IN-LB Inch-Pound Units

Low-Carbon Concrete—Code Requirements and Commentary

Reported by ACI Committee 323

ACI CODE-323-24

American Concrete Institute
Always advancing

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Low-Carbon Concrete—Code Requirements and Commentary

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ACI CODE-323-24

Low-Carbon Concrete—Code Requirements and Commentary

An ACI Standard

Reported by ACI Committee 323

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"Low-Carbon Concrete—Code Requirements and Commentary" ("Code") provides provisions for concrete where reduced global warming potential (GWP) is required. The Code was developed by a consensus process and addresses cast-in-place concrete with specified compressive strength greater than 2500 psi and less than or equal to 8000 psi. Precast concrete, tremie concrete, auger-cast concrete/grout, shotcrete, pavers, and masonry units are not included in the scope of the Code. This is the first edition of the Code and the scope is limited by the available benchmark data. Future editions of the Code will be broader in scope as data beyond strength benchmarks and for other types of concrete becomes available.

The Code may be adopted as a stand-alone code or can be used in combination with a structural design code or low-carbon material code adopted by an authority having jurisdiction. The Code is in a format that allows reference to a set of chapters based on the structure type. Adoption would include all of Chapters 1 to 4, the applicable Chapter(s) of 5, 6, 7, and/or 8, plus Appendix A. This Code is written in a format that allows reference without change to its language. Therefore, background details or suggestions for carrying out the requirements or intent of the Code provisions cannot be included with the Code itself. The Commentary is provided for this purpose.

Some considerations of the committee in developing the Code are discussed in the Commentary along with references for the user desiring to study individual questions in greater detail.

Keywords: baseline; benchmark; bridge; building; compressive strength; concrete; cradle-to-gate; environmental product declaration (EPD); environment; global warming potential (GWP); hardscape; life cycle assessment (LCA); low-carbon concrete (LCC); low-embodied carbon concrete; pavement; performance requirement; residential; sustainability; sustainable; structure.

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CODE

CHAPTER 1—GENERAL

1.1—Scope of ACI CODE-323

1.1.1 This Code shall apply to cast-in-place concrete structures as:

1. A reference in a building or structural design code.
2. A reference in a design and construction standard, rule, or regulation.
3. A reference in a sustainable construction code.
4. A reference in a code, standard, rule, or regulation governing the global warming potential (GWP) of materials,
5. A reference in construction documents, or
6. A stand-alone code governing the GWP of concrete.

1.1.2 The provisions of this Code shall be in addition to those of the governing building or structural design code, standard, rule, or regulation.

1.1.3 The provisions of this Code shall not be deemed to supersede any provisions of local, state, or federal law.

1.2—General

1.2.1 ACI CODE-323, "Low-Carbon Concrete—Code Requirements and Commentary," is hereafter referred to as "this Code."

1.2.2 The official version of this Code is the English language version, using inch-pound units, published by the American Concrete Institute, except for GWP values expressed as kg CO_2e.

1.3—Purpose

1.3.1 The purpose of this Code is to provide requirements for limiting the maximum GWP of concrete on a project.

1.3.2 This Code does not provide for public health, safety, and general welfare.

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CHAPTER R1—GENERAL

R1.1—Scope of ACI CODE-323

R1.1.1 The Code includes provisions for low-carbon structural concrete governed by a building code, bridge code, or other infrastructure code that governs the use of concrete. Throughout the Code, the term "structure" means a building, non-building structure, member, system, or element, if the construction includes concrete. Pavements are considered structures for purposes of the Code.

Chapters 1 through 4 of the Code apply to all structure types. Chapters 5 through 8 of the Code include requirements by structure type.

Refer to Chapter 2 for definitions of global warming potential (GWP), structural concrete, and low-carbon concrete.

R1.1.2 The Code is used in addition to building or structural design code requirements.

The regional nature of concrete as a material requires that data used for benchmarking also be regional. The requirements of the Code permit the use of values collected for eight regions of the contiguous United States and published in *Appendix C: NRMCA Member National and Regional LCA Benchmark (Industry Average) Report – V 3.2* (Athena Sustainable Materials Institute 2022).

The overall concept of the Code can be followed with the use of locally developed benchmark values within or outside of the United States.

R1.2—General

R1.2.2 GWP values in the Code are provided in kg CO_2e (kilograms carbon dioxide equivalents) per yd^3. Kilograms are the worldwide accepted units for CO_2e emissions and are the traditional unit used in EPDs and LCAs. For this reason, they are maintained in this inch-pound unit version of the Code. Benchmark data referenced in the Code also use kg CO_2e for GWP.

R1.3—Purpose

R1.3.1 The Code is intended to provide additional requirements to a building or structural design code. The licensed design professional (refer to Chapter 2 for definition) may specify project requirements that exceed the minimum requirements of the Code.

R1.3.2 While the immediate concerns of public health and safety provided by a building or structural design code are not the intent of the Code, the reduction of greenhouse gas

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1.3.3 This Code does not address strength, stability, serviceability, durability, and integrity of concrete structures. This Code shall not supersede specified requirements forstrength, stability, serviceability, durability, or integrity of the concrete structure.

1.3.4 This Code does not address construction means and methods.

1.4—Applicability

1.4.1 This Code shall apply where reduced GWP is required for concrete structures.

1.4.2 Provisions of this Code shall be permitted to be used for repair, alterations, and additions to existing structures.

1.4.3 This Code shall not apply to precast concrete, tremie concrete, auger-cast concrete/grout, shotcrete, pavers, masonry units, or concrete with specified compressive strength less than or equal to 2500 psi or greater than 8000 psi.

1.4.4 The authority having jurisdiction or entity adopting this Code shall be permitted to limit or exclude GWP requirements of the Code if it determines the requirements in Chapters 5 through 8 are not feasible for a project.

1.4.5 The licensed design professional shall be permitted to specify more stringent requirements than those provided in this Code.

1.5—Administration

1.5.1 Where referenced in a code adopted by the authority having jurisdiction, the provisions of this Code shall not

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emissions contributes to the long-term health of the planet and the health of its occupants.

R.1.3.3 In many cases, concrete mixtures that are proportioned for performance may result in a reduction in the concrete's GWP. Collaboration between the parties involved can often aid in the development of a lower GWP solution that meets or exceeds all other performance requirements.

R1.4—Applicability

R1.4.1 The Code provides minimum requirements to reduce greenhouse gas emissions from manufacturing concrete mixtures. The user is encouraged to exceed the minimum requirements to further reduce greenhouse gas emissions from concrete mixtures as well as to examine methods to reduce emissions in other aspects of the life cycle of a structure.

R1.4.2 Specific provisions for assessment, repair, and rehabilitation of existing concrete structures are provided in ACI CODE-562. Existing structures in ACI CODE-562 are defined as structures that are complete and permitted for use.

When a structure can be reused, repaired, or rehabilitated rather than entirely replaced, greenhouse gas emissions will be significantly reduced compared to new construction (Hasik et al. 2019; Padget and Tapia 2013; Meryman et al. 2013).

The Code is intended to apply to new concrete that meets the provisions of 1.4.3, including concrete used for additions to existing structures.

