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Guide to Improving Specifications for Ready Mixed Concrete

With Notes on Reducing Embodied Carbon Footprint

2021



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Foreword

This publication has been developed by the National Ready Mixed Concrete Association and its members through the Research Engineering and Standards (RES) Committee. This document evolved based on comments developed when reviewing project specifications used in the concrete construction industry. This publication is intended as a guide for ready mixed concrete or contractor personnel who are responsible for compliance with project specifications or for design professional who develop project specifications. This document proposes specification clauses and includes accompanying commentary as guidance. The commentary essentially emphasizes the fundamental concepts of specifications for ready mixed concrete addressed in industry standards published by ACI or ASTM International. Provisions of ACI 318-19, *Building Code for Structural Concrete*, as it relates to requirements concrete ingredient materials and mixtures, production and delivery are incorporated in this document. Requirements in this document are consistent with those addressed in ACI 301-20, *Specification for Concrete Construction*

This publication uses the most recent version of the AIA MasterSpec format, Section 033000 for Cast-in-place concrete to provide context to the typical sections seen in project specifications of private design firms or owners. The document only covers those sections pertinent to concrete materials and mixtures. It does not include or discuss sections pertinent to reinforcement, formwork or other products and construction means and methods. This publication is not written as a guide or reference specification. The intent of writing this publication in this format is to provide advisory information to designers, contractors, concrete producers, and other stakeholders on a project to discuss the intent or for the designers to incorporate these suggestions. It is anticipated that this publication will be updated as standards evolve or with feedback, which is encouraged.

Reducing Embodied Carbon Footprint of Concrete: Concrete is unique among building materials. The composition of each mixture is highly influenced by its application. Design professionals and contractors have a greater influence on concrete mixture composition than they do with other building products. Concrete's mixture proportions has the greatest impact on carbon footprint of concrete. This special edition provides recommendations for specifying concrete to meet specific carbon footprint reduction goals while still maintaining all the performance characteristics required for concrete on the project. It provides guidance on how to establish a carbon budget for a building, the submittals required to demonstrate compliance and the qualifications of concrete producers to participate on a project that has a carbon reduction goal. Items specific to carbon footprint reduction are listed in blue.

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Disclaimer

This publication is intended for the use of professional personnel, competent to evaluate the significance and limitations of its content, and who will accept responsibility for the application of the material it contains. The National Ready Mixed Concrete Association and the other organizations cooperating in the preparation of this publication strive for accuracy but disclaim any and all responsibility for application of the stated principles or for the accuracy of the sources.

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This list of contents is based on AIA MasterSpec, version 12/18. This publication only covers discussion on all or some of the articles in the sections identified in bold font. These sections are pertinent to ready mixed concrete.

SECTION 03300 – CAST-IN-PLACE CONCRETE

PART 1 – GENERAL

1.1 RELATED DOCUMENTS

<Retain or delete this article in all Sections of Project Manual.>

A. Drawings and general provisions of the Contract, including General and Supplementary Conditions and Division 01 Specification Sections, apply to this section

<Provide pertinent list of reference standards as used in the following specification from standards setting organizations such as ACI, ASTM International, AASHTO, etc. Include the date of the standard in the document designation.>

- Referenced documents that are incorporated as part of this specification and Contract Documents need to be written in mandatory language. Referenced standards, such as ASTM standards, should include the date of adoption because they are revised often. In some cases, it may be necessary to reference version of standards referenced in the locally adopted building code.
- Non-mandatory language documents, such as guides, guide specifications, state-of-the-art reports or recommended practices should not be referenced in a project specification. Guide documents written in non-mandatory language; they often have several alternative recommendations; and they often do not require any specific action. If the intent of a specific reference is not clear, enforcement of this intent is subject to interpretation and opinion. Many ACI documents such as ACI 302R, 304R, 305R, 306R, 311R, and 347R are guide documents and are not written in mandatory language. These should not be included in the list of referenced standards section or referenced for compliance in the body of the specification. If there are specific items in these guides that the specification writer intends to use, these should be written into the specification in mandatory language so that the requirements and responsibilities are clearly defined.
- General statements requiring compliance with building codes and reference specifications should be avoided. The introduction to the ACI 318-19 Building Code states: *General references requiring compliance with the Code in the project specifications should be avoided since the contractor is rarely in a position to accept responsibility for design details or construction requirements that depend on a detailed knowledge of the design.* It is recognized that specific portions of the design can be delegated to a specialty engineer employed by the contractor – common for precast concrete members. Design-build projects also typically have responsibility for design and construction by the same entity. ACI 318 indicates that specifications and contract documents should contain all the necessary requirements to ensure that construction is in compliance with the Code. Ensuring compliance with the construction requirements of the Building Code is the responsibility of the design professional who is in a position to know the design requirements, detailing, and applicable exposure conditions for all concrete members. The applicable requirements should be stated in the project specifications. In 318-19, Chapter 26 collects all construction requirements that must be incorporated in construction documents as applicable to the project. The requirements are split into “design information” and “compliance requirements”. Design information includes project-specific requirements based on the design of the structure; compliance requirements are construction-related requirements to provide an acceptable level of construction quality. Requirements applicable to the project should be included in project specifications or drawings. A comprehensive list of Code-related requirements for concrete mixtures that must be addressed in construction documents is included in 26.4.2 of ACI 318-19. Section 26.13 of ACI 318-19 includes inspection requirements to be used in the absence of general building code inspection provisions. Inspection requirements are intended to provide verification that the Work complies with the construction documents. Inspection requirements of the governing jurisdiction or the general building code take precedence over those included in Section 26.13 of ACI 318.
- Reference specifications, such as ACI 301, can be incorporated by reference in project specifications. The date of the referenced specification needs to be included. ACI construction specifications, such as ACI 301, has a mandatory requirements checklist that includes items that the design professional has to state in contract documents to make the reference specification complete. Do not copy individual sections, parts, articles, or

paragraphs into the project specifications because taking them out of context may change their meaning. Do not refer to section numbers in a reference specification because of the loss of context and flow. ACI reference specifications, such as ACI 301, establish default requirements and have optional requirements checklists that advise the designer on alternatives. ACI reference specifications, such as ACI 301 permit the contractor to submit a written alternative to any requirement in the specification.

- B. The basis for designing concrete mixtures and demonstrating compliance with carbon budget targets shall be in accordance with:
1. National Ready Mixed Concrete Association (NRMCA) Cradle-to-Gate Life Cycle Assessment of Ready-Mixed Concrete Manufactured by NRMCA Members – Version 3 (or later).
 2. National Ready Mixed Concrete Association, NRMCA Member Industry Average EPD for Ready Mixed Concrete – Version 3 (or later).

- The two documents listed above are published by NRMCA to establish benchmark mixtures with industry average impacts for various common concrete mixtures. The second document provides examples of mixtures with varying quantities of supplementary cementitious materials that could be used on a project. These documents were developed by NRMCA using a third party verified Cradle-to-Gate Life Cycle Assessment. Armed with this information, one can conduct a Whole Building LCA to determine the embodied impacts of concrete of a benchmark building using typical concrete mixes with typical amounts of SCMs, and a proposed building using concrete mixes with high volumes of fly ash and slag. An example of how to use these documents to establish carbon footprint targets for the concrete on a building is provided in Appendix C.
- There may be other documents that use the same rigorous statistical methodologies and LCA principles to calculate benchmark and average GWP and other impacts. These could be developed by other organizations such as state and local ready mixed concrete associations, designer groups, or federal, state and local government entities that could be used as substitutes for these documents. Substitute those documents in this Section and elsewhere in this specification to be used as the basis for embodied carbon budget determination.

1.2 SUMMARY

- A. Section includes cast-in place concrete, including concrete materials, mixture design, placement procedures, and finishes.
- B. Related Requirements

<Retain subparagraphs below to cross-reference requirements Contractor might expect to find in this Section but are specified in other Sections>

1. Section 031000 “Concrete Forming and Accessories” – for form-facing materials, form liners, insulating concrete forms, and waterstops
2. Section 032000 “Concrete Reinforcing” – for steel reinforcing bars and welded-wire reinforcement.
3. Section 033300 “Architectural Concrete” – for general building applications of specially finished formed concrete.
4. Section 033543 “Polishing Concrete Finishing” – for floors scheduled to receive a polished concrete finish
5. Section 035300 “Concrete Topping” – for emery- and iron-aggregate concrete floor toppings
6. Section 321000 “Earth Moving” – for drainage fill under slabs-on-ground.
7. Section 321313 “Concrete Paving” – for concrete pavement and walks.

8. Section 321316 “Decorative Concrete Paving” for decorative concrete pavement and walks.

C. Embodied Carbon Footprint Goals

1. This project has a goal of reducing the embodied carbon footprint relative to a benchmark or typical project by _____%. To accomplish this goal, the target carbon footprint reduction for concrete is _____% below benchmark established in the NRMCA Cradle-to-Gate Life Cycle Assessment of Ready-Mixed Concrete Version 3 (or later). Specific targets for Global Warming Potential (GWP) are provided in Section 2, CONCRETE MIXTURES. It shall be permitted to propose innovative products and manufacturing processes for approval by the Engineer of Record. Proposed alternatives shall meet all performance criteria for strength, durability, and constructability, and achieve the required reduction in carbon footprint.

- By establishing upfront that the project has a carbon reduction goal, it provides the concrete contractor and producer indication that they should develop mix designs that not only meet the typical performance criteria for concrete, such as strength, durability and other physical properties, but they should also take into account concrete mixtures with lower carbon footprint than typical concrete mixtures. It also encourages the use of innovative products and processes to meet these goals. Recognize that the compilation of data and information for submittals on carbon footprint reduction and test data complying with the specification may require substantial lead time. It may also impact the cost of the proposed products.
- There may be other documents that use the same rigorous statistical methodologies and LCA principles to calculate benchmark and average GWP and other impacts. These could be developed by other organizations such as state and local ready mixed concrete associations, designer groups, or federal, state and local government entities that could be used as substitutes for these documents. Substitute those documents in this Section and elsewhere in this specification to be used as the basis for embodied carbon budget determination.

1.3 DEFINITIONS

- A. Cementitious Materials: materials that have cementing value if used in grout, mortar, or concrete, including portland cement, blended hydraulic cements, expansive cement, fly ash, raw or calcined natural pozzolan, ground glass pozzolan, slag cement, and silica fume
- B. Water-to Cementitious Materials Ratio (w/cm): ratio of mass of water, excluding that absorbed by aggregate, to the mass of cementitious materials in a mixture, stated as a decimal.

- All cementitious materials, including portland and blended cements, and supplementary cementitious materials are included in the calculation of w/cm
- The mixing water content in a mixture includes batch water (water weighed or metered at a plant), ice, free moisture on aggregates, wash water retained in the mixer before batching, water added at the jobsite or by an automated truck mixer system, and water introduced from admixtures if the quantity added increases the w/cm by more than 0.01 (ASTM C94/C94M)

- C. Embodied Carbon Footprint: embodied carbon is the carbon dioxide equivalent (CO₂e) footprint of a building or infrastructure project before it becomes operational. ... Embodied carbon is distinct from operational carbon — the carbon that comes from energy, heat, lighting, etc. Embodied carbon is generally expressed as Global Warming

Potential. Typically, the embodied carbon is the *initial* embodied carbon which only accounts for the cradle to gate impacts.

- D. Global Warming Potential: Global warming potential (GWP) is the heat absorbed by any greenhouse gas in the atmosphere, as a multiple of the heat that would be absorbed by the same mass of carbon dioxide. GWP is 1 for CO₂. For other gases it depends on the gas and the time frame. GWP for concrete is expressed in kg of CO₂e per unit of concrete (cubic yard or cubic meter)
- E. Environmental Product Declaration: An Environmental Product Declaration (EPD) quantifies environmental information on the life cycle of a product to enable comparisons between products fulfilling the same function. EPDs are conducted in accordance with a Product Category Rule for the specific product being evaluated. (International Organization for Standardization 14025 as a Type III declaration)
- F. Product Category Rule: Product Category Rules (PCR) are a set of rules, requirements and guidelines for developing Environmental Product Declarations (EPD) for one or more product categories. The PCR for concrete is published by NSF International.
- G. Life Cycle Assessment: Life cycle assessment (LCA) is a methodology for assessing environmental impacts associated with all the stages of the life cycle of a commercial product, process, or service.

1.4 PREINSTALLATION MEETINGS

- A. Conduct a pre-concreting meeting at **[Location]** at least **[period]** before first placement.
 - 1. Representatives of the following entities concerned with cast-in-place concrete are recommended to attend:
 - a. Architect
 - b. Structural Engineer
 - c. General Contractor/Construction Manager
 - d. Installer (Concrete subcontractor)
 - e. Reinforcing Steel Contractor
 - f. Post-tensioning Contractor
 - g. Pumping Contractor
 - h. Manufacturer (Ready-mixed concrete producer)
 - i. Independent testing agency
 - 2. Review the following:
 - a. Concrete mixtures – specification and constructability requirements
 - b. Scheduling and details for placement
 - c. Contact information of responsible persons during placement
 - d. Placement procedures and rate of placement
 - e. Jobsite adjustments permitted and decision process
 - f. Cold and hot weather requirements
 - g. Concrete protection
 - h. Concrete inspection and field quality control
 - i. Testing frequency, sampling location,
 - j. Initial curing facilities and site access for strength test and other specimens
 - k. Field-cured cylinders curing and intent of results

- NRMCA and American Society of Concrete Contractors have published the *Checklist for the Concrete Pre-Construction Conference*. Pre installation conference is essential for major and/or complex concrete installations. Decisions made should be documented and distributed to stakeholders. These meetings help minimize misunderstandings, allow for a review of specification requirements or project conditions and facilitate resolution of problems during construction. Contact information of all stakeholders should be exchanged to facilitate seamless communication and address contingencies during construction.
- It is recommended that these meetings be scheduled at least 30 days prior to each major class of concrete placed. Multiple meetings may be required.

