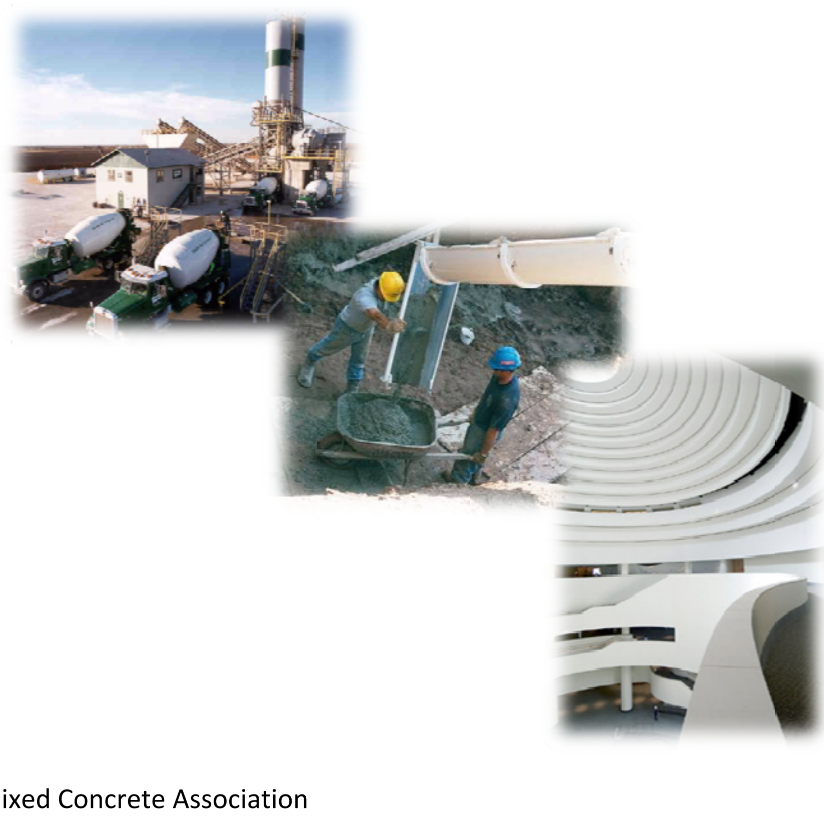
NRMCA Publication 2PE003

Guide to Improving Specifications for Ready Mixed Concrete

May 2009



NRMCA

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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 actual 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 318-08, *Building Code for Structural Concrete,* as it relates to requirements concrete ingredient materials and mixtures, production and delivery are incorporated in this document.

This publication uses the typical Office Master Specification format, Section 03300 for Cast-in-place concrete to provide context to the typical sections seen in commercial project specifications. The document only covers those sections pertinent to concrete ingredients 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 make it easy for the concrete producer or contractor to discuss the intent or for the design professional to incorporate these suggestions. It is anticipated that this publication will be updated as standards evolve or with feedback, which is encouraged.

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This list of contents is the typical section references in specifications for cast in place concrete. 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

<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.>

- References should only include documents written in mandatory language that are incorporated as part of this specification and Contract Documents. A project specification should always reference specific dated reference standards, such as ASTM standards, because these are often revised. Note that the locally adopted building code might reference standards that are not the current version.
- 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 are not written in mandatory language; they often have several alternative recommendations; and they often do not require any specific action. When there are problems on the job and the intent of a specific reference is not clear in the contract documents, enforcement of this intent is subject to interpretation and opinion. 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. Many ACI documents such as ACI 302R, 304R, 305R, 306R, 311R, 347R etc. are guide documents and are not written in mandatory language. These should not be included in the referenced standards section or referenced for compliance in the body of the specification.
- General statements requiring compliance with building codes and reference specifications should be avoided. The introduction to the ACI 318 Building Code indicates that it is not appropriate to make general references requiring compliance with the Code. It goes on to say that project specifications should contain all the necessary requirements to ensure compliance with the Code. Ensuring compliance with the provisions of the Building Code is generally the responsibility of the design professional who is in a position to know the design requirements, detailing and exposure conditions the structural or other concrete members will be subject to. Reference to these provisions is accomplished by incorporating pertinent code sections in the project specifications.
- Reference specifications such as ACI 301 can be incorporated by reference in project specifications, but it needs to be clear as to which dated version is being referenced. ACI 301 also has some mandatory checklist items that the specifier has to state or chose before it can be considered a complete reference. It is important to avoid referencing selected articles in a reference specification because of the loss of context and flow. ACI 301 establishes defaults and uses checklists that advise the A/E on alternatives. Checklists are also used in ACI 301 in context with a clause "as permitted" when the contractor can make a submittal requesting an alternative.