R1.4.3 The scope is limited in the first edition of the Code due to available benchmark data. As noted in 1.4.5, the licensed design professional may specify requirements beyond those listed in the code, thus GWP limits for the applications listed in 1.4.3, or concrete specified by flexural strength, could be made if data are available.

R1.4.4 The reasons for limiting or excluding the requirements of the code should be listed with detail provided to demonstrate what exceptions, if any, should be made.

For instance, in some regions, concrete suppliers and materials may be limited. This may restrict the feasibility of meeting all project requirements along with GWP requirements.

R1.5—Administration

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supersede the provisions of the code adopted by the authority having jurisdiction.

1.5.2 Where referenced in a standard, rule, or regulation, the provisions of this Code shall not supersede the provisions of such standards, rules, or regulations.

1.5.3 If the provisions in this Code conflict with requirements of standards referenced within this Code, this Code shall govern.

1.5.4 Alternative materials, design, and construction shall be permitted in accordance with the governing building or structural design code or by the authority having jurisdiction.

1.6—Construction documents and design records

1.6.1 The licensed design professional shall provide in construction documents the information necessary to satisfy the requirements of this Code and that required by the authority having jurisdiction.

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R1.5.4 Materials and methods are evolving quickly in low-carbon concrete construction, but materials used in concrete mixtures must follow the acceptance provisions in the governing design code or specification.

If the structural code adopted by the authority having jurisdiction includes provisions for approval of alternative materials, those provisions may be used for review of materials used to reduce the GWP of concrete mixtures. Typically, the approval process requires the evaluation to be completed by an approved agency, and the material properties and use requirements be summarized in a written evaluation report. This process is intended to allow for use of new materials and classes of materials that do not have approved design standards or material specifications. Recommendations for concrete properties to be evaluated are discussed in Holland and Hover (2020), Becker et al. (2019), ACI ITG-10R, and ACI ITG-10.1R.

R1.6—Construction documents and design records

R1.6.1 Low-carbon concrete can often be achieved without sacrificing the strength, safety, and serviceability requirements that are paramount in concrete structural design. Mixture design optimization can enable the production of concrete that meets performance requirements with lower GWP material choices. The LDP should develop project specifications to accommodate the requirements for safety, strength, serviceability, durability, and constructability while also lowering total GWP of the concrete. Recommendations for constructability items to consider when reducing GWP of the concrete are discussed in Kammer et al. (2023).

For instance, specifications requiring minimum cementitious material contents, the exclusion or limitation of supplementary cementitious materials, and mixture requirements of 1200 psi overdesign, will reduce the flexibility needed by the concrete supplier to meet specified GWP limits. Recommendations for improving specifications for low-carbon concrete are discussed in NRMCA (2021). The impact of overdesign is discussed in Buffenbarger et al. (2023).

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CHAPTER 2—NOTATION AND TERMINOLOGY

2.1—Scope

2.1.1 This chapter defines notation and terminology used in this Code.

2.2—Notation

f_c' = specified compressive strength of concrete, psi

$GWP_{benchmark\ avg}$ = weighted average benchmark GWP for concrete used on the project, kg CO_2e/yd^3

$GWP_{benchmark\ i}$ = benchmark GWP for class of concrete, i, kg CO_2e/yd^3

$GWP_{project\ avg}$ = weighted average project GWP for the concrete mixtures used on a project, kg CO_2e/yd^3

$GWP_{project\ i}$ = project GWP for class of concrete, i, kg CO_2e/yd^3

n = number of concrete classes proposed for use on the project

Vol_i = volume of concrete for class of concrete, i, yd^3

α = GWP reduction factor

2.3—Terminology

class of concrete—characterization of concrete of various qualities or usages, usually by compressive strength.

cradle-to-gate—corresponding to life cycle modules A1 through A3 according to ISO 21930.

environmental product declaration (EPD)—declaration providing environmental data using predetermined parameters meeting the requirements of ISO 21930.

global warming potential (GWP)—index used to determine the energy absorption caused by the emissions of different gases associated with a product, normalized to an equivalent mass of carbon dioxide over a period of 100 years.

gross floor area—the floor area within the inside perimeter of the exterior walls of the building under consideration.

independent third-party verified—an assessment and confirmation of the validity of a written claim by a person not under the control or influence of the claim. The person shall be knowledgeable in the area of the claim.

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CHAPTER R2—NOTATION AND TERMINOLOGY

R2.3—Terminology

class of concrete—The class of concrete is based on the strength and use in a given project. Although compressive strength is specified for most applications, pavement specifications may specify flexural strength.

global warming potential (GWP)—The estimation of GWP uses factors that can be applied to greenhouse gases to compare the global warming potential of different gases. Specifically, these factors are applied to reflect the energy absorption caused by the emissions of various gases that contribute to global warming, normalized to the emissions of CO_2e. A larger GWP factor for a gas indicates greater warming potential relative to CO_2e. GWP factors are most commonly taken over a period over 100 years but can be examined for other time periods. While GWP is not synonymous with greenhouse gas (GHG) emissions, "GWP" is used as an impact category in EPDs to reflect the GHG emissions associated with a given product. In the Code, the term "GWP" is consistent with its use in EPDs.

independent third-party verified—The independence and competencies of verifiers is detailed in ISO 14025.

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licensed design professional (LDP)—(1) an engineer or architect who is licensed to practice structural design as defined by the statutory requirements of the professional licensing laws of the state or jurisdiction; (2) the architect or engineer, licensed as described, who is responsible for the structural design of a particular project (also historically known as the engineer of record).

life cycle assessment (LCA)—compilation and evaluation of the inputs, outputs, and potential environmental impacts of a product throughout its life cycle.

low-carbon concrete (LCC)—concrete designed with reduced cradle-to-gate global warming potential compared to a benchmark and Tier 1 requirements of this Code.

product category rule (PCR)—set of specific rules, requirements, and guidelines for developing EPDs for one or more product categories.

project—a contiguous construction project.

structural concrete—concrete used for structural purposes, including plain and reinforced concrete.

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licensed design professional (LDP)—The LDP may also be referred to as "registered design professional" in other documents; a licensed design professional in responsible charge of the design work is often referred to as the "engineer of record" (EOR).

life cycle assessment (LCA)—An LCA is a systematic process of quantifying environmental impacts of a product. There are standardized methods of assessment, which include defining the scope of analysis, compilation of inputs and outputs to the system being analyzed, application of factors (such as GWPs) to facilitate assessment of potential environmental impacts, and interpretation. Assessments are commonly performed for cradle-to-gate, gate-to-gate, and cradle-to-grave life cycle stages of products. In the Code, only the cradle-to-gate GWP is addressed. These are the cradle-to-gate GWP of concrete mixtures, reported as the sum of GWP impacts for the A1, A2, and A3 modules.

low-carbon concrete (LCC)—Requirements of the Code are anticipated to become more stringent in future editions. The most stringent requirements in the Code for each chapter are Tier 1: BL1 (5.3.1), PH1 (6.3.1), BR1 (7.3.1), and STR1 (8.3.1).

project—The term "project" in the Code is not intended to include groups of distinct projects that have been bundled for bidding purposes. Residential developments are considered a single contiguous project.

