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THE STATUS OF SUSTAINABLE CONCRETE CODES IN THE UNITED STATES

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Abstract.

As the focus on embodied carbon within the built environment has grown in the U.S., local jurisdictional codes have increasingly proposed and implemented code language that requires the use of concrete mixtures that have reduced environmental impacts. This paper provides details about the various ways that localized sustainable concrete provisions have been proposed and implemented in the U.S., including limits on cement content and Global Warming Potential (GWP). These laws and code revisions vary in their measurement of low-carbon concrete and their exemptions and incentives. While the current version of the ACI Building Code, ACI 318-19, does allow for the consideration of sustainability in concrete design, specifics about how the relative sustainability of concrete mixtures and systems are to be measured and compared are not included. This paper addresses how the changing landscape of local jurisdictional codes is driving the development of future ACI 318 provisions to play a part in providing more consistency in the application of sustainable design practices in the United States.

Keywords: Codes, concrete, sustainability.

1. Introduction

In the last decade engineers, architects, local and national government agencies, and national building code committees in the United States have started to evaluate and take measures to mitigate the environmental impacts of building construction and operations. As these efforts mature, new programs to encourage more sustainable design and operation of buildings, and new regulations that require the reduction of carbon emissions, have been established.

Regarding concrete structures, it is most common for new programs and regulations to focus on the carbon emissions associated with the initial construction of a building: atmospheric carbon released by the manufacturing of portland cement, by the mining and transportation of constituent materials, and by the construction process itself. Less often, consideration is given to the carbon emissions associated with the complete life-cycle of the building: the construction period; the operating life of the building; and the demolition and disposal or recycling of the building materials. When viewed in this broader life-cycle sense, the carbon emissions associated with portland cement manufacturing make up a smaller proportion of the total atmospheric carbon impact than when only the initial construction emissions are considered.

This paper describes the most recent programs and regulations implemented in the United States that promote the reduction of carbon emissions associated with concrete buildings. Programs and regulations that consider only the atmospheric carbon emissions related to initial construction, as well as one program that consider the impacts of the entire life cycle of the building, are summarized

2. Metric for global warming potential

The de facto international standard for assessing the global warming potential (GWP) of construction materials is the Environmental Product Declaration (EPD). An EPD is prepared in accordance with ISO 14025 [1], and each EPD provides a quantitative measure of GWP in terms of kilograms of CO_2 per cubic meter of material (kg CO_2e/m^3). An EPD is required for each variation of a construction material; thus a unique EPD is necessary for each concrete mixture that is incorporated into a building project for which a carbon emissions assessment is performed.

The existence of EPDs, and GWP ratings provides a consistent basis for evaluating the overall GWP of a project. EPDs and GWP ratings also enable government agencies and code-writing authorities to establish objective frameworks for quantifying the greenhouse gas (GHG) emissions associated with a particular building project, group of projects, type of construction, or regional or national construction activity.

The GWP of a particular concrete mixture depends on many factors, including portland cement content, supplementary cementitious materials content, coarse and fine aggregate sources, and the density of aggregates (normal weight vs. light weight aggregates). In general, the GWP of most concrete mixtures commonly produced in the United States varies between about 200 and 700 kg CO_2e/m^3

3. Organizations promoting reduced GWP of concrete

In the United States several organizations have emerged as leaders of the movement to reduce the environmental impacts of concrete. Generally, these are not-for-profit organizations, professional societies, or industry consortia. Four organizations that support a reduction in GWP of concrete are described below.

3.1. Carbon Leadership Forum

The Carbon Leadership Forum (CLF) is a not-for-profit forum operated within the College of Built Environments at the University of Washington, in Seattle. The CLF was founded in 2009 with the objective of developing and promoting quantitative and standardized measures of embodied carbon in construction materials. A primary focus of the CLF has been embodied carbon of construction materials, including the promotion of standardized and verified EPDs, which will allow valid comparisons between various materials and between various suppliers of a given material.

A major accomplishment of the CLF has been to foster development of computer software that provides a standardized method for calculating the embodied carbon in construction materials. This software was released on November 19, 2019 and is called the Embodied Carbon in Construction Calculator, or EC3. The EC3 software is available without charge. It relies on a database of over 19,000 EPDs from the United States and Canada. The vast majority of the EPDs in the database are for concrete mixtures; EPDs for other materials as well as additional EPDs for concrete are continuously added as they become available [2].