1.5 ACTION SUBMITTALS

A. Product Data for each of the following, if used for concrete mixtures:

1. Portland cement
2. Blended Hydraulic cement
3. Fly ash
4. Slag cement
5. Silica Fume
6. Natural or other pozzolanic materials
7. Mineral Fillers
8. Aggregates
9. Admixtures

- “Action submittals” are those representing products or materials that require review and approval by the A/E. “Informational submittals” (Sec 1.6) are used to represent compliance with contract requirements that are not within the scope of work for the project. This type of submittal includes items like warranties, quality control certifications, and information to support the work, but is not part of it. Informational submittals are usually kept as record documents and typically does not require a response from the designer.
- Product data for materials used in concrete typically represent mill test reports and can include additional information or test results required by the specification.

B. Embodied Carbon Footprint Submittals

1. Plant specific Environmental Product Declaration (EPD) for each concrete mixture proposed for the project accompanying each concrete mixture submittal
 - a. It shall be permitted to substitute plant-specific EPDs with those listed in NRMCA Member Industry Average EPD for Ready Mixed Concrete if the proposed mixtures are similar to those listed and the concrete producer participated in providing data for the NRMCA Cradle-to-Gate Life Cycle Assessment of Ready-Mixed Concrete.
2. A calculation showing that the Global Warming Potential (GWP) of all the concrete supplied for the project shall be lower than the GWP target set in Section 2.

- For each concrete mixture, supply a plant specific EPD. An EPD includes several environmental impacts including GWP. GWP reported in the EPD should be used as the basis for calculating the embodied carbon footprint for the building.

- In some cases, the concrete mixtures proposed for use on the project are similar to those listed in the NRMCA Member Industry Average EPD for Ready Mixed Concrete. In those cases, concrete producer may identify those mixtures from the Industry Average EPD in lieu of plant specific EPDs.
- The calculation showing that the GWP of the concrete supplied for the building is lower than the target carbon budget shown in Section 2 can be achieved using sophisticated LCA software or quantified by the following equations:

$$GWP_{\text{actual}} = \sum_{i=1}^n [GWP_{\text{actual } i} \times VOL_i]$$

$$GWP_{\text{benchmark}} = \sum_{i=1}^n [GWP_{\text{benchmark } i} \times VOL_i]$$

$$R_{\text{gwp}} = (GWP_{\text{benchmark}} - GWP_{\text{actual}}) / GWP_{\text{benchmark}}$$

Where:

GWP_{actual} = Total global warming potential of all concrete mixtures proposed for use on project

$GWP_{\text{benchmark}}$ = Total global warming potential for industry average benchmark measurement index

$GWP_{\text{actual } i}$ = global warming potential for individual (i) concrete mixtures proposed for use on project for mixture

$GWP_{\text{benchmark } i}$ = global warming potential for industry average benchmark measurement index for individual concrete mixture class representative of proposed individual mixture (i)

n = number of classes of concrete mixtures for benchmark and mixtures proposed for use on project

R_{gwp} = Reduction in GWP

VOL_i = Volume of concrete for concrete mixture class (i)

C. Concrete Mixtures: For each concrete mixture, submit the following:

1. Mixture Identification by class
2. Type and source information on concrete materials proposed for use including:
 - a. Cementitious Materials
 - b. Aggregates
 - c. Mineral Fillers
 - d. Admixtures
 - e. Water
 - f. Fibers, color pigments, and other additions
3. Compressive strength, f'_c , applicable for the class
4. Required average compressive strength, f'_{cr} , for each class of concrete
5. Documentation of strength test records of similar class of concrete used to establish standard deviation in accordance with ACI 301, when test records exist
6. Documentation of compliance with f'_{cr} of proposed mixture(s) and test age
7. Strength of concrete at other specified ages
8. The applicable durability exposure classes for each class of concrete.
9. w/cm of proposed concrete mixtures, when specified
10. Nominal maximum aggregate size or Size number (ASTM C33) of coarse aggregate

11. Target slump or slump flow
12. Air content of concrete assigned to Exposure Classes F1, F2, and F3
13. Density, if specified
14. Documentation of compliance with maximum limits on supplementary cementitious materials for concrete assigned to Exposure Class F3
15. Cementitious materials and documentation of tests or service for concrete assigned to Exposure Class S1, S2, and S3
16. Documentation on chloride content of concrete mixtures for conformance to limits in Exposure Class C – calculated total chloride or measured water-soluble chlorides by ASTM C1218/C1218M, expressed as a percentage of cementitious materials.
17. Documentation on alkali aggregate reactivity for concrete assigned to Exposure Class W1 or W2, as specified
18. Intended placement method
19. Equilibrium density of lightweight concrete and correlated density of fresh concrete, if specified
20. Documentation supporting other specified requirements of concrete mixtures
21. Intended placement method
22. Anticipated changes to concrete mixtures for anticipated routine variability of in materials, and changes in project conditions, weather, test results, or other circumstances that warrant adjustments

- These submittal items are drawn from a list that the designer must include in construction documents related to concrete mixtures from Section 26.4 in ACI 318-19. These are related to Code requirements for concrete mixtures for strength and durability. Some additional items are included. Some of these items may not be applicable to a specific project and should be modified based on project requirements. In a performance-based specification some of these prescriptive items would be replaced by performance-based requirements. Details regarding acceptance criteria of performance-based requirements should be stated in this specification.
- The mixture proportioning process of establishing the required average strength based on the specified strength used in design has been eliminated from ACI 318-19. Article 4.2.3 of ACI 301 for establishing the required average strength for proposed concrete mixtures.
- ACI 301 establishes the required average strength, f'_{cr} , for a concrete mixture proposed for the project to be established based on:
 1. *Strength test record exists:* In this case, the standard deviation from a strength test record of a similar class of concrete produced under similar conditions is used to calculate the required average strength. The specified strength, f'_c , of the similar class should be within 1000 psi of that for the proposed Work. The strength test record cannot be more than 24 months old and has to have been collected over a period not less than 45 days.
 2. *Strength test record does not exist:* If there is no strength test record of a similar class of concrete, the required average strength, f'_{cr} , is at a given increment above the specified strength, f'_c . The increment varies from 1000 psi to $(1.1 f'_c + 700)$ psi depending on the level of f'_c .Case 2 results in a larger value for the required average strength than the first case. A fixed over-design value should not be specified as a default requirement for establishing f'_{cr} . Proportioning a concrete mixture for a required average strength based on the standard deviation is preferred if a strength test record for that class of concrete exists. The use of an unnecessary higher level of required strength should be avoided as it can

cause unintended consequences related to higher heat of hydration (due to a higher quantity of cementitious materials) and increased shrinkage that increase the potential for cracking and curling of concrete slabs.

If Case 2 is used to establish f'_{cr} to start a project, the designer should permit a reduction of the level of strength after at least 15 strength tests are collected and the standard deviation of that test record is used to indicate that a lower required average strength can be used. This requires a submittal of the revised mixture proportions to achieve the reduced level of average strength.

The concrete producer may need to make adjustments to concrete mixtures during the course of a project when strength tests fail the acceptance criteria or when trends indicate a potential for failure. The designer may require that these adjustments have to be submitted for acceptance.

- The concrete supplier submits information on the proposed concrete mixture documenting that it will achieve the established required average strength and other specification requirements. This can include:
 1. *Field data*: Field test records of at least 10 consecutive strength tests of the proposed class of concrete documenting the strength equals or exceeds the established f'_{cr} , including documentation that it meets other specification requirements. This test record can be different from that used to determine the standard deviation. It should be permitted to interpolate information from two sets of field test records of similar classes of concrete to establish the water-cementitious materials ratio or cementitious material content for the classes of mixtures for proposed Work.
 2. *Laboratory trial mixture data*: ACI 301 permits the concrete supplier to interpolate using three or more trial mixtures varying w/cm or cementitious materials content to arrive at the proportions of the proposed mixture.
Laboratory trial mixtures can be used even if the f'_{cr} was established using the standard deviation method to document that the proposed mixture will satisfy the specified requirements. It is also acceptable to document the characteristics of a proposed mixture by producing a batch of at least 3 cu. yd. in the concrete production facility.

Laboratory trial batch evaluation should not be required when a satisfactory field test record exists.

ACI 318-19 requires that trial mixture data should have been developed within 24 months of submittal. The time restriction for test records applies only to strength tests. Some durability tests require a longer lead time and older data should be considered acceptable if similar materials are used.

- The specification should not require laboratory trial batches to be prepared by an independent laboratory. This should be at the option of the concrete supplier. When the concrete supplier has laboratory facilities, documentation of concrete mixtures for submittals is best accomplished in those facilities. The concrete supplier has the best knowledge of the ingredient materials used and the ability to optimize their use to develop mixture proportions for a mixture submittal. Ultimately the acceptance criteria on a project govern over the submittal and an inappropriate submittal represents a significant risk to the concrete supplier and the project.

- A guide to submittal of concrete mixture proportions is provided in ACI 211.5R. A recommended format is in Appendix B of this document.
- If the specification includes performance-based requirements, the submittal information should be pertinent to compliance with the performance requirements of the specification. Documentation of concrete material quantities and other details of mixture proportions may not necessarily indicate such compliance. A certification of concrete mixtures signed by a professional engineer and test record and other prequalification performance data linked to the mixture identification should suffice as the submittal to the design professional. It is appropriate to require information about the concrete materials to demonstrate compliance with applicable material specifications. Development of optimized performance-based mixtures involves significant cost and effort by concrete suppliers and the resultant mixtures represent their proprietary intellectual property. Public disclosure of such information can impact their competitiveness. If mixture proportions of performance-based concrete are required to be submitted because of contractual

requirements, this information should be retained by the owner's representative under a confidentiality agreement with the manufacturer.

- The designer's review of the submittal of concrete mixtures for compliance with the project requirements should be the responsibility of the engineer of record or a qualified delegate.
- Review of the submittal could include verification that the concrete mixture certification is signed and sealed by a licensed engineer; include verification that it demonstrates compliance with certified requirements; and includes specific properties that can be verified during construction. These can include slump or slump flow, air content, density, temperature or other properties. Some of these can be used as indicators that the mixture delivered is similar to that in the submittal. The density of fresh concrete is a good measure of batch-to-batch uniformity and is useful for detecting batching errors.
- Some of the fresh concrete properties should be selected by the contractor and producer unless it is specifically required by the design professional for approving the construction means and methods. These characteristics can include slump and its adjustment, setting characteristics, finishability characteristics, characteristics for pumping mixtures, air content adjustments to accommodate placement methods, etc. The designer should avoid specifying a slump requirement as it might impact the ability to place the concrete. ACI 301 indicates slump selection by the contractor and the established value be documented in the submittal. Characteristics of fresh concrete recommended by the contractor, such as slump, may be used as a measure of consistency of concrete furnished to the project.
- (Item 12) The required air content of concrete depends on anticipated exposure of the concrete member and the nominal maximum size of the coarse aggregate. Air content should be as required for the applicable Exposure Class for Exposure Category F. It is permitted to reduce the air content by 1 percentage point from the table values for specified strength equal to or exceeding 5000 psi. This recognizes that air content results in a greater reduction of strength for higher strength and can increase the content of cementitious materials to achieve the required strength. Additionally, higher strength concrete has reduced porosity, which reduces its potential for becoming saturated with water that affects freeze thaw resistance. Exterior vertical members can be assigned to Exposure Class F1 that requires a lower air content because these are unlikely to become saturated in service.
- (Item 14) The maximum limits on supplementary cementitious materials (SCMs) should only be specified for members assigned to Exposure Class F3. These types of members are not common in buildings. The quantity of SCMs in blended cements needs to be known and this will limit the amount of additional SCMs that can be used.
- (Item 15) For Exposure Category S, besides using cementitious materials listed in ACI 318-19 Table 19.3.2, mixtures with SCMs that improve sulfate resistance as documented by previous service record or ASTM C1012 results are permitted.
- (Item 16) Water-soluble chloride limits are stated on the basis of total cementitious material content. Compliance with the chloride limits can be done by either the calculated chloride content based on the chloride content of constituent materials and mixture proportions; or a water-soluble chloride content measured in accordance with ASTM C1218/C1218 at an age of 28 to 42 days.
- (Item 17) Documentation for alkali-silica reactivity can include test results indicating that the aggregates proposed for use are non-reactive. If aggregates are reactive, mitigation may include using a minimum quantity of fly ash or slag cement as determined by testing in accordance with ASTM C1567 or the calculated alkali content in the concrete in lb./yd^3 can be documented to be less than specified limits provided in ACI 301. Only the alkali from portland cement is used in this calculation. More detail on alkali aggregate reactivity is covered in practice ASTM C1778.
- Consider defining the period of time for retention of batch records of individual concrete deliveries for forensic purposes (3-5 years from delivery date). Ready mixed concrete companies have internal policies for retention of records.
- The contractor might have requirements for uniform setting characteristics of deliveries of concrete batches. These requirements can be established by the producer and concrete contractor along with a means to verify

this requirement. This can impact the changing types and dosage of admixtures depending on environmental conditions.