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CHAPTER 3—REFERENCED STANDARDS

3.1—Scope

3.1.1 Standards, or specific sections thereof, cited in this Code, including Appendix A, are referenced without exception unless specifically noted. Cited standards are listed with their serial designations, including year of adoption or revision.

3.2—Referenced standards

3.2.1 *International Organization for Standardization (ISO)*

ISO 14025:2006—Environmental Labels and Declarations – Type III Environmental Declarations – Principles and Procedures

ISO 14040:2006—Environmental Management – Life Cycle Assessment – Principles and Framework

ISO 14040:2006/Amd 1:2020—Environmental management – Life Cycle Assessment – Principals and Framework – Amendment 1

ISO 14044:2006—Environmental Management – Life Cycle Assessment – Requirements and Guidelines

ISO 21930:2017—Sustainability in Buildings and Civil Engineering Works – Core Rules for Environmental Product Declarations of Construction Products and Services

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CHAPTER R3—REFERENCED STANDARDS

R3.1—Scope

R3.1.1 In the Code, references to standard specifications or other materials are to a specific edition of the cited document. This is done by using the complete serial designation for the referenced standard, including the title indicating the subject and year of adoption. All standards referenced in the Code are listed in this chapter, with the title and complete serial designation. In other sections of the Code, referenced standards are abbreviated to include only the serial designation without a title or date. These abbreviated references correspond to specific standards listed in this chapter.

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CHAPTER 4—CONCRETE MIXTURE GLOBAL WARMING POTENTIAL (GWP)

4.1—Scope

4.1.1 This chapter shall apply to concrete mixture materials.

4.1.2 This chapter shall apply to the cradle-to-gate global warming potential (GWP) of concrete mixtures.

4.2—General

4.2.1 The licensed design professional shall specify the GWP-related concrete requirements for the concrete mixture based on the applicable structure type in Chapters 5, 6, 7, or 8. For projects containing multiple structure types, each portion of the project shall follow the requirements of the appropriate structure chapter.

4.2.2 The licensed design professional shall examine the documentation in 4.3 and verify that documents are in compliance with the project requirements and this Code.

4.3—GWP documentation

4.3.1 The GWP of each class of concrete shall be documented as defined in 4.3.2.

4.3.2 GWP values for each concrete mixture shall be documented in one of the following: an independent third-party verified LCA report, an independent third-party verified product-specific EPD, or an independent third-party verified LCA tool. LCA reports, EPDs, and LCA tools shall conform to ISO 14040, ISO 14044 and the applicable product category rule that conforms to ISO 21930 and ISO 14025. Where a Product Category Rule (PCR) exists, the method specified in the PCR shall be used for quantifying $GWP_{benchmark\ i}$ and $GWP_{project\ i}$. Where a PCR does not exist, $GWP_{project\ i}$ shall be calculated using the same method used for quantifying $GWP_{benchmark\ i}$.

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CHAPTER R4—CONCRETE MIXTURE GLOBAL WARMING POTENTIAL (GWP)

R4.1—Scope

R4.1.1 Only the GWP of the concrete mixture is included in the Code. Reinforcing materials are not included at this time. Fibers contribute to the GWP of the mixture and should be included in the GWP reported in the mixture EPD.

Currently, there is insufficient available data regarding baseline GWP values for mixtures containing fibers, and as such they have not been included in baseline mixtures in the Code. Future editions of the Code will endeavor to include mixtures such as fibers and reinforcement as the data becomes available for analysis."

R4.1.2 Benchmark data is currently based on cradle-to-gate GWP values. Later life cycle stages may be of interest to stakeholders on a project, and the Code does not preclude their consideration in design. Future editions of the Code may extend to the full life cycle of concrete.

R4.2—General

R4.2.2 The contractor should receive the data from the concrete supplier to provide to the LDP.

Local and regional availability and variability in material properties has a significant impact on the options for a low-carbon concrete mixture. Allowing the concrete supplier to provide mixtures that meet the GWP limits, along with other design requirements, allows flexibility to achieve mixtures that meet all project requirements and minimizes cost.

R4.3—GWP documentation

R4.3.2 An EPD or LCA conducted in accordance with ISO 21930 and the ready-mixed concrete PCR (NSF International 2021), can be used for GWP data and includes the cradle-to-gate GWP which is equivalent to raw material supply, transport, and manufacturing.

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4.4—GWP weighted average

4.4.1 The $GWP_{project\ avg}$ shall be calculated using Eq. (4.4.1).

$$GWP_{project\ avg} = \frac{\sum_{i=1}^{n} GWP_{project\ i} \times Vol_i}{\sum_{i=1}^{n} Vol_i} \quad (4.4.1)$$

4.4.1.1 The $GWP_{project\ i}$ values used in Eq. (4.4.1) shall meet the requirements of 4.3.

4.4.2 The weighted average benchmark GWP shall be provided as a weighted average of the classes of the total volume of concrete on the project using Eq. (4.4.2).

$$GWP_{benchmark\ avg} = \frac{\sum_{i=1}^{n} GWP_{benchmark\ i} \times Vol_i}{\sum_{i=1}^{n} Vol_i} \quad (4.4.2)$$

4.4.3 The design volumes of concrete used per class shall be the same for Eq. (4.4.1) and Eq. (4.4.2).

4.5—GWP benchmark

4.5.1 The GWP benchmark by class and region shall be determined by the authority having jurisdiction or entity adopting this Code.

4.5.2 If the authority having jurisdiction or entity adopting this Code has not developed GWP benchmark values by concrete class, the values from Tables A.3.1a through A.3.1h shall be used.

COMMENTARY

R4.4—GWP weighted average

R4.4.1 The weighted average approach allows flexibility in balancing concrete components that typically require higher GWP with applications that typically require lower GWP, such as foundations.

R4.5—GWP benchmark

R4.5.1 Chapters 5 through 8 include GWP limits provided as a percentage of the defined GWP benchmark. The regionally variable nature of concrete GWP is best benchmarked in the region where the materials will be used. Benchmark values should be averages based on a statistical study of concrete in that region. If the authority having jurisdiction or entity adopting the code has not developed representative local data, 4.5.2 provides an option based on regional industry averages in the United States.

Benchmarks determined in 4.5.1 may use different classes of concrete than shown in Appendix A, if they are deemed appropriate by the authority having jurisdiction or entity adopting the code. For example, benchmarks for concrete pavement applications may be based upon flexural strength.

R4.5.2 The benchmarks presented in Tables A.3.1a through A.3.1h are based on regional values from *Appendix C: NRMCA Member National and Regional LCA Benchmark (Industry Average) Report – V 3.2* (Athena Sustainable Materials Institute 2022).

The concrete classes are given by f_c' (specified 28-day compressive strength) in the Code because that is currently the most comprehensive data available.

Research has shown that there is poor correlation between concrete class and concrete GWP (DeRousseau et al. 2020; Wang et al. 2021). A higher GWP is not a necessary component of higher-strength concrete; however, current data limitations mean that benchmark concrete GWP values available for the entire United States show a correlation between strength in concrete and GWP.

As additional data correlating more directly to use and application are collected and published in future documents, the Code will be updated to reflect a more representative series of concrete classes.

