned mixes and restrict the concrete supplier's ability to reduce embodied carbon while still delivering a mixture that satisfies the required performance criteria. Global warming potential limits on a mixture or a project-wide basis are examples of performance criteria that will become increasingly common to specify along with traditional requirements for strength, shrinkage, and durability.

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06 Environmental Product Declarations (EPDs) quantify reductions and inform decisions.

The concrete industry is a leader in the development of EPDs. EPDs are becoming increasingly available from local suppliers for specific mix designs from specific batch plants. The NRMCA publishes industry-wide average EPDs, which are the industry standard for establishing baselines. NRMCA also has published regional data offering additional granularity when desired. Typical values of GHG emissions for concrete are between 250 and 400 kg-CO2e/CY.

07 One way to reduce embodied carbon is through specification of compressive strength (f'c).

On average, an increase in specified compressive strength is directly correlated with an increase in GHG emissions. Consider specifying f'c based on testing at 56 or even 90 days in lieu of 28 days. Be efficient with your choice of compressive strength in design; don't over specify and add additional mix types as appropriate. Improved data and quality control in the field and at the ready-mix plants can reduce the factor of safety in mix designs and allow for reductions in cement to achieve the specified strength.

08 Intelligent design that efficiently uses material can meaningfully reduce the embodied carbon of concrete construction.

Make designs more efficient by leveraging coordination and calculations. Get involved early in the design process to influence the building form and material selection. Be diligent through the design process. Design choices that have a significant impact on efficiency include transfers, podiums, below grade construction, foundation system selection, post-tensioned versus mildly reinforced slabs, utilization of drop caps, span lengths, and irregular column spacings. Structural engineers can and should help educate architects and owners about these issues

09 Supplementary cementitious materials (SCM) can play a big role in the embodied carbon reduction of concrete.

Replace cement and maintain performance. Fly ash has been historically available, cheaper than cement, and has a proven track record but the supply of fresh fly ash is expected to decline over time, and it is likely other SCMs will need to be implemented. Ground granulated blast furnace slag (GGBFS, or slag cement), raw natural pozzolans, and silica fume are other traditional options. Newer alternatives include calcined clays, harvested and/or beneficiated fly ash to supplement traditional sources, and ground bottom ash (ASTM C618 now utilizes the term "coal ash" to reflect a variety of ash sources), and ground glass pozzolans produced from post-consumer recycled glass. Many SCMs contribute to improved durability characteristics and later-age strength gain. Material availability varies regionally and it is best practice to talk with your local ready mix suppliers regarding material availability.

10 Innovations like carbon capture and novel SCMs are necessary to further reduce the embodied carbon footprint of the industry.

Significant reductions in GHG emissions will require innovation. Engineers are likely to see new systems and materials enter the market in the future including new structural systems, CO2 capture and sequestration technologies, novel SCMs, novel cements, and new admixtures. Collaboration and research will be required. Innovation can and will come from structural engineers, architects, concrete suppliers, contractors, and new players to the market.