D. Shop Drawings

E. Samples:

F. Concrete Schedule: For each type of concrete mixtures indicated in Article C, include the following:

1. Mixture Designation by Class
2. Location with Project
3. Exposure Class Designation
4. Other details on finishes, curing process, floor treatment, if any

1.6 INFORMATIONAL SUBMITTALS

A. Qualification Information

1. Installer: Include applicable ACI Certificates
2. Ready mixed concrete manufacturer
3. Testing agency retained by the contractor for field quality control: Include conformance to ASTM C1077 or ASTM E329 and copies of ACI certificates of testing technicians

B. Concrete Mixture Certification: For each class of concrete:

1. Signed and sealed by professional engineer licensed in the state of the Project.
2. Documentation of test results indicating compliance with specified requirements for each concrete mixture
3. Identity characteristics of each mixture that will be used for quality assurance during construction

- Certification of concrete mixtures by an independent licensed engineer for compliance with specification requirements can be used for performance-based specifications. This review can cover documentation of test data for different requirements for all classes of concrete. It can reduce some of the documentation in action and informational submittals traditionally required by the project design professional. Review of these details would be accomplished by the independent engineer.
- Several performance requirements for durability, volume change, and some mechanical properties of proposed concrete mixtures would be accomplished using pre-qualification testing. The process should indicate some identity characteristic of the different concrete mixtures that can be reliably measured when concrete is delivered for the purpose of quality assurance. This would not replace longer term testing of samples obtained at the jobsite, such as for strength at different ages.

C. Material Certificates: For each material provided by the material supplier

1. Cementitious materials
2. Aggregates
3. Admixtures
4. Fiber Reinforcement
5. Curing compounds
6. Floor and slab treatments
7. Bonding agents
8. Adhesives
9. Vapor retarders

10. Joint fillers
11. Repair materials
- D. Material Test Reports: For the following, from a qualified testing agency
 12. Portland cement
 13. Fly ash
 14. Slag cement
 15. Blended hydraulic cement
 16. Silica fume
 17. Performance-based hydraulic cement
 18. Aggregates
 19. Admixtures
- E. Floor surface flatness and levelness measurements report, indicating compliance with specified tolerances.
- F. Research Reports:
 1. Products with ICC evaluation
 2. Performance data for ASTM C494 Type S admixtures
- G. Preconstruction Test Reports: For each concrete mixture as specified
- H. Field quality-control reports
- I. Minutes of preinstallation meetings

1.7 QUALITY ASSURANCE

- A. Installer Qualifications: A qualified installer who employs Project personnel as an ACI-certified Flatwork Associate, Finisher, or Advanced Finisher and a supervisor who is certified by one of the ACI Flatwork Finisher Certification Levels.
 1. Post-Installed Concrete Anchors Installers: ACI-certified Adhesive Anchor Installer

- Flatwork finisher certification is important for constructing slabs on grade, however, general standard of care of concrete construction is addressed in this certification program. ACI Flatwork Finisher certification is a requirement in ACI 301. Review the levels and criteria for ACI Flatwork certification at www.concrete.org.
- The concrete contractor can be required to submit a quality control plan that outlines activities and procedures to minimize problems on the project.

- B. Ready Mixed Concrete Manufacturer Qualifications: A company manufacturing ready mixed concrete who complies with ASTM C94/C94M requirements for production facilities and equipment
 1. Concrete shall be supplied from concrete plants with current certification under the NRMCA Certification of Ready Mixed Concrete Production Facilities, certification or approval by a state or highway agency or equivalent. Criteria of equivalent certification shall be included in the submittal.
 2. Quality Control personnel with responsibility for concrete mixtures shall document qualifications demonstrating knowledge and experience with concrete technology and development of performance-based concrete mixtures. certified as an NRMCA

Concrete Technologist Level 2, or equivalent. Details covered in equivalent certification program shall be documented in the submittal.

3. When requested, the manufacturer shall furnish a Quality Plan.

- NRMCA certified concrete production facilities demonstrate compliance with requirements of ASTM C94 relative to production and delivery of ready mixed concrete. The certification includes an annual inspection and certification of delivery vehicles by inspectors approved by NRMCA. The certification of the production facility is valid for 2 years from the date of the inspection. Proper procedures for handling and storage of concrete ingredient materials that are important for product quality are also verified through the NRMCA Certification program. An equivalent state transportation department's plant approval or a company possessing ISO 9001 certification are acceptable alternatives.
- Industry programs can be considered for qualifications of ready mixed concrete personnel responsible for review of specifications and development of mixtures for performance-based and other specifications. ACI has the Concrete Quality Technical Manager certification. NRMCA has the Concrete Technologist Certification Program Levels 2, 3, and 4 that validates a person's knowledge of fundamentals of concrete technology, including mixture proportioning and concrete durability. Other NRMCA certifications pertinent to concrete quality include the Concrete Plant Operator certification for batch plant operators and the Concrete Delivery Professional certification for mixer truck drivers. For more information visit www.nrmca.org/certifications.
- NRMCA has developed a guideline for development of a quality plan. The document, along with a sample quality plan is available at www.nrmca.org/quality.

4. Documentation that the concrete supplier participated in supplying data to the NRMCA Cradle-to-Gate Life Cycle Assessment of Ready-Mixed Concrete.

- For concrete producers to be able to compare their product specific EPD results to the industry benchmarks, they must have provided data to the LCA report that presents the industry benchmarks. A list of companies that participated in the industry average benchmark report is provided at www.nrmca.org/sustainability.
- There may be other documents that use the same rigorous statistical methodologies and LCA principles to calculate benchmark and average GWP and other impacts. These could be developed by other organizations such as state and local ready mixed concrete associations, designer groups, or federal, state and local government entities that could be used as substitutes for these documents. Substitute those documents in this Section and elsewhere in this specification to be used as the basis for embodied carbon budget determination.

C. Testing Agency Qualifications: Independent testing agency complying with the requirements of ASTM C1077 for testing indicated and employing an ACI-certified Concrete Quality Control Technical Manager.

1. Personnel performing field tests for acceptance shall be certified as ACI Concrete Field Testing Technician Grade I, or equivalent.
2. Personnel conducting laboratory tests for acceptance shall be certified as ACI Concrete Strength Testing Technician or ACI Concrete Laboratory Testing Technician – Level I, or equivalent.
3. Test results for the purpose of acceptance shall be certified by a registered design professional employed with the Testing Agency.

- ACI 318, ACI 301, and ASTM C94 require that testing agencies contracted to perform acceptance testing should comply with ASTM C1077. This clause is included in the AIA MasterSpec. Compliance with ASTM C1077 can be a documented laboratory inspection by organizations such as the Cement and Concrete Reference Laboratory (CCRL) or accreditation by the AASHTO Accreditation Program (AAP). These programs

involve a thorough evaluation of laboratory equipment, procedures, personnel qualifications, and certifications and require participation in reference sample testing program to assure proficiency of testing. Other national, local, or regional evaluation authorities also perform inspection and accreditation functions to verify conformance to ASTM C1077. This standard establishes the requirements and criteria for evaluating the proficiency of testing laboratories involved in testing concrete and aggregates. The standard defines certification requirements for field and laboratory personnel of the testing agency.

- Results of concrete testing are sensitive to how specimens are fabricated, cured, handled, and tested. Procedural requirements for acceptance testing are addressed in ASTM C94/C94M and the referenced standard practices and test methods. Field and laboratory procedures that conform to established standards are essential to achieving reliable results. Deviations from standardized procedures will most often result in unacceptable results that increase project costs and delay schedules. Hence, technician certification is essential. Equivalent certifications to ACI should include a component whereby the technician physically demonstrates the performance of the test method and practices, and written examination on the content of the applicable standards.

1.8 PRECONSTRUCTION TESTING

A. Preconstruction Testing Service: When required, engage a qualified testing agency to perform specified tests on concrete mixtures.

- Many ready mixed concrete companies have well equipped laboratory facilities and can perform most of the common tests on concrete and concrete materials. A separate testing agency should not be required if the laboratory can perform mixture development and most of the standard test methods. There may be some tests that could be contracted out to an independent testing agency to perform.

1.9 DELIVERY, STORAGE, AND HANDLING

A. Comply with ACI 301 and ASTM C94/C94M.

1.10 FIELD CONDITIONS

A. Cold-Weather Placement: Comply with ACI 301 and ACI 306.1 and as follows:

1. Protect concrete work from physical damage or reduced strength that could be caused by frost, freezing actions, or low temperatures.
2. When average high and low temperature is expected to fall below 40°F for three consecutive days, maintain delivered concrete mixture temperature within the temperature range required by ACI 301
3. Do not use frozen materials or materials containing ice or snow
4. Do not place concrete in contact with surfaces less than 35°F, other than reinforcing steel
5. Do not use calcium chloride, salt, or other materials containing antifreeze agents or chemical accelerators unless other specified and approved in mixture designs.

B. Hot-Weather Placement: Comply with ACI 301 and ACI 305.1 and as follows:

6. Maintain concrete temperature at time of discharge to not exceed 95°F.
7. Fog-spray forms, steel reinforcement, and subgrade just before placing concrete. Keep subgrade uniformly moist without standing water, soft spots, or dry areas.

- There could be some conflicts between cold weather and hot weather requirements in ACI 301 and ACI specifications for cold weather concreting (ACI 306.1) and for hot weather concreting (ACI 305.1). Review these ACI specifications for differences if they are invoked. Guidance for hot and cold weather concrete

construction are addressed in the respective guides developed by these committees (ACI 305R for hot weather, and ACI 306R for cold weather). The guides developed by these committees, ACI 306R and ACI 305R, should not be referenced in a specification.

- For placement in cold weather, ACI 301 includes minimum concrete temperature as delivered based on minimum section dimension: 55°F if less than 12 in.; 50°F between 12 to 36 in.; 45°F between 36 to 72 in.; and 40°F if greater than 72 in. Temperature of embedded items, including bars with cumulative cross-sectional area less than 4 in², and formwork should be greater than 10°F. Temperature of ground, base, or mud mats should be at 32°F or greater before concrete is placed.
- For placement in hot weather, ACI 301 requires that temperature of reinforcement, embedments, or formwork should be less than 120°F.

PART 2 – PRODUCTS

2.1 CONCRETE, GENERAL

A. Comply with ACI 301 unless modified by requirements in the Contract Documents

2.2 CONCRETE MATERIALS

A. Regional materials

B. Source Limitations

1. Obtain all concrete mixtures from the same ready mixed concrete manufacturer for entire Project.
2. Use cementitious materials, aggregates, and admixtures of the same type or class and from the same sources as materials used in concrete represented by submitted concrete mixtures.

C. Cementitious Materials: Materials conforming to the following are permitted:

1. Portland Cement: ASTM C150/C150M,
2. Blended hydraulic cement: ASTM C595/C595M, excluding Type IS(>70) and Type IT(S>70)
3. Hydraulic cement: ASTM C1157/C1157M
4. Fly ash or natural pozzolan: ASTM C618/C618M
5. Slag cement: ASTM C989/C989M
6. Silica Fume: ASTM C1240/C1240M
7. Ground Glass Pozzolan: ASTM C1866/C1866M

- ASTM C150 is the specification for portland cement that defines 5 types. Type I is for general use; Type II is for moderate sulfate resistance – this cement type is more common; Type II (MH) is additionally a moderate heat of hydration cement, but for members where temperature rise is a concern, use of SCMs is common; Type III is a high early strength cement, typically used by the precast industry; Type IV is a low heat of hydration cement but is not available unless specifically ordered; Type V is a high sulfate resistance cement that is typically available in regions that need higher level of sulfate resistance.
- ASTM C595 is a specification for blended cements defining 3 essential types, with fly ash or pozzolan - Type IP(X), slag cement Type IS(X), and limestone – Type IL(X); or a ternary blend – Type IT. The quantity of the blended material is indicated by the value X in the type designation. Concrete producers can use additional SCMs with blended cement to meet strength and durability requirements. For projects that have a sustainability goal for reduced embodied carbon, blended cements and separately added SCMs can reduce the carbon footprint of concrete. Requiring a specific cement type or setting limits on cement or SCM content in concrete mixtures for sustainability goals should be avoided in a specification as these could impact achieving performance and constructability requirements. Generally, a portland limestone cement, ASTM C595, Type IL, can be considered equivalent to ASTM C150, Types I, II, or V, and can reduce the embodied carbon content of concrete by approximately 10% for projects with a sustainability goal. Type IL can be qualified for sulfate resistance – MS (moderate) and HS (high). Type IL cement can contain between 5 and 15% limestone that is not considered as a supplementary cementitious material. The same quantity of SCMs can be used with a Type IL cement as needed for strength and durability.
- ASTM C1157 is a performance specification for cement that does not restrict its composition but establishes requirements in terms of performance tests. It is more common for a concrete supplier to separately batch supplementary cementitious materials – fly ash or natural pozzolan, slag cement, or silica fume.
- If there is no pertinent durability concern such as sulfate resistance or concerns with excessive heat build-up, do not restrict the specific type of hydraulic cement. In most cases the predominant cement used by a

concrete supplier will be ASTM C150 Type I or Type II, ASTM C595 Types IP, IS, or IL, or ASTM C1157 Type GU. Other cement types or optional provisions of cement standards are generally invoked for durability concerns, high early strength or reduced heat of hydration.