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4.5.2.1 When a benchmark is assigned to a class of concrete based on f_c', the concrete on the project shall be permitted to be categorized to the class of concrete of the same f_c' regardless of the age required to achieve that strength.

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R4.5.2.1 If the class of concrete is defined by f_c', the GWP associated with the f_c' at any age can be compared to the GWP limit even if the GWP limit is determined from a benchmark f_c' at a different age. While most benchmarks at this time use 28-day f_c' data, designers may specify later ages (for example, 56 or 91 days) to achieve an f_c' value as a strategy to reduce GWP.

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CHAPTER 5—BUILDINGS

5.1—Scope

5.1.1 This chapter shall apply to building projects.

5.1.1.1 A residential development shall be considered a single building project for 5.3.

5.2—General

5.2.1 Concrete mixtures, GWP calculations, and GWP documentation shall be in accordance with Chapter 4.

5.2.2 Project tier in 5.3 shall be determined using the combined gross floor area of the building project.

5.3—Determination of requirements

5.3.1 Building projects shall comply with the requirements of Table 5.3.1, where α shall be 0.85 when Appendix A benchmarks are used. The authority having jurisdiction shall set α if they develop their own benchmarks as per 4.5.1.

Table 5.3.1—Building requirements by gross floor area

Building project tier	Building gross floor area	GWP limit	Minimum documentation requirements
BL1	≥ 50,000 ft²	$GWP_{project\ avg} \leq \alpha GWP_{benchmark\ avg}$	5.3.2, 5.3.3
BL2	< 50,000 ft² and ≥ 5000 ft²	None	5.3.2, 5.3.3
BL3	< 5000 ft²	None	5.3.3

COMMENTARY

CHAPTER R5—BUILDINGS

R5.1—Scope

R5.1.1 The requirements of this chapter are tied to the size of the building. Building size is calculated by gross floor area regardless of material type. Once a requirement is determined, GWP calculations include all concrete in the building project (refer to R5.3.1).

The concrete building projects in this section include those that are within the scope of the following ACI documents:

ACI SPEC-301-20—Specifications for Concrete Construction

ACI CODE-318-19(22)—Building Code Requirements for Structural Concrete and Commentary

ACI CODE-332-14—Residential Code Requirements for Structural Concrete and Commentary

ACI CODE-562-21—Assessment, Repair, and Rehabilitation of Existing Concrete Structures—Code and Commentary

If a building is within the scope of one of the above codes, the Code (ACI CODE-323) only applies if adopted by the authority having jurisdiction or other entity.

R5.1.1.1 Buildings in residential developments are considered a single building project for calculations of gross area in 5.3. The gross area of all the buildings in the development are summed to get the gross area value in Table 5.3.1.

R5.2—General

R5.2.2 For new buildings, the entire combined gross floor area should be used regardless of the types of materials used. For alterations and additions, the combined gross floor area of the altered and added areas should be used.

R5.3—Determination of requirements

R5.3.1 The floor area determines the requirement for the concrete in the building project. The requirements are met through calculations of GWP per unit volume of concrete on the project.

The $GWP_{project\ avg}$ includes all concrete in the building including, but not limited to, walls, columns, floors, foundations, footings, and façade.

The floor area divisions in Table 5.3.1 were developed to place the most stringent requirements on large commercial buildings and significant residential developments. Future editions of the Code are anticipated to have lower GWP limits and include GWP limits on smaller projects.

The U.S. Energy Information Administration (2023a,b) collects energy usage data along with building size data for commercial buildings (2018 CBECS Survey Data) and residential buildings (2020 RECS Survey Data) that is useful in understanding the breakdown of building sizes and their contribution to total square footage of buildings in the

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5.3.2 Documentation for building projects shall report the following:

(a) ($GWP_{project\ avg}/GWP_{benchmark\ avg}$)

(b) $GWP_{project\ avg}$

(c) $GWP_{benchmark\ avg}$

(d) $GWP_{benchmark\ i}$, $GWP_{project\ i}$, and Vol_i for every class of concrete on the project

5.3.3 Building projects shall document all concrete mixtures used on the project with their corresponding use, specified compressive strength, exposure categories and any other performance requirements, and a summary of any strategies used to reduce the GWP of the concrete on the project.

COMMENTARY

United States. Other countries have similar statistics that can be used to adapt the requirements in the Code for use outside the United States.

Appendix B provides a form that meets the documentation requirements of Table 5.3.1, Section 5.3.2, and Section 5.3.3 as well as example calculations. An online GWP calculation tool is available online at www.concrete.org.

R5.3.2 Documentation requirements supporting GWP values are given in 4.3.2. Refer to 4.5.1 and 4.5.2 for details on establishing GWP benchmark values.

Appendix B provides example documentation for meeting this requirement.

R5.3.3 Appendix B provides example documentation for meeting this requirement.

Documentation for the final concrete mixtures and volumes used on the project is required. Submittal of preliminary documentation at the beginning of construction along with the concrete mixture design can serve as an early review, but the final documentation should be based on actual concrete mixtures used on the project

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CHAPTER 6—PAVEMENT AND HARDSCAPE

6.1—Scope

6.1.1 This chapter shall apply to concrete pavement and hardscape.

6.2—General

6.2.1 Concrete mixtures, GWP calculations, and GWP documentation shall be in accordance with Chapter 4.

6.2.2 Design concrete volume calculations in 6.3 shall include all concrete used as pavement and hardscape.

6.3—Determination of requirements

6.3.1 Pavement and hardscape concrete shall comply with the requirements of Table 6.3.1 where α shall be 0.85 when Appendix A benchmarks are used. The authority having jurisdiction shall set α if they develop their own benchmarks as per 4.5.1.

COMMENTARY

CHAPTER R6—PAVEMENT AND HARDSCAPE

R6.1—Scope

R6.1.1 Pavements are considered streets, local roads, and highways. Ancillary concrete includes sidewalks, curbs, gutters, median barriers, barrier walls, noise barriers, shoulders, signage foundations, and other concrete directly associated with a pavement project. For non-concrete pavements that have associated ancillary concrete, the ancillary concrete is covered in this chapter. The term "pavement" in this chapter refers to the combination of pavement and ancillary concrete.

Hardscape elements include sidewalks, parking lots, driveways, and aesthetic concrete features not covered elsewhere in the Code.

The concrete pavement in this section includes those that are within the scope of the following documents:

ACI PRC-325.14-17—Guide for Design and Proportioning of Concrete Mixtures for Pavements

ACI SPEC-330.1-14(20)—Specification for Unreinforced Concrete Parking Lots and Site Paving

FAA A/C 150-5370-10H-2018—Standard Specification for Construction of Airports (Section P-501 Cement Concrete Pavements)

State Departments of Transportation (DOTs) also maintain their own standard specifications for pavements, which can generally be obtained from each DOT's website.

The requirements of this chapter are tied to the volume of concrete used on the entire project, including pavement and hardscape concrete.

If pavement or hardscape is within the scope of one of the above codes or guides, the Code (ACI CODE-323) only applies if adopted by the authority having jurisdiction or other entity.