3.2. Structural Engineers 2050 Challenge

The Structural Engineers 2050 Challenge (SE 2050) was conceived in 2016 as a way to encourage the structural engineering profession to actively participate in a movement towards buildings with greatly reduced, or zero, net embodied carbon. Since structural engineers are responsible for the selection of structural materials, structural engineers are in the best position to implement structural materials with the lowest possible embodied carbon, and to report embodied carbon of individual projects to a centralized database. It is envisioned that such a database will be used to track annual total embodied carbon for buildings in the United States. Membership in the challenge is voluntary. As of this writing, signatories to the SE 2050 challenge include 19 structural engineering consulting companies, 62 individual structural engineers, and 32 other individuals or companies affiliated with the building design and construction industry.

3.3. Architecture 2030 Challenge

The non-profit group Architecture 2030 was founded in 2002 to address the need for reducing operating carbon emissions from the built environment. In 2006 Architecture 2030 launched the 2030 Challenge, which defines quantitative goals for reducing the greenhouse gas emissions associated with the ongoing operations of buildings. Emphasis is placed on reducing the consumption of energy generated by fossil fuels, with the goal of reducing operational greenhouse gas emissions of all new or renovated buildings to zero by 2030. "These targets may be met by implementing innovative sustainable design strategies, generating on-site renewable energy, and/or purchasing (20% maximum) off-site renewable energy." [3].

To support the Architecture 2030 Challenge, the American Institute of Architects (AIA) has created the "2030 Commitment." This is a program under which signatory design firms voluntarily report project data, in a standardized format, which quantifies the operational greenhouse gas emissions over the life of the building. Reported data is collected in a central database called the Design Data Exchange (DDx). The DDx can be searched using multiple project attributes (like building type, size, and environmental conditions) to help designers create buildings with reduced operational carbon emissions. Currently over 600 design firms have signed on to the 2030 Commitment, and each year project reports are added to the DDx for hundreds of millions of square meters floor area of new and renovated buildings.

3.4. The American Concrete Institute

In recent years the American Concrete Institute (ACI) has sought to address the challenge of reducing greenhouse gas emissions through a range of initiatives and publications. These include more than 40 standards and guides containing information on sustainability in concrete construction; over 60 journal articles related to sustainability; 200 practice-oriented papers and articles on sustainable design and construction methods; more than 100 online learning tools; and sponsorship or co-sponsorship of over 25 events that have supported the advancement of sustainability in concrete design and construction.

In 2008, the American Concrete Institute (ACI) initiated a focus on mitigating the environmental impacts of concrete with the formation of technical committee ACI 130 "Sustainability of Concrete." The committee currently has over 100 voting and associate members, and maintains eight subcommittees:

- Materials
- Production/Transportation/Construction
- Structures in Service
- Rating Systems/Sustainability Tools
- Design/Specifications/Codes/Regulations
- Education

Figure 1. Local government and state initiatives related to sustainability of construction materials.

- Climate Change Impacts on the Sustainability of Concrete
- Liaison Subcommittee

In 2019 Committee 130 published Report on the Role of Materials in Sustainable Concrete Construction [4] which provides comprehensive background on sustainability topics, and describes available practices for design, production, and construction that reduce the environmental impacts of concrete.

ACI formed Innovation Task Group 10 (ITG-10), which in 2019 published two important reports that provide guidance on the characteristics and implementation of alternative cements (i.e. alternatives to portland cement): Report on Alternative Cements [5], and Practitioner's Guide for Alternative Cements [6]. These reports present practical approaches to incorporating alternative cements in concrete mixtures, as a means of reducing greenhouse gas emissions caused by production of portland cement.

It should be noted that in the 2019 edition of the ACI 318 Building Code [7], Section 26.4.1.1.1 was added with the intention of providing increased flexibility to engineers and contractors for incorporating alternative cements in concrete construction: "Alternative cements shall be permitted if approved by the licensed design professional and the building official. Approval shall be based upon test data documenting that the proposed concrete mixture made with the alternative cement meets the performance requirements for the application including structural, fire, and durability."

In order to further develop sustainability provisions in the ACI 318 Code, in 2019 a new technical subcommittee of the building code committee was established: Subcommittee N, "Sustainability." This new subcommittee is currently working on revisions to the 2025 edition of the ACI 318 Code, including an appendix with expanded provisions regarding sustainability.