- Many specifications include a clause requiring a single source of cement for the duration of the project. It is sometimes not practical to use single sources of cementitious materials for the duration of the project. Even single supply sources of cementitious materials vary over time and in periods of high demand there may be some changes in point sources of manufacture of cement or the collection of supplementary cementitious materials (SCMs) such as fly ash, slag cement, and silica fume. Cement companies and suppliers of supplementary cementitious materials attempt to control the uniformity of products shipped to the concrete producer. It is also the responsibility of the concrete supplier to make minor changes to concrete mixture proportions to address these material source variations. These minor adjustments should not typically require re-submittals. Single source is appropriate for architectural concrete and concrete producers will generally isolate a sufficient supply of such materials for the duration of a project.
- ASTM C1866/C1866M is a recently released specification and covers two different types of ground glass – Type GS that is typically from container glass and may have a higher alkali content; and GE glass that is processed from E-glass, a post-industrial glass fiber reinforcement, and has a lower alkali content. In general, GGP may not mitigate alkali aggregate reactions but does not exacerbate the problem. As a pozzolan it provides the beneficial properties to concrete. This specification is not referenced in ACI 318-19.
- Avoid limiting the type or minimum and maximum quantities of SCMs like fly ash, slag cement or silica fume, as this may limit the performance of concrete. SCMs provide many benefits to the mechanical and durability properties of concrete. Further, the use of SCMs supports sustainable construction and can be used to reduce the embodied carbon content of concrete. ACI 318 only places a maximum limit on the quantity of SCMs for exterior structural members that will be continuously moist in freezing weather and subject to application of deicing chemicals (Exposure Class F3). The concrete supplier may need to work with the contractor to ensure the type and quantity of SCM results in a mixture that can be placed and finished. Such limitations should be indicated in a submittal.
- Consideration should be given to not restrict fly ash only to Class F. In many parts of the country good quality Class C fly ash is also available. In some regions a good quality natural pozzolans (Class N) pozzolan, such as calcined clay or other naturally extracted and sometimes processed materials are available. Avoid invoking limits on the loss on ignition (LOI) of fly ash to less than that in the reference specifications. ASTM C618 has a LOI limit of 6%. Most fly ashes that are commercially available will not comply with a specified LOI limit of 2%, so in effect this will restrict its use. Avoid including limits on the available alkali of fly ash. ASTM has recognized that the available alkali does not have a good correlation to the performance of fly ash or its ability to mitigate alkali aggregate reactions and has deleted this limit from the specification.
- Note that concrete producers will not generally stock more than one or two types of SCM. The project specification will need to address local availability and experience. Requiring the use of the material that is not locally available will increase cost and could cause problems due to unfamiliarity with its use.
- Silica fume is mostly available in a densified powder form and batched in bags or bulk. Avoid specifying minimum (such as 10%) or maximum quantities of silica fume. Using higher quantities of silica fume can lead to stickiness and increased tendency for early age cracking unless additional precautions are taken during construction (see ACI 234R). There are synergies on concrete strength, permeability and ASR mitigation when fly ash and/or slag are used in combination with lower quantities of silica fume.
- Separately batched SCMs can be used with blended cements. Mixtures containing 3 or more cementitious materials are also used. The specification should not restrict these uses or place limits on separately added SCMs to mixtures using blended cement.

D. Normal-weight Aggregate: Coarse and fine aggregate that conform to ASTM C33

1. Nominal maximum size of coarse aggregate: *<indicate the size as per design requirements for each class of concrete> <indicate ASTM C33 Class if applicable>*

2. Provide documentation of tests or service record of adequate strength/durability for aggregates that do not conform to ASTM C33
3. Alkali Silica Reactivity: Comply with one of the following:
 - a. Aggregates are determined to be non-reactive: ASTM C1260 14-day expansion less than or equal to 0.10%, or ASTM C1293 1-year expansion less than or equal to 0.04%.
 - b. Aggregate and cementitious materials combination determined to be innocuous: ASTM C1567 14-day expansion less than or equal to 0.10%
 - c. Alkali content in concrete:
for aggregate with C1260 expansion between 0.1 and 0.3 percent or C1293 expansion between 0.04 and 0.12 percent – concrete alkali content shall be less than 4 lb/yd³;
for aggregate with C1260 expansion between 0.3 and 0.45 percent or C1293 expansion between 0.12 and 0.24 percent – concrete alkali content shall be less than 3 lb/yd³.
Alkali content is determined by weight of portland cement content in mixture multiplied by the equivalent alkali content of portland cement.

- ASTM C33 is the specification for aggregates that can be used in concrete. It addresses requirements for coarse and fine aggregates and sets limits on grading, deleterious materials, and other requirements. Coarse aggregate grading is defined by Size number with grading limits for each size fraction and defines the maximum size and nominal maximum size of the aggregate. Size restrictions on coarse aggregate should be based on clear cover and spacing of reinforcing steel and minimum dimension of members. ASTM C33 permits the use of aggregates that do not comply with its requirements when there is adequate documentation of the aggregate's use and performance in concrete. Local aggregates sources in some regions of the country will not comply with some requirements in ASTM C33.
- Combined aggregate grading requirements such as Coarseness Factor - Workability Factor charts or the 8-18 grading or other criteria are good concrete mixture optimization tools that can be used by the concrete producer when appropriate for the application and if the aggregate sources available make this possible. Including these as specified requirements should be avoided as they are generally not verifiable or enforceable. Studies have shown that there is no assurance that a requirement for combined aggregate grading criteria will result in reduced mixing water content or lower shrinkage as is typically intended. If the intent is to control shrinkage – a shrinkage limit using ASTM C157 can be specified. This information can be included in the submittal. Specification requirements for reduced shrinkage are addressed in 2.11.
- Use of aggregate that does not meet a coarse aggregate gradation size number within ASTM C33 but would otherwise meet all the other coarse aggregate requirements of C33 can be considered. This is often necessary when the concrete producer needs to optimize the grading of available local aggregates. This has the potential to improve the concrete performance and such supporting documentation of concrete performance can be included in the submittal. The scope section of ASTM C33 has language that allows for this.

- For alkali aggregate reactivity and associated deterioration, service records of aggregate in a region should be used with caution. Changes in aggregate sources and other ingredients in concrete can change the performance characteristics of concrete relative to alkali aggregate reaction. However, if there are no visible signs of ASR distress in exterior structures in a region, it could be considered when establishing specification requirements for ASR.
- Mitigation measures for alkali aggregate reactions are pertinent to structural members that will be wet in service (Exposure Class W1 and W2) and when there is a history of deleterious ASR cracking in the region. There is considerable guidance on ASR. ASTM C1778, *Guide for Reducing Risk of Deleterious Alkali-Aggregate Reaction in Concrete*, is a comprehensive process of assessment of ASR and establishing prescriptive and

performance-based requirements for mitigation. The options for ASR addressed here are from ACI 301 and are consistent with the guidance in ASTM C1778.

- ASTM C1260 is a severe test that has a high frequency of classifying non-reactive aggregates as being potentially reactive. If an aggregate source passes this test, there is a good likelihood that it will be non-reactive in service. However, there are few aggregate sources that will test to be non-reactive by this test and have shown ASR distress in structures. ASTM C1260 is commonly used because of its shorter testing duration.
- The more reliable test relative to field service performance is the concrete prism test, ASTM C1293, which requires 1-year for results to be obtained and does not suit most project schedules, unless such data already exists. ASTM C1293 evaluates the potential reactivity of aggregates (1-year test) or for determining mitigation of combination of cementitious materials with the aggregates (2-year test). The 2-year time period for evaluating mitigation measures is not practical for project schedules in specifications. In general ASTM C1567 provides a conservative assessment of mitigation measures in shorter time period.
- ASTM C1567 is a standard test method for determining mitigation effectiveness of the cementitious materials with a source of potentially reactive aggregates in minimizing the potential deleterious expansive cracking due to alkali-silica reactivity (ASR) in the field. The test can be completed in 2 weeks. Generally, fly ash, slag cement, or other pozzolans are used in concrete mixtures as mitigative measures for ASR. Higher quantity of SCMs results in improved mitigation. If the service records or tests indicate that the aggregate is potentially reactive, the concrete supplier can perform ASTM C1567 tests with different types and proportions of SCMs and choose that combination that yield a 14-day expansion less than or equal to 0.1%. For example, if the test result with 25% of a fly ash has an expansion equal to or less than 0.1% the concrete supplier should use at least 25% of that fly ash in the concrete mixture.
- An alternative option is to limit the total alkali content in concrete mixtures, from the portland cement. ACI 301 includes limits of to 3 or 5 lb./yd³. depending on the degree of reactivity of the aggregate based on expansions in either ASTM C1260 or ASTM C1293. Using a low alkali cement is not considered a reliable means of mitigating deleterious expansion due to ASR. ASTM C150 has removed the optional criteria that defines a “low-alkali” cement.
- Other prescriptive alternatives to mitigate ASR, requiring minimum quantities of fly ash or slag cement based on the risk level of the structure are addressed in ASTM C1778.
- In regions where sources of fly ash, natural pozzolans, or slag cement are of characteristics that cannot mitigate ASR or are not available, the use of lithium-based admixtures is an option. Refer to ASTM C1778 for guidance on use of lithium admixtures or consult with the admixture supplier on dosage requirements.
- A minimum cementitious materials content is not needed for mitigating deleterious expansions due to ASR.

E. Mineral Filler: ASTM C1797

- Finely ground mineral filler composed from calcium carbonate or other aggregate materials can be used to improve workability and reduce segregation of concrete mixtures. Mineral fillers are often used in self-consolidating concrete mixtures. These materials can provide beneficial improvements to hardened concrete properties. ASTM C1797 includes requirements for three types of mineral filler – A, B, and C. Types A and B are derived from carbonate rock with differences primarily in fineness. Type C can be derived from any aggregate material. At this time ACI 318 restricts the use of carbonate-based mineral fillers from use in concrete that will be exposed to sulfates (Exposure Category S), until more evaluation and research is available.

F. Lightweight Aggregate: ASTM C330/C330M

G. Heavyweight Aggregate: ASTM C637/C637M

H. Water: ASTM C1602/C1602M

- ASTM C1602 includes provisions for using potable water and water from non-potable sources. This standard allows for alternative sources of water with appropriate testing and qualification. Documentation of such qualification can be requested in a submittal. The project specification should avoid restricting mixing water to

only potable sources. Use of non potable water and water from concrete production operations facilitates innovative concrete producers who have progressed to advanced environmental management systems to reuse recycled water from concrete production operations or from other sources. This supports sustainable construction initiatives.

- ASTM C1602 includes optional limits on concentration of sulfates, chlorides and alkalis and additional optional limit on total solids. These limits should be individually invoked when applicable.

I. Chemical Admixtures:

1. Air-Entraining Admixture: ASTM C260/C260M
2. Water-Reducing Admixture ASTM C494/C494M Type A
3. High-Range Water-Reducing Admixture: ASTM C494/C494M Type F or G
4. Accelerating Admixture: ASTM C494/C494M Type C or E
5. Retarding Admixture: ASTM C494/C494M Type B or D
6. Extended Set-Retarding Admixture: ASTM C494/C494M Type B or D
7. Workability-Retaining Admixture: ASTM C494/C494M Type S
8. Shrinkage-Reducing Admixture: ASTM C494/C494M Type S
9. Viscosity Modifying Admixtures: ASTM C494/C494M Type S
10. Alkali-Silica Reaction Inhibiting Admixture: ASTM C494/C494M Type S
11. Corrosion-Inhibiting Admixture: ASTM C1582/C1581M
12. Admixtures that do not conform to an existing specification shall be used with the permission of the engineer of record when its use for specific properties is required.

- Avoid limiting the types of admixtures that can be used unless there is a specific reason.
- Set control admixtures should be permitted in cold weather concreting. Chloride based admixtures should be avoided only for reinforced concrete. Chloride based admixtures are very effective for controlling set time and allowing rapid construction schedules in plain concrete such as ground supported building slabs or lightly reinforced walls.
- Listing brand name products should be avoided. It is preferable to make a reference to a generic classification, such as “Water reducers conforming to ASTM C494 Type A”.
A list of acceptable brand name products cannot be all inclusive; often brand names listed are dated and not available; the ready mixed producer may not have the specific product available due to regional differences or business relationships with an admixture supplier; using a product unfamiliar to the producer may result in a cement-admixture incompatibility; and controlling brands stifles innovation.
There are situations where invoking a brand name may be appropriate when there is experience with its use or documented performance significantly exceeds specification requirements for admixtures.
- Limits on chloride ions for admixtures should not be invoked. Instead specify appropriate chloride limits for concrete mixtures consistent with ACI 318 and ACI 301. Defining the Exposure Class in Section 2.11 accomplishes this. Limiting chloride concentration for admixtures does not protect against chlorides from other sources and the potential for corrosion or reinforcing steel in concrete. It is not necessary and may not be justified for economic reasons to restrict chloride ions in admixtures for concrete without structural reinforcement (plain concrete) or for concrete structural members that will be dry in service.
- Consider specifying or permitting the use of admixtures which do not have a specific ASTM designation with appropriate documentation indicating beneficial use to concrete properties. These may include color pigments, viscosity modifying admixtures, shrinkage reducing admixtures, hydration stabilizing admixtures, pumping aids, anti-freeze admixtures, alkali silica reactivity, etc. Documentation should satisfy the professional engineer on the product performance and service history. ASTM C494 Type S is a general

classification intended to cover admixture products that provide a specific performance enhancement to concrete. The performance enhancement should be documented by appropriate testing.