R6.3—Determination of requirements

R6.3.1 The volume divisions in Table 6.3.1 were developed to place the most stringent requirements on larger projects. Future editions of the Code are anticipated to have lower GWP limits and to include GWP limits on smaller projects.

Appendix B provides a form that meets the documentation requirements of Table 6.3.1, Section 6.3.2, and Section 6.3.3 as well as example calculations. An online GWP calculation tool is available online at www.concrete.org.

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CODE

Table 6.3.1—Pavement and hardscape requirements by volume of concrete

Pavement and hardscape tier	Pavement and hardscape concrete volume	GWP limit	Minimum documentation requirement
PH1	≥7500 yd^3	$GWP_{project\ avg} \leq \alpha GWP_{benchmark\ avg}$	6.3.2, 6.3.3
PH2	<7500 and ≥2000 yd^3	None	6.3.2, 6.3.3
PH3	<2000 yd^3	None	6.3.3

6.3.2 Documentation for pavement and hardscape projects shall report the following:

(a) $(GWP_{project\ avg}/GWP_{benchmark\ avg})$

(b) $GWP_{project\ avg}$

(c) $GWP_{benchmark\ avg}$

(d) $GWP_{benchmark\ i}$, $GWP_{project\ i}$, and Vol_i for every class of concrete on the project

6.3.3 Pavement and hardscape projects shall document all concrete mixtures used on the project with their corresponding use, specified compressive or flexural strength, durability requirements, and any other performance requirements, and a summary of any strategies used to reduce the GWP of the concrete on the project.

COMMENTARY

R6.3.2 Documentation requirements supporting GWP values are given in 4.3.2. Refer to 4.5.1 and 4.5.2 for details on establishing GWP benchmark values.

Appendix B provides example documentation for meeting this requirement.

R6.3.3 Appendix B provides example documentation for meeting this requirement.

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CODE

CHAPTER 7—BRIDGES

7.1—Scope

7.1.1 This chapter shall apply to bridge superstructure, substructure, deep foundations, and associated ancillary concrete.

7.2—General

7.2.1 Concrete mixtures, GWP calculations, and GWP documentation shall be in accordance with Chapter 4.

7.2.2 Design deck area calculations in 7.3 shall be the length of the deck multiplied by the out-to-out width of the deck.

7.3—Determination of requirements

7.3.1 Bridges shall comply with the requirements of Table 7.3.1 where α shall be 0.85 when Appendix A benchmarks are used. The authority having jurisdiction shall set α if they develop their own benchmarks as per 4.5.1.

Table 7.3.1—Bridge requirements by deck area

Bridge project tier	Deck area	GWP limit	Minimum documentation requirements
BR1	≥ 25,000 ft²	$GWP_{project\ avg} \leq \alpha GWP_{benchmark\ avg}$	7.3.2, 7.3.3
BR2	< 25,000 ft² and ≥ 5000 ft²	None	7.3.2, 7.3.3
BR3	< 5000 ft²	None	7.3.3

7.3.2 Documentation for bridge projects shall report the following:

(a) $(GWP_{project\ avg}/GWP_{benchmark\ avg})$
(b) $GWP_{project\ avg}$
(c) $GWP_{benchmark\ avg}$
(d) $GWP_{benchmark\ i}$, $GWP_{project\ i}$, and Vol_i for every class of concrete on the project

7.3.3 Bridge projects shall document all concrete mixtures used on the project with their corresponding use, specified compressive strength, durability requirements, and any other performance requirements, and a summary of any strategies used to reduce the GWP of the concrete on the project.

COMMENTARY

CHAPTER R7—BRIDGES

R7.1—Scope

R7.1.1 The requirements of this chapter are tied to deck area of bridge spans on the project regardless of the type of material used. GWP calculations include all concrete on the bridge including superstructure and substructure.

Ancillary concrete includes sidewalks, curbs, gutters, median barriers, barrier walls, noise barriers, and other concrete directly associated with a bridge project.

The bridges in this section include those within the scope of the *AASHTO LRFD Bridge Design Specifications*, ninth edition, 2020.

If a bridge is within the scope of the AASHTO LRFD Bridge Design Specifications, the Code (ACI CODE-323) only applies if adopted by the authority having jurisdiction or other entity.

R7.2—General

R7.2.2 This definition for deck area follows that used for the National Bridge Inventory (FHWA 1995).

R7.3—Determination of requirements

R7.3.1 The deck area determines the requirement for the bridge. The $GWP_{project\ avg}$ includes all concrete in the bridge including superstructure and substructure elements.

The deck area divisions in Table 7.3.1 were developed to place the most stringent requirements on larger bridge projects. Future editions of the Code are anticipated to have lower GWP limits and to include GWP limits on smaller projects.

Appendix B provides a form that meets the documentation requirements of Table 7.3.1, Section 7.3.2, and Section 7.3.3 as well as example calculations. An online GWP calculation tool is available online at www.concrete.org.

R7.3.2 Documentation requirements supporting GWP values are given in 4.3.2. Refer to 4.5.1 and 4.5.2 for details on establishing GWP benchmark values.

Appendix B provides example documentation for meeting this requirement.

R7.3.3 Appendix B provides example documentation for meeting this requirement.

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CHAPTER 8—OTHER STRUCTURES

8.1—Scope

8.1.1 This chapter shall apply to any structure and associated ancillary concrete not covered by Chapters 5 through 7 at the discretion of the authority having jurisdiction or the entity adopting this code.

8.2—General

8.2.1 Concrete mixtures, GWP calculations, and GWP documentation shall be in accordance with Chapter 4.

8.2.2 Design concrete volume calculations in 8.3 shall include all concrete used on a project that is not already covered by Chapters 5 through 7.

8.3—Determination of requirements

8.3.1 The structure shall comply with the requirements of Table 8.3.1 where α shall be 0.85 when Appendix A benchmarks are used. The authority having jurisdiction shall set α if they develop their own benchmarks as per 4.5.1.

COMMENTARY

CHAPTER R8—OTHER STRUCTURES

R8.1—Scope

R8.1.1 The requirements of this chapter are tied to the size of the structure and any associated ancillary concrete on the project.

This chapter provides requirements for structures not covered explicitly in the designated type chapters (Chapters 5 through 7). These may include environmental structures, containment structures, locks, dams, and heavy industrial projects. The structures in this section may include, but are not limited to, those that are within the scope of the following ACI documents:

ACI CODE-307-23—Requirements for Reinforced Concrete Chimneys—Code and Commentary

ACI SPEC-313-16—Design Specification for Concrete Silos and Stacking Tubes for Storing Granular Materials and Commentary

ACI CODE-349-13—Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary

ACI CODE-350-20—Code Requirements for Environmental Engineering Concrete Structures and Commentary

ACI CODE-376-11—Code Requirements for Design and Construction of Concrete Structures for Containment of Refrigerated Liquefied Gases and Commentary

If a structure is within the scope of one of the above codes, the Code (ACI CODE-323) only applies if adopted by the authority having jurisdiction or other entity.

R8.3—Determination of requirements

R8.3.1 Appendix B provides a form that meets the documentation requirements of Table 8.3.1, Section 8.3.2, and Section 8.3.3 as well as example calculations. An online GWP calculation tool is available online at www.concrete.org.