4. Local and state initiatives to quantify and reduce GWP of concrete

In the United States within the last two years several local and state government initiatives have been either proposed or enacted to reduce the environmental impacts of concrete construction. These initiatives are identified in Figure 1. In addition, the author is aware of preliminary discussions within other jurisdictions that may lead to further concrete sustainability initiatives, but it is still too early to report on the details of those efforts. For example, the Marin County Ordinance (Figure 1, and section 4.3) is likely to serve as a model ordinance for adoption by other San Francisco Bay area governments.

4.1. The Buy Clean Washington Act

On January 8, 2018 a proposal was introduced to the Washington State House of Representatives, House Bill 2412, titled the "Buy Clean Washington Act." [7] This proposed legislation recognizes that "Climate change will have devastating global impacts," and that "All scientific evidence points to the need for Washington and the world to reduce greenhouse gas emissions to avert the worst effects of climate change." To reduce greenhouse gas emissions, the legislation proposes "Incorporating emissions information from throughout the supply chain and product life cycle into procurement decisions, and using that information to help direct expenditure." In other words, if adopted, the legislation would make global warming potential a key factor in the selection of construction materials and suppliers in Washington State.

This act would apply to new construction with a floor area greater than 500 square meters and a building renovations greater than 500 square meters where

the cost of the renovation is greater than 50 percent of the value of the building. The list of construction materials that this act would apply to includes

- Carbon steel concrete reinforcing bars
- Flat glass
- Mineral wool board insulation
- Structural steel
- Cement
- Structural timber
- Solar panels
- Refrigerants in new equipment
- Aluminum
- Gypsum
- Concrete

The proposed legislation was not adopted during the 2018 Washington State legislative session, but it is likely the proposal will be re-introduced in 2020.

4.2. City of Portland Ordinance

The City of Portland, in the state of Oregon, enacted an ordinance in January 2020 that is intended to be the starting point of regulations to limit the greenhouse gas emissions of concrete purchased by the city. At this time the ordinance requires reporting of a product-specific Type III Environmental Product Declaration that is verified by a third party and is less than 5 years old for every concrete mixture supplied for city-funded projects.

The ordinance does not, however, currently set limits on embodied carbon or global warming potential of concrete. Such limits will be published by the city by April 1, 2021, when the city will issue limits on the maximum global warming potential of any concrete mixtures on city-funded projects. The ordinance does not apply to small projects that require less than 38 cubic meters of concrete.

4.3. Marin County Ordinance

One of the most significant recent developments in regulatory rules regarding the global warming potential of cement and concrete is the enactment of an ordinance in Marin County, California. This ordinance, titled "Low Carbon Concrete Requirements," forms Section 19.07 of the Marin County Code [9]. It was adopted in November, 2019. In establishing the rationale for implementing this ordinance, the county Board of Supervisors stated, "... Marin County experiences climatic seasonal reduction in vegetative moisture content, combined with our heavily populated steep terrain, which presents increased wildfire risk to our residents from carbon-induced global warming; and is also bordered by sea water on three sides and subject to direct adverse local impact from sea-level rise as the result of construction related contributions to climate change, including significant carbon emissions from cement production."

To accomplish the goal of reducing greenhouse gas emissions by controlling embodied carbon in concrete, Marin County has taken the approach of providing two alternatives: all concrete used in Marin County must either meet maximum limits on cement content, or it must meet maximum limits on embodied carbon. These limits are dependent on the minimum specified compressive concrete strength (f'_c). Table 1 below is adapted from Table 19.07.050 of the Marin County ordinance [9].

An exception to the limits in Table 1 is permitted for concrete that must attain a high early strength, such as concrete used in precast or pre-stressed construction, concrete used in above-ground beams and slabs, and pneumatically placed concrete (shotcrete). In those cases the values in Table 1 may be exceeded by 30 percent. Another exception is allowed to the limits in Table 1 if a pre-approved cement is used that has an environmental product declaration with embodied carbon less than 1,040 kg CO_2e per metric ton.

The Marin County regulations permit compliance with the Table 1 limits on the basis of either a) the concrete mixture design, or b) based on the total volume of concrete used in the project. The latter method provides a way to use a variety of concrete mixtures on a project, some of which may not meet the Table 1 limits, provided the total cement usage or the total embodied carbon of concrete used on the project does not exceed the hypothetical total cement usage or the total embodied carbon of concrete calculated based on the actual volume of materials and the upper limits of Table 1.