J. Color Pigment: ASTM C979/C979M

2.3 FIBER REINFORCEMENT

- A. Carbon-Steel Wire Fiber: ASTM A820/A820M, Type 1 <specify length and aspect ratio if needed>
- B. Carbon-Steel Cut Sheet Fiber: ASTM A820/A820M, Type 2 <specify length and aspect ratio if needed>
- C. Synthetic Monofilament Micro-Fiber: ASTM C1116/C1116M, Type III <specify length if needed>
- D. Synthetic Fibrillated Micro-Fiber: ASTM C1116/C1116M, Type III <specify length if needed>
- E. Synthetic Macro-Fiber: ASTM C1116/C1116M, Type III <specify length and quantity if needed>

- ASTM D7508/D7508M addresses requirements for polyolefin-based synthetic fibers and includes requirements for chopped strands for micro, macro, and hybrid fibers including Denier, Finish Content, Tensile Strength, and cut length

2.10 CONCRETE MIXTURES, GENERAL

- A. Prepare design mixtures for each type and strength of concrete on the basis of laboratory trial mixtures or field test data, or both according to ACI 301.
- B. Cementitious Materials: Limit percentage, by weight of cementitious materials other than portland cement in concrete for concrete assigned to Exposure Class F3 as follows:
 - 1. Fly ash or other pozzolans: 25 percent by mass
 - 2. Slag Cement: 50 percent by mass
 - 3. Silica Fume: 10 percent by mass
 - 4. Total of fly ash or natural pozzolans and silica fume: 35 percent by mass
 - 5. Total of fly ash or natural pozzolans, slag cement, and silica fume: 50 percent by mass

- These maximum limits on SCMs should only be specified for members assigned to Exposure Class F3 and not to all concrete in a structure. The intent is to minimize the potential for scaling of concrete surfaces when the application of deicing salts. Imposing these limits for all concrete on a project could adversely impact durability or sustainability goals. The potential for scaling with higher quantities of SCMs is not too common if finishing operations are properly timed. These limits may be deleted for machine finished concrete, such as slip form construction because the potential for scaling is considerably reduced.

- C. Admixtures: Use admixtures in accordance with manufacturer's instructions
- D. Color Pigment: Use color pigment in accordance with manufacturer's instructions. If specified, color of hardened concrete should match approved mockup.

2.11 CONCRETE MIXTURES

- A. Requirements for different classes of concrete mixtures for different locations or structural members shall be as follows:

<provide a schedule for different classes of concrete required for the structure. Include detailed requirements pertinent to exposure classes in accordance with ACI 318.>

Class	Location	Nominal Max. Aggregate Size	Exposure Classes	f'_c , psi	Max w/cm	Slump or Slump Flow	Air Content	Water-soluble Chlorides

- Provide a schedule of concrete types (classes) for all components of the structure including the pertinent exposure class from ACI 318 based on anticipated exposure conditions for each location in the structure. When the exposure does not apply indicate the “*0” class for that exposure category. The definition of exposure classes and the pertinent requirements for concrete as per ACI 318-19 are provided in Appendix A. The exposure categories include:
 - Category F – Exposure to cycles of freezing and thawing
 - Category S – Exposure to water soluble sulfates in soil or water
 - Category W – Concrete in contact with water
 - Category C – Conditions requiring corrosion protection of reinforcement.
- For clarity it is recommended to state the requirements pertinent to the governing exposure classes in the project specification as the contractor and concrete supplier may not be familiar with code-defined exposure classes and requirements. Ensure that the specified strength is consistent with the most restrictive requirement governed by structural design and the applicable exposure class for each class of concrete.

- The engineer should minimize prescriptive requirements on concrete mixtures and construction means and methods and increase the focus on measurable performance attributes when appropriate. The inclusion of both prescriptive and performance requirements in the specification can lead to inherent conflicts. It is unreasonable for a concrete producer to be held responsible for performance attributes implied (but not clearly stated) from prescriptive requirements.
- Nominal maximum aggregate size and specified compressive strength must always be indicated. Nominal maximum size of coarse aggregate should be in accordance with ACI 318 – 26.4.1.2 Aggregates. The nominal maximum size of aggregate pertains to restrictions of minimum section thickness, spacing of reinforcing steel and clear cover. Permitting the largest nominal maximum size is recommended for economy and reduced volume change characteristics. It should be ensured that the aggregate size is available locally. Using a large aggregate size can be difficult to handle during concrete production relative to control of segregation.
- Indicate strength as “specified strength” using notation f'_c consistent with industry terminology. The strength acceptance criteria are based on this specified strength. This is the strength that the engineer uses in structural design. The higher of the specified strength required for durability criteria and design loads will apply. If the specified strength required by durability criteria governs, the design engineer should take advantage of that strength level when designing structural members.
- In general, specified strength for concrete applies at an age of 28 days. In some cases, it is necessary or appropriate to specify a strength requirement at an earlier or later age. For post-tensioned construction an early age strength requirement may be necessary. For high strength concrete when service loads are not anticipated to be applied until much later, it may be appropriate to use a later age, such as 56 or 90 days, for the specified strength. This allows for more optimized concrete mixtures without using excessively high

cementitious materials content. Higher cement content can increase potential for cracking from shrinkage and thermal effects. It also increases cost and negatively impacts sustainability goals.

- The specified compressive strength requirement for the durability exposure classes is an attempt at matching the strength to the required water to cementitious materials ratio. This is because, in most cases, strength can be more easily verified by strength tests. The engineer should avoid indicating a specified strength that is significantly lower than what might be expected for a specified w/cm, for example 3000 psi and a 0.40 w/cm. A concrete mixture at a 0.40 w/cm will result in a strength level in excess of 6000 psi. The strength acceptance criteria do not work for this type of specification. There is no reliable method to verify the w/cm of samples of concrete obtained at the jobsite.
- Maximum w/cm, air content, cement type are controlled by exposure classes. Avoid specifying these requirements if they are not applicable to the anticipated service conditions of the structural members. Including a maximum w/cm for concrete where it is not essential can adversely affect the ability to place and finish concrete and the concrete performance because of possibly increased paste content, elevated concrete temperature, and increased propensity for cracking.
- Refer to water to cementitious materials ratio (w/cm) instead of water to cement ratio (w/c). SCMs are cementitious materials and should be included in the calculation of w/cm. Referring a water-cement ratio based on the mass of only portland cement is misleading and contrary to industry practice as defined in ACI, ASTM, FHWA and all state departments of transportation.
- Unless there are specific design-related implications, the design professional should allow leeway to the contractor and manufacturer on the characteristics of fresh concrete to accommodate construction means and methods and ambient conditions.
- The engineer should avoid specifying a maximum or target slump as it may impact constructability. It is recommended that the slump should be selected by the contractor and concrete supplier based on the placement and finishing requirements of the concrete. This is the way slump is addressed in ACI 301. The target slump can be provided to the engineer of record in the submittal and can be used as a basis for quality assurance. Realize that with today's concrete technology, slump is not a measure of quality or water content but it can be used as a determining factor of the batch to batch uniformity. If the engineer chooses to specify slump it should be specified as a target limit, where the appropriate \pm tolerances in ASTM C94/C94M will apply. A maximum slump limit is appropriate for slip form applications. Specifications for slump should not be set at a certain level before addition of water reducing admixtures with a subsequent limit after the addition. It is not possible to verify this type of requirement. Admixtures have evolved so that they are generally added at the concrete plant with better control rather than delegating this responsibility to mixer drivers at the jobsite. With the use of water reducing admixtures slump cannot be taken as a representation of the quantity of water in the mixture.
- The contractor might have requirements for uniform setting characteristics of deliveries of concrete batches. These requirements can be established by the producer and concrete contractor along with a means to verify this requirement.
- The specification should avoid specifying minimum contents for cementitious materials. ACI 318-19 or 301-20 do not include any requirement for minimum cementitious materials content. There is no technical reason to include minimum cementitious materials content for other structural elements provided the performance requirements are achieved. In some cases, these are specified for slabs requiring a hard-trowelled finish. However, minimum cement contents may not assure adequate finishability of floor slabs. These issues can be resolved between the concrete supplier and the contractor, more reliably than an expectation by imposing a limit on cementitious materials.
- For projects with a sustainability goal, a maximum cement content should not be specified for concrete mixtures. Cement content requirements vary considerably for constructability, early strength and other properties and should not be limited based on design strength of structural members. For sustainability goals, options may be to establish a carbon budget for all concrete on a project – this permits tradeoffs between different types of member requirements – where concrete for a foundation that can achieve strength at later ages can be at a lower carbon footprint than a post-tensioned member that needs to achieve strength at an

early age. Alternatively, reduction in carbon footprint relative to typical mixtures or industry benchmarks could be used.

- Do not restrict the minimum or maximum percentage of SCM except unless there is a particular requirement in local building codes. ACI 318 establishes maximum limits of SCMs for concrete surfaces subject to deicer salt application in continuously moist conditions (Exposure Class F3) only. The concrete producer should be permitted to optimize SCM content based on strength, durability enhancement, and required characteristics for plastic concrete during placement and curing.
- It is recommended that the specification should not include restrictions on the quantity of SCMs such as “1.2 pounds of fly ash replacement per pound of cement”. This is not a technically sound approach as the fly ash or SCM content as a percent of the cementitious materials will vary for strength targets at different ages, climatic conditions, use of admixtures, cement and SCM sources. This also increases the volume of paste in concrete and can increase the shrinkage. The concept of “replacement” of SCM for portland cement is deprecated. SCM content is always stated as a percentage of total cementitious material.
- It is recommended that the specification should not include a requirement to simulate field temperature and humidity for lab trial batches. It is impossible to anticipate or cover all potential situations. Lab trial batches are tested in accordance with standard procedures by ASTM C192 where laboratory temperatures of $73 \pm 3^{\circ}\text{F}$ apply. If hot weather job concreting must be simulated in the laboratory the approach suggested in ACI 305 for lab trial batches could be adopted. The established acceptance criteria for the project will still apply.

Exposure Category F – Freezing and Thawing

- In accordance with ACI 318, for concrete members that will be exposed to cycles of freezing and thawing, specify minimum specified compressive strength f'_c and maximum w/cm:
Class F1 - 3500 psi and 0.55;
Class F2 - 4500 psi and 0.45;
Class F3 for structural concrete 5000 psi and 0.40 (intent is to be consistent with exposure class C2); or 4500 psi and 0.45 for plain concrete.
The commentary of ACI 318 provides examples of concrete members (include in Appendix A) for assignment of appropriate exposure classes in Exposure Category F.
- Air content requirements for exterior concrete should be in accordance the appropriate exposure class in ACI 318. For exposure classes F2 and F3 where concrete is considered to be saturated in service, a higher air content is required. The air content requirements depend on the nominal maximum size of coarse aggregate. For specified compressive strengths equal to or greater than 5000 psi, the air content is permitted to be reduced by 1.0%. Entrained air content reduces strength and will need a higher cementitious materials content to achieve specified strength requirements.
- Many regions of the country do not need air-entrained concrete for exterior applications. In these regions there is often little experience with producing and finishing air-entrained concretes. For concrete not exposed to freezing conditions an air content requirement should not be specified.
- Building slabs or floors that receive a hard trowelled finish should not be air entrained. This causes a high likelihood of delaminations of the concrete surface. ACI 301 specifies that air content of concrete for slabs to receive a hard trowel finish should not exceed 3%.
- Maximum limits on the quantity of SCMs should be invoked for exposure class F3 – continuous exposure to moisture and exposure to deicing chemicals. Do not include these limits if this exposure does not apply.
- A minimum cementitious materials content is not needed for freeze thaw durability.
- If this exposure category does not apply, do not include these limitations.

Exposure Category S – Concrete in contact with water soluble sulfates in soil and water.

- The following methods are used to determine the concentration of water-soluble in soil and water from which the assignment of Exposure Class applies: ASTM C1580, *Standard Test Method for Water-Soluble Sulfate in*

Soil, ASTM D4130, *Standard Test Method for Sulfate Ion in Brackish Water, Seawater, and Brine*, and ASTM D516, *Standard Test Method for Sulfate Ion in Water*.

- For concrete members in contact with water-soluble sulfate in soil or water, specify minimum specified compressive strength f'_c and maximum w/cm:
Class S1 - 4000 psi and 0.50;
Classes S2 and S3 – 4500 psi and 0.45.
For exposure class S3, Option 2 lists 5000 psi and 0.40 that permits the use of Type V and blended cement with HS designation (high sulfate resistance) with no additional SCMs.
- Permitted types of cementitious materials are addressed in ACI 318 and the design professional may choose to select one of the options or provide the choice to the contractor to document the sulfate resistant cementitious materials proposed for use in the submittal.
- ACI 318 also provides an alternative to the cementitious types when the proposed cementitious materials have been qualified by testing in accordance with ASTM C1012. ASTM C1012 is a standard test method for length change of hydraulic-cement mortars exposed to a sulfate solution. Since the duration of this test is quite long, this qualification will generally be available for cements complying with ASTM C595 – options MS and HS or ASTM C1157 Types MS and HS. Evaluation of SCMs for sulfate resistance is covered as optional requirements in the respective specifications. For Exposure Class S3, Option 2 permits a shorter time test (1 year) with a max w/cm of 0.40 and specified strength of 5000 psi. Suppliers of fly ash or slag cement might have these data documented when these materials are used in regions with higher sulfate content in the soil. Calcium chloride admixtures are not permitted for Classes S2 and S3. ASTM C1012 information is documented in a submittal and not used as a jobsite acceptance test.
- Note that exposure to seawater is considered to be a milder exposure at Exposure Class S1 even though the sulfate ion concentration is high. The more aggressive chemical species in seawater is considered to be chloride ions and some protection is afforded with higher aluminate (C_3A) content in cements for this condition. Members exposed to seawater will need to be assigned to Exposure Class C2 because of the external source of chlorides. The w/cm and specified strength for C2 will govern.
- A minimum cementitious material content is not needed for exposure to water-soluble sulfates.
- If there is no exposure to sulfates, do not include these limitations.