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Table 8.3.1—Structure requirements by volume of concrete

Structure tier	Structure concrete volume	GWP limit	Minimum documentation requirements
STR1	≥7500 yd^3	$GWP_{project\ avg} \leq \alpha GWP_{benchmark\ avg}$	8.3.2, 8.3.3
STR2	<7500 and ≥2000 yd^3	None	8.3.2, 8.3.3
STR3	<2000 yd^3	None	8.3.3

8.3.2 Documentation for structures projects shall report the following:

(a) ($GWP_{project\ avg}/GWP_{benchmark\ avg}$)

(b) $GWP_{project\ avg}$

(c) $GWP_{benchmark\ avg}$

(d) $GWP_{benchmark\ i}$, $GWP_{project\ i}$, and Vol_i for every class of concrete on the project

(e) $GWP_{project\ avg}$ and $GWP_{benchmark\ i}$, $GWP_{project\ i}$, and Vol_i for every class of concrete on the project.

8.3.3 Structures projects shall document all concrete mixtures used on the project with their corresponding use, specified compressive strength, durability requirements, and any other performance requirements, and a summary of any strategies used to reduce the GWP of the concrete on the project.

COMMENTARY

R8.3.2 Documentation requirements supporting GWP values are given in 4.3.2. Refer to 4.5.1 and 4.5.2 for details on establishing GWP benchmark values.

Appendix B provides example documentation for meeting this requirement.

R8.3.3 Appendix B provides example documentation for meeting this requirement.

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COMMENTARY

COMMENTARY REFERENCES

Documents that are cited in the commentary are listed first by document number, year of publication, and full title, followed by authored documents listed alphabetically.

American Concrete Institute (ACI)

ACI SPEC-301-20—Specifications for Concrete Construction

ACI CODE-307-23—Requirements for Reinforced Concrete Chimneys—Code and Commentary

ACI SPEC-313-16—Design Specification for Concrete Silos and Stacking Tubes for Storing Granular Materials and Commentary

ACI CODE-318-19(22)—Building Code Requirements for Structural Concrete and Commentary

ACI PRC-325.14-17—Guide for Design and Proportioning of Concrete Mixtures for Pavements

ACI SPEC-330.1-14(20)—Specification for Unreinforced Concrete Parking Lots and Site Paving

ACI CODE-332-14—Residential Code Requirements for Structural Concrete and Commentary

ACI CODE-349-13—Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary

ACI CODE-350-20—Code Requirements for Environmental Engineering Concrete Structures and Commentary

ACI CODE-376-11—Code Requirements for Design and Construction of Concrete Structures for Containment of Refrigerated Liquefied Gases and Commentary

ACI CODE-440.11-22—Building Code Requirements for Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars—Code and Commentary

ACI CODE-562-21—Assessment, Repair, and Rehabilitation of Existing Concrete Structures—Code and Commentary

ACI ITG-10-18—Practitioner's Guide for Alternative Cements

ACI ITG-10.1R-18—Report on Alternative Cements

American Association of State Highway and Transportation Officials (AASHTO)

LRFD Bridge Design Specifications, ninth edition, 2020

Mechanistic-Empirical Pavement Design Guide: A Manual of Practice, third edition, 2020

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FAA A/C 150-5370-10H-2018—Standard Specification for Construction of Airports (Section P-501 Cement Concrete Pavements)

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APPENDIX A—REGIONAL GWP BENCHMARKS

A.1—Scope

A.1.1 This appendix shall provide the GWP benchmark for classes of concrete by region to meet 4.5.2.

A.2—Notation

$GWP_{benchmark\ i}$ = benchmark GWP for class of concrete, i, kg CO_2e/yd^3

A.3—Benchmark GWP data

A.3.1 Tables A.3.1a through A.3.1h shall be used to determine $GWP_{benchmark\ i}$ for normalweight and lightweight concrete classes.

Table A.3.1a—Region 1 (Eastern) GWP benchmark values by class strength

Specified strength class (f_c') at 28 days, psi	Normalweight concrete $GWP_{benchmark\ is}$ kg CO_2e/yd^3 concrete	Lightweight concrete $GWP_{benchmark\ is}$ kg CO_2e/yd^3 concrete
2501 to 3000	202	396
3001 to 4000	241	438
4001 to 5000	290	481
5001 to 6000	306	Not applicable
6001 to 8000	361	Not applicable

Table A.3.1b—Region 2 (Great Lakes) GWP benchmark values by class strength

Specified strength class (f_c') at 28 days, psi	Normalweight concrete $GWP_{benchmark\ is}$ kg CO_2e/yd^3 concrete	Lightweight concrete $GWP_{benchmark\ is}$ kg CO_2e/yd^3 concrete
2501 to 3000	195	382
3001 to 4000	232	422
4001 to 5000	278	461
5001 to 6000	294	Not applicable
6001 to 8000	346	Not applicable

COMMENTARY

APPENDIX RA—REGIONAL GWP BENCHMARKS

RA.1—Scope

RA.1.1 The regionally variable nature of concrete GWP is best benchmarked in the region where the materials will be used. If the authority having jurisdiction or entity adopting the code has not developed representative local data, the values in this appendix provide an option based on regional industry averages in the United States.

The benchmarks presented in this appendix are based on *Appendix C: NRMCA Member National and Regional LCA Benchmark (Industry Average) Report – V 3.2* (Athena Sustainable Materials Institute 2022). Background on data analysis and collection is presented in the document above.

The concrete classes in this appendix include benchmarks by region for six normalweight ready mixed concrete products by compressive strength f_c', and 3 lightweight concrete products by compressive strength f_c'.

RA.3—Benchmark GWP data

RA.3.1 Figure RA.3.1 shows the contiguous United States regions used in Tables A.3.1a through A.3.1h. Benchmarking data are not available for areas outside of the contiguous United States, so benchmarks are not provided for these areas.

Data in Tables A.3.1a through A.3.1h are adapted from the NRMCA regional industry-wide benchmark values (Athena Sustainable Materials Institute 2022) and rounded up to the nearest kg CO_2e.

The f_c' values in Tables A.3.1a through A.3.1h are rounded to the nearest 1 psi. The f_c' values are given bands and should be used without interpolation. For example, an f_c' value is 3600 psi or 4000 psi would both have the same GWP limit in Tables A.3.1a through A.3.1h.