1.2 SUMMARY

A. This Section specifies cast-in place concrete, including formwork, reinforcement, concrete materials, mixture design, placement procedures, and finishes.

1.4 SUBMITTALS

A. Submit field or laboratory test records used to document that proposed mixture will achieve the required average compressive strength and other specified requirements in section 2.12 for each class of concrete. Field test records for concrete strength test records must be from concrete supplied from the same production facilities proposed for Work. Test data shall be from concrete mixtures containing similar materials proposed for Work. Strength test records for establishing a standard deviation for each class of concrete or for documenting the required average strength for Work shall not be greater than 12 months old and shall be collected over a period not less than 60 days.

- ACI 301 and 318 establishes the required average strength, f'_{cr}, for a concrete mixture proposed for the project to be established based on:

  1. Standard deviation from a strength test record of a similar class of concrete produced under similar conditions. The specified strength, f'_c, of the similar class should be within 1000 psi of that for the proposed Work. The strength test record should not be more than 12 months old and should be collected over a period not less than 60 days.
  2. When no strength test record of a similar class of concrete exists, the required average concrete, f'_{cr}, is at a set increment greater than the specified strength, f'_c. The increment varies from 1000 psi to (1.1 f'_c + 700) depending on the level of f'_c.

  Option 2 is more conservative for the required average strength considering the concrete supplier has no recent history, as indicated in option 1, with producing that class of concrete. It should not be specified as the default requirement. Designing a concrete mixture for a required average strength by option 1 is preferred when a test record for that class of concrete exists. Requiring a higher level of strength should be avoided as it can cause unintended consequences related to higher heat of hydration and increased shrinkage that increase the potential for cracking and curling of concrete slabs.

  When Option 2 is used for f'_{cr} to start a project, ACI 318 and 301 permit the reduction of the level of strength once at least 15 tests are collected on the project based on the standard deviation of that test record. This requires a submittal of the revised mixture proportions to achieve the reduced level of average strength. This should be permitted.

  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. These revisions to concrete mixtures may need to be submitted to the design professional for review and/or 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. Test records of at least 10 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. Note that this test record can be different from that used to determine the standard deviation. It is also permitted to interpolate information from two sets of field test records of similar classes of concrete to establish the water-cementitious materials ratio and mixture proportions for the classes of mixtures for proposed Work. The mixture proportions for f'_{cr} should be based on the required water-cementitious material ratio
  2. Laboratory trial batch data. ACI 318 and 301 permits the concrete supplier to interpolate between 3 or more trial batches varying the w/cm or cementitious materials composition to arrive at the proportions of the proposed mixture.
     Laboratory trial batches can be used even when the f'_{cr}, was established using the standard deviation method to document that the proposed mixture will perform to the specified requirements. It is also acceptable to document the characteristics of a proposed mixture by producing a minimum 3 cubic yard concrete batch in the concrete production facility.

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

  Laboratory trial mixtures may not accurately represent field production and delivery conditions but concrete suppliers establish the necessary correlations based on past experience.

  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 when 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.