Exposure Category W – Concrete requiring low permeability in direct contact with water but not exposed to freezing and thawing, sulfates, or chlorides

- This exposure category has limited application in building structures when the other categories do not apply. Some applications might be for water tanks or substructure elements constructed underwater.
- However, for members assigned to Exposure Classes W1 and W2 – in contact with moisture – the specification should include considerations for alkali aggregate reactivity. See earlier discussion on this.
- When Exposure Class W2 applies the minimum specified strength f'_c is 4000 psi and maximum w/cm is 0.50.
- A minimum cementitious material content is not needed for exposure class W1 or W2.
- If exposure class W1 or W2 do not apply, do not include these limitations.

Exposure Category C – Conditions requiring corrosion protection of reinforcing steel

- The primary intent of exposure classes C0 and C1 are to control an internal source of chlorides in concrete. Additionally, in exposure category C2 the intent is to minimize the penetration of chloride ions from external sources to cause corrosion of reinforcement.
- Chloride ion limits for concrete mixtures are based on ACI 318. The chloride ion content, expressed as a percent by weight of cementitious materials, can be documented by a calculation of the total chlorides contributed by all materials in the mixture such that the calculated value is less than the water-soluble chloride limit. Alternatively, the water-soluble chloride content is measured on hardened concrete specimens in accordance with ASTM C1218 at an age between 28 and 42 days.

- In accordance with ACI 318, the minimum specified strength of 5000 psi and maximum w/cm of 0.40 are only applicable for reinforced concrete structural members that will be exposed to an external source of chlorides in service – exposure class C2. Since chlorides are a component in most deicing chemicals, the requirements for structural concrete members for strength and w/cm are the same for exposure classes C2 and F3.
- For concrete exposed to chlorides (bridge decks, marine structures, parking garages) it is well known that fly ash, silica fume and slag can delay the initiation of corrosion by reducing permeability, with increasing levels typically leading to improved performance. However, it is not advisable to require prescriptive proportions of fly ash and slag to achieve the improved performance. Corrosion inhibiting admixtures provide additional protection by delaying the time to initiation of corrosion. Do not specify maximum limits on SCM quantities if exposure class F3 does not apply.
- A minimum cementitious material content is not needed for corrosion protection.
- If this exposure category does not apply, do not include these limitations.

- For exposure categories F, S, W, and C, ACI 318 includes prescriptive max limits on w/cm for concrete. A limit on w/cm is intended to reduce the permeability of concrete and improve its durability for these exposure conditions. In general, the permeability of concrete is impacted by both the w/cm and the composition of the cementitious materials. The singular limit on w/cm does not recognize benefits to improved durability provided by SCMs. An alternative performance-based approach may be considered by the designer.
- ASTM C1202 is a standard test method for rapid indication of concrete's ability to resist chloride ion penetration. This is an electrical method whereby the electrical charge passed, in coulombs, has been correlated to the "permeability" property of concrete. A lower charge passed represents reduced permeability. Prescriptive limits on quantities of fly ash, slag or silica fume dosage should be avoided. It is suggested that the engineer require at the time of submittal documentation qualifying the proposed concrete mixture by ASTM C1202 with a test value lower than a specific coulomb value at 28 or 56 days depending on curing method used. An accelerated curing procedure in the standard recognizes the benefits provided by fly ash and other SCMs. This subjects test specimens for 7 days in water at 73°F followed by 21 days of curing in 100°F water. If a standard curing procedure is used, the test should be conducted after a curing period of 56 days. This allows for the SCMs to demonstrate effectiveness in reducing permeability of concrete.
Requiring this test should be as an **alternative** to specifying a maximum w/cm.
- Consider the use of ASTM C1202 to replace both the w/cm and f'_c with the following alternative criteria:
 - w/cm = 0.50 → 2500 coulombs
 - w/cm = 0.45 → 2000 coulombs
 - w/cm = 0.40 → 1500 coulombs
- Note that ASTM C1202 test has a high testing variability and often technicians and laboratories are not proficient in sample care and testing required for reliable results. It is not advised to use this test for acceptance purposes unless a statistical approach is adopted. One such statistical approach is discussed in the article *Acceptance Tests for Concrete Durability* in the May 2007 issue of Concrete International. Strength acceptance criteria can be used for quality assurance, as is done for specified w/cm.
- Other test methods and criteria for reduced permeability are evolving. A more recent test method to measure transport properties of concrete is to measure its resistivity in accordance with ASTM C1876. Concrete with a higher measured resistivity is more resistant to penetration of dissolved chemicals. Resistivity in the range of 80 to 120 Ω -m is typically used (higher value represents reduced permeability). The availability of laboratories that can perform this test is evolving. Resistivity is impacted by degree of saturation and the composition of the mixture and its pore solution.

B. For members where control of curling or reduction in the potential for cracking is required and as designated in Contract documents, submit data on the length change characteristics of the concrete mixture tested in accordance with ASTM C157. Perform ASTM C157 tests

and submit data showing length change not exceeding 0.05% after 7 days of moist curing followed by 21 days of air drying.

- ASTM C157 is the standard test method for length change of hardened hydraulic-cement mortar and concrete. The precision in terms of repeatability or reproducibility is not very good. It is a laboratory test and therefore must be used only for mixture qualification documented in the submittal. The test and required specimen care is not conducive for use with samples obtained at the jobsite for concrete acceptance. These factors include preparation of samples, curing at the jobsite, specimen handling, strict adherence to the test procedures and other details that can impact the results and pose a high risk of rejecting acceptable concrete. Knowledge of local materials shrinkage characteristics, optimizing concrete mixtures for lowest paste volume, and the use of shrinkage reducing admixtures, as needed, are ways to achieve reduced shrinkage.
- Establishing specification requirements on grading limits of aggregates does not always assure reduced void content between aggregates, reduced paste volume, and thereby lower shrinkage.
- Shrinkage is impacted by quantity of water in concrete, paste volume, aggregate characteristics, and other factors. A low w/cm does not assure reduced shrinkage.

C. The installer and manufacturer shall coordinate to establish properties of the fresh concrete to facilitate placement and finishing with reduced potential for segregation and bleeding. Factors shall include but are not limited to slump or slump flow, setting time, method of placement, rate of placement, hot and cold weather placement, curing, and concrete temperature. Selection of fresh concrete properties shall be submitted.

- A smaller nominal maximum aggregate size may be needed for improved constructability.
- Air content for concrete is based on the nominal maximum aggregate size indicated. If smaller nominal maximum size aggregate is selected the air content (and acceptance range) should be adjusted accordingly.
- Even if no air entrainment is specified the contractor, installer, and manufacturer may choose to include air entrainment to reduce segregation and to improve placement and finishing characteristics.

D. Contractor shall indicate reportable changes in sources of materials and quantities when such changes are necessary to ensure constructability, performance of concrete and compliance with the specification requirements. The contractor is permitted to make minor adjustments less than the reportable deviations noted in the original submittal to concrete mixtures to ensure uniformity of concrete without a re-submittal for review or approval.

- Real time adjustments to concrete mixtures are necessary to accommodate changes in material characteristics, seasonal ambient conditions, and jobsite conditions. Examples include changing fineness modulus of sand or coarse aggregate grading, cement chemistry, moving from summer to winter construction, placement methods or jobsite constraints, to mention a few. Concrete mixtures will need adjustments to quantities of cementitious materials, admixture dosage, and aggregates to achieve consistent concrete. Requiring a re-submittal with 28-day strength data on relatively minor adjustments is not practical and will delay construction schedules. The design professional may consider obtaining an original submittal stated in acceptable ranges of ingredient quantities or one that documents anticipated changes. Some of these changes in material quantities cannot be ascertained at the beginning of the project. Significant changes in types of ingredients that have been pre-qualified for certain durability requirements may not be appropriate. It is recommended that this issue be discussed in pre-construction meetings.
- The engineer and contractor / concrete supplier should agree at the time of submittal on what is a reportable change that would require a re-submittal. Examples might be different source or classification of materials and defined deviations of quantities of mixture ingredients from that of the original submittal.

E. Provide documentation that the total GWP of all proposed concrete on the project is less than or equal to _____ kg of CO₂ equivalents.

- The design professional should establish a target for GWP, or a carbon budget for all the concrete on the project. Examples of how to establish a carbon budget is shown in Appendix C. The concrete supplier and contractor then can work together to provide concrete mixtures that have GWP such that the total GWP for all the concrete supplied for the building will be lower the target established here. See Section 1.5 for details on how the contractor demonstrates that the concrete supplied has lower GWP than the target.

2.12 CONCRETE MIXING

- A. Measure, batch, mix, and deliver concrete in accordance with ASTM C94/C94M.
- B. Project-Site Mixing: Measure, batch, and mix concrete in accordance with ASTM C94/C94M. Mix concrete in acceptable stationary mixer.

PART 3 – EXECUTION

3.9 CONCRETE PLACEMENT

- A. Before placing concrete, verify that installation of formwork, reinforcement, and embedded items is complete and that required inspections have been performed.
- B. Measure, batch, mix, deliver, and provide delivery ticket for each batch of concrete in accordance with ASTM C94/C94M.
 1. Water is permitted to be added to a batch of concrete at the project site before placement provided that the amount of water added does not exceed the allowed amount indicated on the delivery ticket. Water addition shall only be permitted before any portion of the load is discharged. Samples for quality assurance tests shall be obtained after water addition and additional mixing in accordance with ASTM C94/C94M.
 2. It is permitted to add water to the concrete mixture during transportation to the jobsite when concrete is transported in truck mixers equipped with automated water measurement and slump or slump flow monitoring equipment in accordance with ASTM C94/C94M.

- Water addition at the job site is often necessary to facilitate placement and finishing and should be permitted if it is within the limits of the approved mixture. Ready mixed producers often hold back water to facilitate this job-site addition to accommodate traffic/jobsite delays in placement and to satisfy the needs of the concrete contractor. The concrete mixture can be designed and approved at the maximum stated mixing water content. On request, producers can indicate on the delivery ticket the amount of water that can be added at the jobsite. ASTM C94 permits the addition of water if measured slump is below target levels. It is also common to increase the slump of the concrete using water reducing admixtures at the jobsite followed by appropriate mixing. However, admixture addition requires a certain degree of technical capability to ensure its not overdosed and this may not be available on the job site. Improper tempering concrete with water reducing admixtures at the jobsite can result in excessive slump, setting time retardation or cement-admixture compatibility problems.
- Automated water measurement and slump monitoring devices inject water when a reduction in slump is detected. The quantity of water is recorded and the system can be set to prevent water addition in excess of a maximum limit.
- It is recommended that the specification should not include more restrictive delivery time limits than specified in ASTM C94/C94M. Judicious use of water reducing, workability retaining, and retarding admixtures and methods for reducing concrete temperature can generally ensure that the concrete will meet the project requirements for placing and finishing when discharged. ASTM C94/C94M permits limits on discharge for truck mixer revolutions or time from batching to be set between the contractor and the concrete producer. This is because project conditions vary considerably, and a default time or revolution limit is not considered to be appropriate or protective to the quality of concrete. If the intent of delivery time restriction is uniform setting time for slab pours the contractor and the concrete supplier can work to define an acceptable setting time window that will facilitate proper finishability. In places like Houston, Phoenix, Florida, temperatures exceed 95°F for an extensive duration of the year and discharge of concrete after an extended duration from the time of batching is successfully accomplished with the use of admixtures.

3.15 FIELD QUALITY CONTROL

- A. Special Inspections: Owner will engage a special inspector to perform field tests and inspections and prepare testing and inspection reports

- B. Testing Agency: Owner will engage a qualified testing and inspecting agency to perform tests and inspections and to submit reports
1. Unless otherwise specified, the testing agency shall be responsible for providing containers and securing means with the contractor for initial curing at the jobsite for standard-cured strength test specimens used for determining acceptance of concrete and shall be responsible for maintaining and transporting these specimens to the laboratory in accordance with ASTM C31/C31M; and shall be responsible for verifying that standard-cured and field-cured strength specimens, when specified, are cured in accordance with ASTM C31/C31M.
 2. Testing agency shall report to Architect, Contractor, and concrete manufacturer any failure of Work to comply with Contract Documents
 3. Testing agency shall report results of tests and inspection to Owner, Architect, Contractor, and concrete manufacturer within 48 hours of inspections and completion of tests.
 - a. Test reports of concrete strength shall include reporting requirements of ASTM C31/C31M and ASTM C39/C39M including the following:
 - (1) Project Name
 - (2) Name of testing agency
 - (3) Names and certification numbers of field and laboratory technicians performing tests
 - (4) Name of concrete manufacturer
 - (5) Date and time of sampling and field testing
 - (6) Date and time of concrete placement
 - (7) Location in Work of concrete represented by samples
 - (8) Date and time sample was obtained
 - (9) Truck and batch ticket numbers
 - (10) Specified compressive strength and test age
 - (11) Concrete mixture designation
 - (12) Results of tests of fresh concrete performed
 - (13) Information on storage and curing of test specimens, including curing method and maximum and minimum temperatures during initial curing period
 - (14) Compressive strength test results at required test ages and type of fracture of specimens tested
- C. The contractor shall be responsible for providing space, water, and source of electrical power for storage of test specimens during the initial curing period at the jobsite. Storage of test specimens shall be in a secured location and the testing agency shall be provided access.