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Table A.3.1c—Region 3 (North Central) GWP benchmark values by class strength

Specified strength class (f_c') at 28 days, psi	Normalweight concrete $GWP_{benchmark\ is}$ kg CO_2e/yd^3 concrete	Lightweight concrete $GWP_{benchmark\ is}$ kg CO_2e/yd^3 concrete
2501 to 3000	202	372
3001 to 4000	239	411
4001 to 5000	285	452
5001 to 6000	302	Not applicable
6001 to 8000	352	Not applicable

Table A.3.1d—Region 4 (Pacific Northwest) GWP benchmark values by class strength

Specified strength class (f_c') at 28 days, psi	Normalweight concrete $GWP_{benchmark\ is}$ kg CO_2e/yd^3 concrete	Lightweight concrete $GWP_{benchmark\ is}$ kg CO_2e/yd^3 concrete
2501 to 3000	200	397
3001 to 4000	242	440
4001 to 5000	296	484
5001 to 6000	312	Not applicable
6001 to 8000	373	Not applicable

Table A.3.1e—Region 5 (Pacific Southwest) GWP benchmark values by class strength

Specified strength class (f_c') at 28 days, psi	Normalweight concrete $GWP_{benchmark\ is}$ kg CO_2e/yd^3 concrete	Lightweight concrete $GWP_{benchmark\ is}$ kg CO_2e/yd^3 concrete
2501 to 3000	214	383
3001 to 4000	248	418
4001 to 5000	289	454
5001 to 6000	307	Not applicable
6001 to 8000	349	Not applicable

Table A.3.1f—Region 6 (Rocky Mountains) GWP benchmark values by class strength

Specified strength class (f_c') at 28 days, psi	Normalweight concrete $GWP_{benchmark\ is}$ kg CO_2e/yd^3 concrete	Lightweight concrete $GWP_{benchmark\ is}$ kg CO_2e/yd^3 concrete
2501 to 3000	214	370
3001 to 4000	248	407
4001 to 5000	289	444
5001 to 6000	307	Not applicable
6001 to 8000	349	Not applicable

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Table A.3.1g—Region 7 (South Central) GWP benchmark values by class strength

Specified strength class (f_c') at 28 days, psi	Normalweight concrete $GWP_{benchmark\ is}$ kg CO_2e/yd^3 concrete	Lightweight concrete $GWP_{benchmark\ is}$ kg CO_2e/yd^3 concrete
2501 to 3000	188	358
3001 to 4000	219	391
4001 to 5000	258	425
5001 to 6000	273	Not applicable
6001 to 8000	313	Not applicable

Table A.3.1h—Region 8 (Southeastern) GWP benchmark values by class strength

Specified strength class (f_c') at 28 days, psi	Normalweight concrete $GWP_{benchmark\ is}$ kg CO_2e/yd^3 concrete	Lightweight concrete $GWP_{benchmark\ is}$ kg CO_2e/yd^3 concrete
2501 to 3000	205	366
3001 to 4000	237	399
4001 to 5000	276	430
5001 to 6000	293	Not applicable
6001 to 8000	333	Not applicable

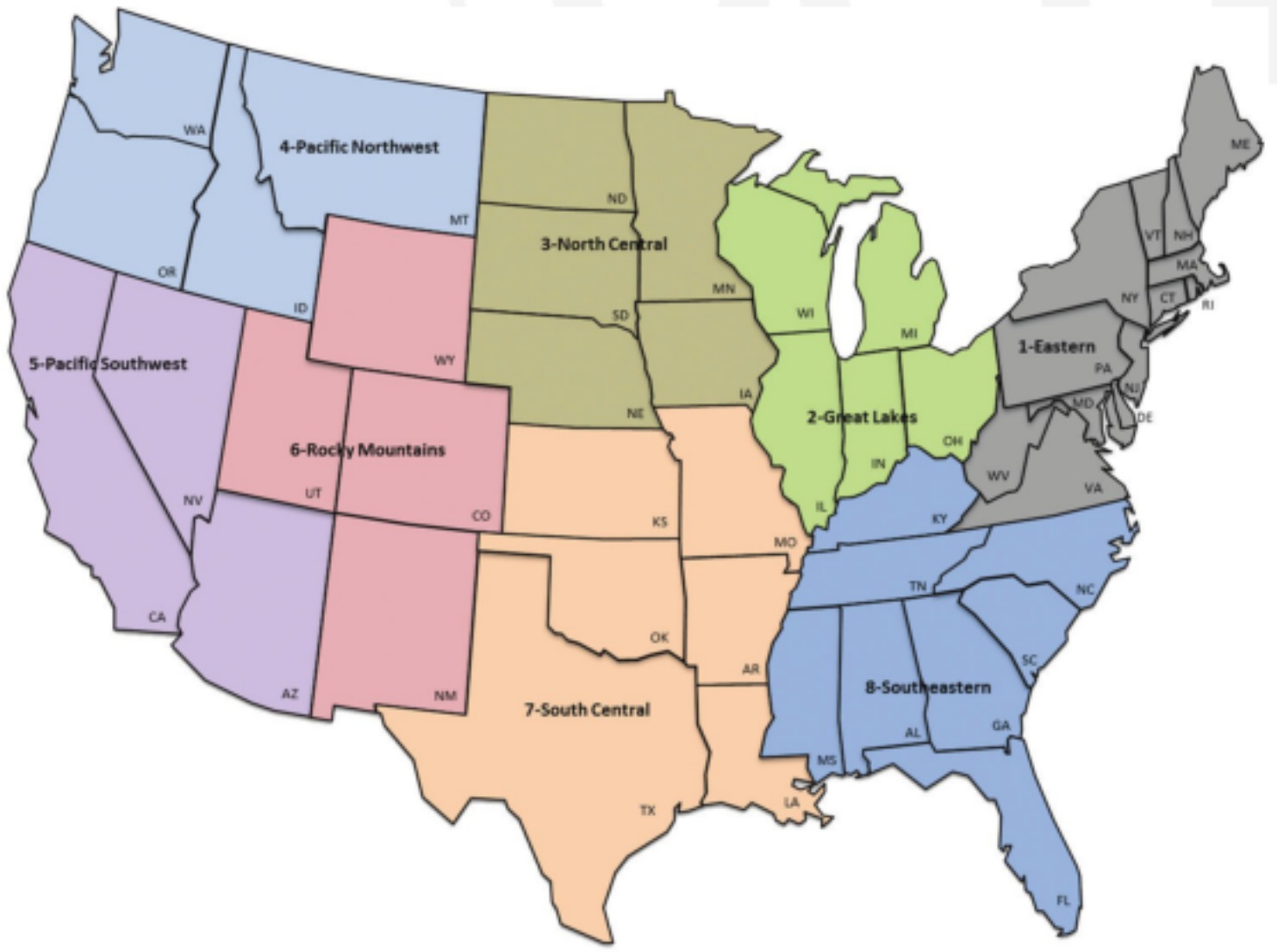

Fig. RA.3.1—Regions for benchmark data (Athena Sustainable Materials Institute 2022).

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APPENDIX B—EXAMPLE CALCULATION AND DOCUMENTATION

Given:

A parking garage in Oregon has been designed with information shown in Table B.1. Assume that the local jurisdiction does not have established benchmarks and that the ACI CODE-323-24 Appendix A values will be used. All concrete is normal-weight. The parking garage has a gross floor area of 7800 ft^2, giving it a classification of BL2 from Table 5.3.2.