The regulations define a "Hardship or Infeasibility Exemption" which may be invoked if a) there is a lack of commercially available material necessary to comply with the regulations; b) the cost of complying with the regulations is disproportionate to the overall cost of the project; or c) compliance with the regulations would impair the integrity of a recognized historic building.

Since passage of the Marin County ordinance, there has been considerable interest from other county and city governments in considering similar regulations, particularly in the state of California.

4.4. The Buy Clean California Act

The California state legislature passed the "Buy Clean California Act" in 2017 [10]. This legislation requires that, for state-funded projects, information about the global warming potential of the materials used in the project must be reported. The Act also mandates that embodied carbon of construction materials must be considered as one of the decision factors when selecting materials, contractors and materials suppliers.

Minimum specified concrete strength f'^{a}_{c} [MPa]	Maximum ordinary portland cement content[b] [kg/m^3]	Maximum embodied carbon, from EPD [kg (CO_2e) /m^3]
≤ 17.2	215	260
20.7	243	289
27.6	271	313
34.4	298	338
41.3	315	356
48.2	352	394
> 48.2	390	433
≤ 20.7 light weight	304	578
27.6 light weight	339	626
34.4 light weight	373	675

[a] For concrete strength between the stated values, use linear interpolation to determine cement and/or embodied carbon limits.
[b] Portland cement of any type meeting the requirements of ASTM C150 [8].

Table 1. Marin County cement and embodied carbon limits.

Certain construction materials are addressed by the Act, but at this time cement and concrete are not among them. Steel reinforcing bars are currently covered by the Act, and it is reasonable to expect that cement and concrete will eventually be included. Any construction material that is listed under the Act is assigned an upper limit on global warming potential; subsequently, when that material is purchased by the State a version of that material must be supplied that meets the global warming potential limit. Because the State of California has a large economic and political influence in the western United States, it is likely that other western states will consider adopting similar "Buy Clean" rules for state-funded construction projects.

4.5. New York State Legislation

On September 12, 2019, a proposal was introduced to the New York State legislature that would require the use of concrete with low embodied carbon on New York State projects (i.e. all state funded projects that incorporate concrete as a construction material). This legislation would also promote the use of concrete that implements CO_2 capture technologies. In addition, the proposal introduced a tax credit system that would promote the preparation of EPDs by allowing concrete suppliers to deduct the cost of preparing EPDs from their tax bill.

Although this proposed legislation was not adopted, a revised version will likely be re-introduced to the New York State legislature in the near future.

5. Discussion

Given the recent surge of interest in the global warming potential of construction materials in general, and cement and concrete in particular, it is incumbent upon codes and standards writing organizations to develop frameworks for quantifying and reporting the global warming potential of construction projects. Because each construction material is unique in terms of its manufacture, transport, and implementation, it naturally falls upon the professional and industrial organizations related to each material to develop such guidelines.

Complementary to the work of professional and industrial organizations to understand the global warming potential of specific construction materials, there is the work of local, state, and national government organizations to develop guidelines and regulations that will lead to reductions in greenhouse gas emissions. These government agencies must balance the technical, economic, and political factors that influence the creation of environmental policies. It is the job of structural and materials engineers to ensure that government agencies have the technical data and analytical tools necessary to make informed decisions about the environmental impacts of construction materials. This is why the American Concrete Institute has embarked on a multi-faceted program to study, quantify, and develop engineering solutions that will reduce the environmental impacts of cement and concrete. Section 3.4 above describes ACI's current activities in this area.

6. Conclusions

This paper provides an overview of current activities in the United States related to building codes and regulations governing the environmental impacts of cement and concrete. This is a societal issue that is evolving rapidly, not only in the United States, but worldwide. Some of the pending regulations described in this paper may soon be enacted into law, and other new initiatives will soon be introduced in local, state, and national jurisdictions. In an effort to support this trend towards improved control of greenhouse gas emissions, various groups in the United States are developing metrics for quantifying

the global warming potential of construction materials. This presents an opportunity for technical organizations in the United States, such as the American Concrete Institute, to provide leadership in matters related to quantifying and reporting the global warming potential of cement and concrete.

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