- The initial curing period of test specimens at the jobsite is critical to obtain reliable test results for acceptance of concrete – typically for strength. One of the most frequent reasons for low strength test results is the lack of proper initial curing (temperature and humidity) of the cylinders as defined for “standard curing” in ASTM C31. The testing agency and contractor responsibilities for initial curing of acceptance specimens have been stated in Sections B and C here. It is generally the contractor’s responsibility to provide facilities and space for testing and storage of specimens during the initial curing period at the jobsite, ensure security, and provide

access to testing agency personnel to transport test specimens to the lab as required. It is emphasized that the testing agency should be responsible for ensuring that the initial curing temperatures are within the stated range according to ASTM C31 for standard curing conditions. In some areas, the contractor is delegated this responsibility in the contract. The owner's representative should ensure the responsibility for acceptance testing details are covered in contract documents. If the contractor or testing agency do not provide the necessary resources to perform proper testing or initial curing, such deficiencies should be communicated to the owner or his representative before any acceptance testing is performed.

- D. Concrete Delivery Tickets: For each load delivered, collect and submit delivery tickets that include the reporting requirements of ASTM C94/C94M and include additional information as specified. Record jobsite addition of water or admixtures with a signature of person requesting the adjustment.
- E. Inspections:
1. Headed bolts and studs
 2. Verification of concrete mixtures delivered consistent with submittal
 3. Concrete placement, including conveying and depositing
 4. Curing procedures and maintenance of curing temperature
 5. Verification of concrete strength before removal of shores and forms from beams and slabs
 6. Batch Plant Inspections – as required
- F. Concrete Tests: Composite samples of concrete shall be obtained in accordance with ASTM C172/C172M and tests shall be performed in accordance with the following:
1. Testing Frequency: Obtain one composite sample for each class of concrete at least once per day, once for each 150 yd³ of concrete, or once for each 5000 ft² surface area for slabs or walls.
 - a. If the total volume of concrete for a class is such that frequency of testing required is less than five tests, then samples shall be obtained from at least five randomly selected batches or from each batch if fewer than five batches are used.
 2. Slump: ASTM C143/C143M
 - a. One test on each sample obtained to prepare strength test specimens
 - b. Additional tests as needed to monitor control of batches
 3. Slump Flow: When applicable for self-consolidating concrete ASTM C1611/C1611M
 - a. One test on each sample obtained to prepare strength test specimens
 - b. Additional tests as needed to monitor control of batches
 4. Air Content: ASTM C231/C231M, or C173/C173M for lightweight concrete
 - a. One test on each sample obtained to prepare strength test specimens
 - b. Additional tests as needed to monitor control of batches
 5. Temperature: ASTM C1064/C1064M
 - a. One test on each sample obtained to prepare strength test specimens
 - b. One test hourly when ambient temperature is 40°F or lower or 90°F or higher
 6. Density: ASTM C138/C138M
 - a. One test on each sample obtained to prepare strength test specimens

- b. For lightweight concrete, one test as needed and at least once daily to verify conformance to equilibrium density determined in accordance with ASTM C567/C567M
7. Compressive Strength Specimens: ASTM C31/C31M
 - a. For strength specimens to be standard cured for acceptance of concrete, cast a set of cylinders and cure specimens at the jobsite in accordance with ASTM C31/C31M. Cast at least two specimens for each age that strength will be tested for information and additional reserve specimens as needed. Strength test results at the designated age shall be the average of two 6 × 12-in. or three 4 × 8-in. specimens.
 - b. If required, cast additional sets of cylinders for field-curing in accordance with ASTM C31/C31M
 - c. Transport specimens to the lab within 48 hours after casting and cure them in accordance with final curing requirements of ASTM C31/C31M until tested.
 8. Compressive Strength Tests: ASTM C39/C39M
 - a. Test specimens for compressive strength at 7 days or at an alternative early age as required and one set at 28 days or at an alternate test age as designated for specified strength.
 - b. Acceptance of concrete shall be based on strength test results of standard cured cylinders in accordance with ASTM C31 and tested at 28 days in accordance with ASTM C39. Strength test results at the designated age shall be the average of two 6 × 12 inch or three 4 × 8 inch specimens.
 - c. When strength cylinders are made, tests of slump, air content, temperature and density shall be made and recorded with the strength test results.
 - d. Strength of each concrete class shall be deemed satisfactory when both of the following criteria are met:
 - (1) The average of three consecutive compressive-strength tests equals or exceeds specified compressive strength
 - (2) Any individual compressive-strength test result does not fall below specified compressive strength, f'_c
 - (a) by more than 500 psi when $f'_c \leq 5000$ psi
 - (b) by more than $0.1f'_c$ when $f'_c > 5000$ psi
 - e. When compressive strength tests fail to meet the provisions of (d), follow procedure in ACI 301 for evaluation of concrete strength tests. .
 - f. When it is deemed necessary to evaluate the adequacy of concrete strength, at least 3 cores shall be obtained from the portion of the structure represented by the low strength tests. Cores shall be removed and conditioned in accordance with ASTM C42. The strength of cores shall comply with the following:
 - (a) Average strength of 3 cores $\geq 0.85f'_c$
 - (b) Individual core strength $\geq 0.75f'_c$

- Clearly indicate the sampling location for acceptance samples: “point of placement or discharge”. ASTM C172 does not describe procedures for sampling at the point of placement if another means of conveyance such as a pump, conveyor belt, or crane and bucket is employed. For determination that the concrete is supplied in accordance with the specified requirements, samples obtained from the point of discharge from the transportation unit is the stated requirement in ACI 318, ACI 301, and ASTM C94.

- When the placement method can cause differences in fresh concrete characteristics as discharged from the transportation unit to the point of placement, the requirements for concrete at the point of discharge from the transportation unit should be established between the material supplier and the contractor/sub-contractor. The designer should be notified of a change in requirements for the concrete as discharged from the transportation unit.
- Placement methods, such as the use of pumps, can change the characteristics of slump and air content of the concrete for a variety of reasons. The point of discharge represents a change of “custody” and responsibility of concrete. The concrete producer has no control of placement operations employed by the operator of the placement device or the contractor. Obtaining samples at the point of discharge from the truck mixer has been standard industry practice and is implicitly “calibrated” to some anticipated change in characteristics for normal placement methods. If the design professional needs to ensure “point of discharge” air content levels at the point of placement then the concrete at the point of discharge will likely need to have a modified slump or air content. For this to occur there needs to be proper coordination between the concrete as delivered and the placement method. A typical option is to measure slump and air as the concrete is discharged from the truck as well as at the point of placement to quantify the effects of the placement method. Concrete can be delivered at the job site to meet a **modified** slump and air content to compensate for an anticipated change. If the anticipated change through the placement procedure does not occur, a consequence will be reduced strength of concrete in the structure. Modifying slump and air content requirements to account for placement methods must be agreed upon at the pre-placement conference and if necessary, by conducting some trial pours. Density measurements at the two locations are a quick means of estimating changes in air content of concrete.
- Caution should be exercised when sampling at the discharge end of a pump to ensure that the slump and air content of subsequent loads are NOT adjusted to compensate for poor sampling or testing practices. Manipulation of the pumping process to facilitate sampling, such as shutting off, jogging etc., will cause temporary vacuum in the pump line resulting in lower air content in the concrete sample. This loss of air is minimized in productive conveyance of concrete in full pump lines in a constant discharge stream. Samples obtained from “sputtering” discharge will not be representative of the concrete delivered. The operative procedure when “point of placement” is specified, the concrete sample should be obtained at the “the point of placement” and not an alternate location. If sampling at the point of placement is not possible for safety reasons, sample location should then be at the point of discharge to eliminate the introduction of temporary, “non representative” conditions noted. A technician obtaining a sample of concrete from a pump line right beside the pump represents the worst sampling condition. A suggested method to obtain samples when “point of placement” is specified is to allow normal operation of pumps into the placement and obtain test samples from that location rather than to control the pumping operations to obtain samples in the sampling receptacle.
- Another problem with air content measurement, regardless of point of sampling, is insufficient effort when measuring air content by the volumetric method, ASTM C173 (roll-a-meter). This method is generally used for lightweight concrete. Insufficient agitation of the test sample will result in a lower measured air content that will then be called in for an adjustment at the plant. This often results in higher air content in the placed concrete and resulting lower strength.
- ACI 318 states minimum frequency for strength tests. Random sampling from different delivery vehicles should be followed. For smaller volumes of concrete on a project, the Code permits the engineer to not require strength tests. It is typically not common to test every load of concrete as this can cause considerable delays in placement with associated problems.
- Consider strength testing at later ages such as 56 or 90 days when high volumes of SCMs are used.
- An average of two 6x12 inch cylinders or three 4x8 inch cylinders tested at 28 days represents a strength test result for acceptance. Consider allowing the use of 4 x 8-inch specimens. This is permitted in ACI 318. ASTM C39 recognizes 4 x 8-inch specimens as a standard size. The smaller specimens facilitate better care and curing, especially during the critical early age phase at the jobsite. The commentary of ACI 318 clarifies that the strength acceptance criteria apply as stated regardless of specimen size used.

- If additional cylinders are specified be sure to include exact requirements and use of those results. For example, if a cylinder is to be tested at 7 days for informational purposes, clearly indicate that purpose and that there are no acceptance criteria associated with this result. If 7-day tests indicate a potential for lower strengths, it provides the concrete supplier with an opportunity to make modest changes to the mixture to increase the level of strength and these adjustments should be permitted with appropriate notification to the design professional. If additional cylinders are specified to be tested at 56 days for the purposes of acceptance if the 28-day tests don't meet the acceptance criteria, then that should be indicated in the specification. Strength tests, even for informational purposes, should be the average of at least two test specimens. The rate of strength gain of concrete depends on the type of mixture. There are no established percentage of 28-day strength at other test ages. These assumptions should not be used to "red-flag" results of tests performed at ages other than that required by the acceptance criteria.

- The installer and manufacturer may choose to make additional cylinders, identified as field-cured specimens, to monitor early age in-place strength to accommodate form removal, prestress release, opening to traffic and reshoring. In cold weather, standard-cured cylinders (lab) may provide a false indication on whether the structure has achieved the necessary strength necessary for these construction stages. An even better option for estimating in-place strength would be to take advantage of maturity-based techniques. The strength results of field-cured specimens are not recognized for determining the acceptability of the quality of concrete furnished for the work.

ACI 318, in section 26.5.3, does recognize the use of field cured cylinders to determine whether curing and protection of the structure was adequate. The requirement indicating adequate curing and protection is when the field cured cylinders achieve a strength of at least 85% of standard cured cylinders but does not apply if the strength of the field cured cylinders exceed the specified strength by more than 500 psi. Note that this evaluation is not attributed to be the responsibility of the concrete supplier.

- It is important that the procedure for evaluating non-compliance with specification requirements, such as low strength and the ultimate referee testing and resolution procedures be clearly defined in the project specifications. All parties need to know their financial exposure and risk prior to bidding a job.
- ACI 318 requires tests of cores from the structure only when strength tests do not comply with acceptance criteria in d.(2) above. Core tests are required if the likelihood of low-strength is confirmed and calculations indicate that structural adequacy is significantly reduced. Cores should be obtained and conditioned in accordance with ASTM C42. The conditioning procedure is important to attain a uniform moisture distribution in the core as this has a significant effect on measured strength of cores.
- The acceptance criteria for cores (ACI 318 and ACI 301) are: three cores are required for each placement represented by a low strength test result
 - average of 3 cores $\geq 0.85 f'_c$, and
 - each individual core $\geq 0.75 f'_c$
- When it can be demonstrated that low strength test results are caused by non-adherence to standard practices for specimen preparation and it is documented that curing facilities used at the jobsite or at the laboratory did not conform to the standards, the expense associated with additional testing and evaluation should be appropriately covered at no cost to the contractor or concrete supplier.

- Only use air content testing as an acceptance criterion for concrete that has an air content requirement in the specification. It is also appropriate to test the air content of concrete that needs a hard-trowelled finish to ensure that there is no inadvertent generation of excessive air content. Density tests can also be used as an indicator for this purpose.
- For air content tests, C94 establishes a tolerance of $\pm 1.5\%$; it permits a jobsite adjustment if the air content is less than the lower limit of the allowed tolerance; and sets forth procedures for retesting prior to a decision to reject the concrete. ASTM C94 requires that when air content needs to be verified, a preliminary sample be obtained from the initial portion of discharge. This sample is not in accordance with ASTM C172 and should not be used to make strength specimens. It permits an adjustment to the mixture if the air content is

not within required tolerance. ASTM C94 also requires a retest on a separate sample before a load of concrete is rejected for slump or air content that do not meet the specified requirements.