Terminology from ACI CODE-323-24 Section 2.2:

$GWP_{benchmark\ avg}$ = weighted average benchmark GWP for concrete used on the project, kg CO_2e/yd^3
$GWP_{benchmark\ i}$ = benchmark GWP for class of concrete, i, kg CO_2e/yd^3
$GWP_{project\ avg}$ = weighted average project GWP for the concrete mixtures used on a project, kg CO_2e/yd^3
$GWP_{project\ i}$ = project GWP for class of concrete, i, kg CO_2e/yd^3
n = number of concrete classes proposed for use on the project
Vol_i = volume of concrete for class of concrete, i, yd^3

where

$$GWP_{project\ avg} = \frac{\sum_{i=1}^{n} GWP_{project\ i} \times Vol_i}{\sum_{i=1}^{n} Vol_i} \qquad (4.4.1)$$

$$GWP_{benchmark\ avg} = \frac{\sum_{i=1}^{n} GWP_{benchmark\ i} \times Vol_i}{\sum_{i=1}^{n} Vol_i} \qquad (4.4.2)$$

Reporting requirements for ACI CODE-323-24 Section 5.3.2:

(a) ($GWP_{project\ avg}/GWP_{benchmark\ avg}$)
(b) $GWP_{project\ avg}$
(c) $GWP_{benchmark\ avg}$
(d) $GWP_{benchmark\ i}$, $GWP_{project\ i}$, and Vol_i for every class of concrete on the project

Step 1: Calculate project averages

Table B.2 shows the values for GWP by class of concrete and the calculation for the weighted average project GWP. Five classes of concrete are used on this project ($n = 5$).

Step 2: Calculate benchmark averages

Table B.3 shows the values for the benchmark GWP by class of concrete and the calculated weighted average benchmark GWP. Benchmark values are found in Table A.3.1d for Oregon (Region 4, Pacific Northwest).

Step 3: Calculate the ratio of the weighted averages of the project GWP to the benchmark GWP

$$\frac{GWP_{project\ avg}}{GWP_{benchmark\ avg}} = \frac{251.5}{298.7} = 0.84$$

Note that the BL2 classification does not require a limit on $GWP_{project\ avg}/GWP_{benchmark\ avg}$. However, this structure would meet the BL1 requirement of $GWP_{project\ avg} \leq \alpha GWP_{benchmark\ avg}$, where $\alpha = 0.85$

Submittal information

As a BL2 classified structure, the parking garage has the following requirements:

5.3.2 Documentation for building projects shall report the following:
(a) ($GWP_{project\ avg}/GWP_{benchmark\ avg}$)
(b) $GWP_{project\ avg}$
(c) $GWP_{benchmark\ avg}$
(d) $GWP_{benchmark\ i}$, $GWP_{project\ i}$, and Vol_i for every class of concrete on the project.

5.3.3 Building projects shall document all concrete mixtures used on the project with their corresponding use, specified compressive strength, exposure categories and any other performance requirements, and a summary of any strategies used to reduce the GWP of the concrete on the project.

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Table B.1—Given information for parking garage design

Application	Mixture no.	f_c', psi	Volume, yd^3	EPD GWP, $kgCO_2e/yd^3$
Topping slabs, curbs, SOMD[1]	A	4000	1199	202.6
Below-grade walls, footings, SOG[2]	B	5000	569	247.7
Elevator pit walls	C	5000	23	281.4
Columns, shear walls, vehicle barrier walls	D	6000	1366	247.7
Elevated decks	E	6000	3867	268.4

[1]SOMD: slab on metal deck.

[2]Slab-on-ground.

Table B.2—Weighted average project GWP calculations

Column:	A	B	C	D	E
Application	**Concrete class**	**f_c', psi**	**Vol_i, yd^3**	**$GWP_{project\ i}$, kg CO_{2e}/yd^3**	**Total $GWP_{project}$ for class, kg CO_{2e} (Column C x D)**
Topping slabs, curbs, SOMD	1	4000	1199	202.6	242,907
Below-grade walls, footings, SOG	2	5000	569	247.7	140,941
Elevator pit walls	3	5000	23	281.4	6472
Columns, shear walls, vehicle barrier walls	4	6000	1366	247.7	338,358
Elevated decks	5	6000	3867	268.4	1,037,902
			$\sum$ = 7024		**$\sum$ = 1,766,592**

$$GWP_{project\ avg} = \frac{\sum_{i=1}^{v} GWP_{project\ i} \times Vol_i}{\sum_{i=1}^{v} Vol_i} = \frac{1{,}766{,}592}{7024} = 251.5 \text{ kg } CO_{2e}/yd^3$$

Table B.3—Weighted average benchmark GWP calculations

Column:	A	B	C	D	E
Application	**Concrete class**	**f_c', psi**	**Vol_i, yd^3**	**$GWP_{benchmark\ i}$, kg CO_{2e}/yd^3**	**Total $GWP_{benchmark}$ for class, kg CO_{2e} (Column C x D)**
Topping slabs, curbs, SOMD	1	4000	1199	242	290,158
Below-grade walls, footings, SOG	2	5000	569	296	168,424
Elevator pit walls	3	5000	23	296	6808
Columns, shear walls, vehicle barrier walls	4	6000	1366	312	426,192
Elevated decks	5	6000	3867	312	1,206,504
			$\sum$ = 7024		**$\sum$ = 2,098,086**

$$GWP_{benchmark\ avg} = \frac{\sum_{i=1}^{n} GWP_{benchmark\ i} \times Vol_i}{\sum_{i=1}^{n} Vol_i} = \frac{2{,}098{,}086}{7024} = 298.7 \text{ kg } CO_{2e}/yd^3$$

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This information is summarized below from the calculations listed previously in this appendix.

Requirements of 5.3.2:
(a) $GWP_{project\ avg}/GWP_{benchmark\ avg} = 0.84$
(b) $GWP_{project\ avg} = 250.8$ kgCO_2e/yd^3
(c) $GWP_{benchmark\ avg} = 297.9$ kgCO_2e/yd^3
(d) As given below:

Concrete class	$GWP_{benchmark\ i}$, kg CO_2e/yd^3	$GWP_{project\ i}$, kg CO_2e/yd^3	Vol_i, yd^3
1	242	202.6	1199
2	296	247.7	569
3	296	281.4	23
4	312	247.7	1366
5	312	268.4	3867

Requirements of 5.3.3:

Concrete class	Use	f_c', psi	Exposure category[1]				Additional requirements	GWP reduction strategies [2]
			F	S	W	C		
1	Topping slabs, curbs, SOMD	4000	3	3	2	2	None	Alternative requirements I, II
2	Below-grade walls, footings, SOG	5000	3	0	2	2	None	Alternative requirements I, II
3	Elevator pit walls	5000	3	0	2	2	None	Alternative requirements I, II
4	Columns, shear walls, vechicle barrier walls	6000	3	0	2	2	None	Alternative requirements I, II
5	Elevated decks	6000	3	0	2	2	None	Alternative requirements I, II

[1]Based on ACI CODE 318-19(22) with corresponding prescriptive durability requirements.

[2]Based on examples from Obla and Lobo (2023).

General reduction strategies included use of supplementary cementitious materials (SCMs) to reduce portland cement content, improved aggregate gradation to reduce total binder content, and reduced total cement content by accepting 56-day strength to meet specification.

Alternative requirements:
I: As an alternative to the maximum *w/cm*:
1) Maximum charnge passed of 1500 coulombs measured in accordance with ASTM C1202; or
2) Minimum resistivity of 395 Ω-ft determined in accordance with ASTM C1876
II: The limits on maximum SCM contents for F3 expose class concrete can be exceeded if the mixture submittal documents an ASTM C672 visual rating less than or equal to 2.

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