- Concrete contractor and concrete supplier may have a slump requirement and may choose to accept, reject or make jobsite adjustment to the concrete based on slump. Historically slump limits were specified due to concern of excessive water. With the use of admixtures, the relationship of slump to water content is weak. Compliance with target slump established by the producer and contractor as a means of verifying uniformity between loads of concrete.
- If engineer chooses to specify slump, it should be specified as a target limit, where the appropriate \pm tolerances in C 94 will apply. A maximum 8-in. slump limit will preclude the use of self-consolidating concrete that has the benefit of reduced consolidation requirements and reduced mix segregation. It is not advisable to require a target slump prior to addition of HRWR admixtures followed by a target after the addition. The general preference is for plant-added HRWR for better control. Allow a variance on slump limits with HRWR and include a statement regarding lack of segregation, if necessary. Also C 94 permits a jobsite adjustment if the slump is less than the lower limit of the allowed tolerance; and sets forth procedures for retesting prior to a decision to reject the concrete.
- Slump flow of self consolidating concrete is stated as the spread of the concrete after it is released from the slump cone. Other useful observation with the slump flow test is a visual stability index that is a qualitative measure of the degree of segregation of the mixture. The rate at which the concrete spreads is called the T50 value which is the time it takes to achieve a spread of 50 cm or 20 inches. This is a measure of the viscosity of the mixture that is important to the type of application being placed. A larger T50 value indicates a more viscous mixture.

- A commonly specified temperature limit is 95°F, primarily to prevent the addition of excessive water for proper consistency for placement. With today's concrete technology it is possible to provide concrete within the designed water content at the appropriate slump. Thermal cracking in massive concrete members is another concern. If it is not critical for the Work, it is recommended that the specification should not include a maximum temperature limit. Such temperature limits may be unrealistic in southern states in summer. Controlling concrete temperature adds to the cost of concrete, especially with extreme steps like the use of liquid nitrogen are necessary.
- A thermal control plan is a good performance-based alternative for mass concrete structural elements. The thermal control plan should indicate how concrete construction will be managed even with higher concrete temperature. Guidance on thermal control plans is available. CIP 42 from NRMCA discusses thermal cracking and prevention.

- Density is specified and used as an acceptance criterion only for lightweight or heavyweight concrete. While the engineer uses the equilibrium density of lightweight concrete in design, an equivalent value for the density of fresh lightweight concrete should be established for acceptance of lightweight concrete. The density of fresh concrete is typically 3 to 5 lb/ft³ greater than the equilibrium density.
- Even for normal weight concrete it is strongly recommended that the density test (ASTM C138) be performed whenever cylinders are made. This is a requirement in ASTM C94. This set of tests support each other in case there are problems with the strength test results. ASTM C138 can be used as a check test for results of the ASTM C173, and ASTM C231. It is not unusual that improper testing procedures for measurement of air are followed; or for air meters to not function properly; and result in inaccurate air content measurements.

- Distribution of all test results is very important for quality control. The distribution of test reports is required by ACI 318 (26.12.1.1). The ready mixed concrete supplier must be provided with copies of test reports in a timely manner – 48 hours is reasonable and the use of electronic communication could narrow this time further. This facilitates rapid corrective action in the case of low strength results. Strength test reports

should follow all the reporting requirements of ASTM C39 that includes important information on jobsite conditions and specimen care.

- Strength test results should also be made available to the construction manager, general contractor and concrete contractor.

Appendix A
Definition of Exposure Classes and Requirements for Concrete
in accordance with ACI 318-19

Table 19.3.1.1 – Exposure categories and Classes (ACI 318-19)

Category	Class	Condition	
Freezing and thawing (F)	F0	Concrete not exposed to freezing and thawing cycles	
	F1	Concrete exposed to freezing and thawing cycles with limited exposure to water	
	F2	Concrete exposed to freezing and thawing cycles with frequent exposure to water	
	F3	Concrete exposed to freezing and thawing cycles with frequent exposure to water and exposure to deicing chemicals	
Sulfate (S)		Water-soluble sulfate (SO_4^{2-}) in soil, percent by mass ⁽¹⁾	Dissolved sulfate (SO_4^{2-}) in water, ppm ⁽²⁾
	S0	$\text{SO}_4^{2-} < 0.10$	$\text{SO}_4^{2-} < 150$
	S1	$0.10 \leq \text{SO}_4^{2-} < 0.20$	$150 \leq \text{SO}_4^{2-} < 1500$ or seawater
	S2	$0.20 \leq \text{SO}_4^{2-} < 2.00$	$150 \leq \text{SO}_4^{2-} < 1500$
	S3	$\text{SO}_4^{2-} > 2.00$	$\text{SO}_4^{2-} > 10,000$
In contact with water (W)	W0	Concrete dry in service	
	W1	Concrete in contact with water and low permeability is not required	
	W2	Concrete in contact with water and low permeability is required	
Corrosion protection of reinforcement (C)	C0	Concrete dry or protected from moisture	
	C1	Concrete exposed to moisture but not to an external source of chlorides	
	C2	Concrete exposed to moisture and an external source of chlorides from deicing chemicals, salt, brackish water, seawater, or spray from these sources	

⁽¹⁾ Percent sulfate by mass in soil shall be determined by ASTM C1580

⁽²⁾ Concentration of dissolved sulfates in water, in ppm, shall be determined by ASTM D516 or ASTM D4130

Excerpted from ACI 318R – Commentary to the Building Code

Table R19.3.1—Examples of structural members in Exposure Category F

Exposure Class	Examples
F0	<ul style="list-style-type: none"> • Members in climates where freezing temperatures will not be encountered • Members that are inside structures and will not be exposed to freezing • Foundations not exposed to freezing • Members that are buried in soil below the frost line
F1	<ul style="list-style-type: none"> • Members that will not be subject to snow and ice accumulation, such as exterior walls, beams, girders, and slabs not in direct contact with soil • Foundation walls may be in this class depending upon their likelihood of being saturated
F2	<ul style="list-style-type: none"> • Members that will be subject to snow and ice accumulation, such as exterior elevated slabs • Foundation or basement walls extending above grade that have snow and ice buildup against them • Horizontal and vertical members in contact with soil
F3	<ul style="list-style-type: none"> • Members exposed to deicing chemicals, such as horizontal members in parking structures • Foundation or basement walls extending above grade that can experience accumulation of snow and ice with deicing chemicals

Table 19.3.2.1—Requirements for concrete by exposure class (ACI 318-19)

Exposure Class	Max w/cm ^(1,2)	Min f' _c psi	Additional Requirements			Limits on SCM
			Air content			
F0	N/A	2500	N/A			N/A
F1	0.55	3500	Table 19.3.1.1 (Table 19.3.3.3 for shotcrete)			N/A
F2	0.45	4500	Table 19.3.1.1 (Table 19.3.3.3 for shotcrete)			N/A
F3	0.40 ⁽³⁾	5000 ⁽³⁾	Table 19.3.1.1 (Table 19.3.3.3 for shotcrete)			26.4.2.2(b)
			Cementitious materials ⁽³⁾ - Types			Calcium chloride admixture
			ASTM C150	ASTM C595	ASTM C1157	
S0	N/A	2500	No type restriction	No type restriction	No type restriction	No restriction
S1	0.50	4000	II ⁽⁵⁾⁽⁶⁾	Types with (MS) designation	MS	No restriction
S2	0.45	4500	V ⁽⁶⁾	Types with (HS) designation	HS	Not permitted
S3	Opt. 1	0.45	V plus pozzolan or slag cement ⁽⁷⁾	Types with (HS) designation plus pozzolan or slag cement ⁽⁷⁾	HS plus pozzolan or slag cement ⁽⁶⁾	Not permitted
	Opt. 2	0.45	V ⁽⁸⁾	Types with (HS) designation	HS	Not permitted
			None			
W0	N/A	2500	None			
W1	N/A	2500	26.4.2.2(d)			
W2	0.50	4000	26.4.2.2(d)			
			Maximum water-soluble chloride ion (Cl ⁻) content in concrete, percent by weight of cementitious materials ^(9,10)		Additional provisions	
			Nonprestressed concrete	Prestressed concrete		
C0	N/A	2500	1.00	0.06	None	
C1	N/A	2500	0.30	0.06	None	
C2	0.40	5000	0.15	0.06	Concrete cover ⁽¹¹⁾	

⁽¹⁾ The w/cm is based on all cementitious and supplementary cementitious material in the concrete mixture

⁽²⁾ The maximum w/cm limits do not apply to lightweight concrete.

⁽³⁾ For plain concrete, the maximum w/cm shall be 0.45 and the minimum f'_c shall be 4500 psi.

⁽⁴⁾ Alternative combinations of cementitious materials to those listed are permitted when tested for sulfate resistance and meeting the criteria in 26.4.2.2(c).

⁽⁵⁾ For seawater exposure, other types of portland cements with tricalcium aluminate (C₃A) contents up to 10 percent are permitted if the w/cm does not exceed 0.40.

⁽⁶⁾ Other available types of cement such as Type I or Type III are permitted in Exposure Classes S1 or S2 if the C₃A contents are less than 8 percent for Exposure Class S1 or less than 5 percent for Exposure Class S2.

⁽⁷⁾ The amount of the specific source of the pozzolan or slag cement to be used shall be at least the amount that has been determined by service record to improve sulfate resistance when used in concrete containing Type V cement. Alternatively, the amount of the specific source of the pozzolan or slag cement to be used shall be at least the amount tested in accordance with ASTM C1012 and meeting the criteria in 26.4.2.2(c).

⁽⁸⁾ If Type V cement is used as the sole cementitious material, the optional sulfate resistance requirement of 0.040 percent maximum expansion in ASTM C150 shall be specified.

⁽⁹⁾ The mass of supplementary cementitious materials used in determining the chloride content shall not exceed the mass of the portland cement.

⁽¹⁰⁾ Criteria for determination of chloride content are in 26.4.2.2.

⁽¹¹⁾ Concrete cover shall be in accordance with 20.5.

Table 19.3.3.1—Total air content for concrete exposed to cycles of freezing and thawing (ACI 318-19)

Nominal maximum aggregate size, in	Target air content, percent	
	F1	F2 and F3
3/8	6.0	7.5
½	5.5	7.0
¾	5.0	6.0
1	4.5	6.0
1 ½	4.5	5.5
2	4.0	5.0
3	3.5	4.5

Table 26.4.2.2(b)—Limits on cementitious materials for concrete assigned to Exposure Class F3 (ACI 318-19)

Cementitious Materials	Maximum percent of total cementitious materials by mass
Fly ash or natural pozzolans conforming to ASTM C618	25
Slag cement conforming to ASTM C989	50
Silica fume conforming to ASTM C1240	10
Total of fly ash or natural pozzolans and silica fume	35
Total of fly ash or natural pozzolans, slag cement, and silica fume	50

Table 26.4.2.2(c)—Requirements for establishing suitability of combinations of cementitious materials For Exposure Category S (ACI 318-19)

Exposure class	Maximum length change for tests in accordance with ASTM C1012, percent		
	At 6 months	At 12 months	At 18 months
S1	0.10 percent	No requirement	No requirement
S2	0.05 percent	0.10 percent ⁽¹⁾	No requirement
S3	Option 1	No requirement	0.10 percent
	Option 2	0.05 percent	0.10 percent ⁽¹⁾

⁽¹⁾ The 12-month expansion limit applies only if the measured expansion exceeds the 6-month maximum expansion limit.

Appendix B Suggested Mixture Submittal Format

Concrete Supplier					
Address					
City, State, Zip					
Submitted by					
Phone		Fax		E-Mail	

Project		Date	
Location		Contractor	

		CONCRETE MIX CODE				
SPECIFICATION	Mixture Identification by Class					
	Structural Requirements					
	• Specified Exposure Class in Section 2.12					
	• Minimum Specified Strength - age					
	• Air Content and range (%)					
	• Nominal Maximum Aggregate Size					
	Durability Requirements					
	• Alkali Aggregate Reactivity					
	• Other					
	Architectural Requirements					
• Color/Texture						
• Other						
CONTRACTOR REQUIREMENTS	Quantity, cubic yards					
	Rate (yd ³ /h)					
	Slump or Slump flow - Range (in)					
	Method of Placement					
	Strength/Age (psi/hr/days)					
	Other					
	Specialty Information					
	• Concrete Set (Delay, Normal, Accelerated)					
	Floor or Slab Type – (Exposed / Covered)					
Other (e.g. Fibers)						
MATERIALS SECTION	Type & Information					
	• Portland Cement					
	• SCM – Slag, Fly Ash, Silica Fume					
	• Fine Aggregate					
	• Coarse Aggregate					
	• Air Entraining Admixture					
	• Water Reducing Admixture					
	• Other (e.g. Fibers)					

NOTES:

- 1) All Concrete and materials shall be supplied in conformance to ASTM C94.
- 2) Concrete test reports shall be provided to the owner, contractor and concrete supplier within 48 hours.
- 3) Concrete tests not done according to ASTM Standards shall not be accepted for any basis of measurement.
- 4) Additional supporting documentation as required by the project specification are attached to this submittal

APPENDIX C

Whole Building LCA Example for Establish Carbon Budget for a Building



**NRMCA Publication 2PE004-21c - Guide to Improving Specifications for Ready Mixed Concrete
with Notes on Reducing Embodied Carbon Footprint**

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