B. Submit properties of mixtures for each class of concrete including:
   1. Mixture Identification by class
   2. Specified compressive strength, f'_c, that is applicable for the class
   3. Specified exposure class in Section 2.12
   4. Documentation of strength test records of similar class of concrete used to establish standard deviation in accordance with ACI 318, when test records exist
   5. Required average compressive strength, f'_{cr}, for each class of concrete
   6. Documentation of f'_{cr} of proposed mixture(s)
   7. Intended placement method
   8. Slump or slump flow
   9. Air content
   10. Density
   11. w/cm, when specified
   12. Documentation supporting other specified requirements of concrete mixtures
   13. Nominal maximum aggregate size or Size number
   14. Type and information about the ingredient materials proposed for use including:
       a. Cementitious Materials
       b. Aggregates
       c. Admixtures
       d. Water
       e. Fibers, color pigments, and other additions

C. Submit documentation indicating installer, manufacturer, and testing agency meet the qualifications specified in Section 1.5 Quality Control.

- A guide to submittal of concrete mixture proportions is provided in ACI 211.5R.
- When specifications include performance-based requirements, the submittal information should be pertinent to compliance with the performance requirements of the specification. Documentation of actual ingredient material quantities and other details of mixture proportions may not necessarily indicate such compliance. A 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 types and information about the ingredient materials. Development of optimized performance-based mixtures involves a significant cost and effort for development by the concrete supplier and represents his proprietary intellectual property. Public disclosure of such information can impact his competitiveness. When 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 review of submittals of concrete mixture proportions for compliance with the requirements for the pertinent Work should be the responsibility of the engineer of record or his delegate who is qualified to do the submittal review. Not all testing laboratories have the expertise to make judgments and decisions relative to performance characteristics by reviewing mixture proportions of concrete on paper.
- Review of the submittal can include the types of ingredients used, the slump, air content, density, temperature and other properties as they relate to the specified or other requirements. Some of these items reported in the submittal 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 supplementary information on water content, air content, batching errors etc.
- Most 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 engineer should avoid specifying a slump requirement as it might impact the ability to place the concrete. 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.

- Consider defining the period of time for retention of batch records of individual concrete deliveries for forensic purposes (3-7 years from delivery date).
- 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.

1.5 QUALITY ASSURANCE

A. Installer Qualifications: At least one person on the finishing crew must be certified as an ACI Flatwork Finisher, or equivalent.
   1. When requested, the installer shall furnish a Quality Control Plan.

- 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 301-05.
- The concrete contractor can be required to submit a quality control plan that outlines activities and procedures to minimize problems on the project.

B. Manufacturer Qualifications:
   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 certified as an NRMCA Concrete Technologist Level 2, or equivalent. Criteria of equivalent certification shall be included 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. 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.
- The NRMCA Concrete Technologist Level 2 Certification validates personnel's knowledge of fundamentals of concrete technology including mixture proportioning. Certification is obtained by passing a 90 minute exam administered by NRMCA with ACI Grade I Field Testing Technician Certification as the prerequisite. Other NRMCA certifications pertinent to concrete quality include the Concrete Plant Operator certification for batchmen 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/p2p or can be obtained by contacting NRMCA.

C. Testing Agency Qualifications: Independent testing agency shall meet the requirements of ASTM C1077.
   1. Personnel conducting 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.

- 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.
- Concrete testing is very sensitive to the way specimens are collected, cured, and tested. Procedural requirements for acceptance testing are addressed in ASTM C94 and the standard test methods. Field and laboratory procedures that conform to established standards are essential to achieving meaningful results. Deviations from standardized procedures will most often result in unacceptable results that translate to increased project costs and delayed schedules. For this purpose technician certification is essential. Equivalent certifications to ACI should include a physical test performance and written component to the certification.

D. Pre Installation Conference: Conduct conference to coordinate work and to assure compliance with requirements in Division 1 Section "Project Management and Coordination."
   1. Representatives of each entity directly concerned with cast-in-place concrete are recommended to attend, including:
      a. Architect
      b. Structural Engineer
      c. General Contractor/Construction Manager
      d. Installer (Concrete Contractor)
      e. Reinforcing Steel Contractor
      f. Post-tensioning Contractor
      g. Pumping Contractor
      h. Manufacturer (Ready-mixed concrete producer)
      i. Independent testing agency

- NRMCA and American Society of Concrete Contractors have published the *Checklist for the Concrete Pre-Construction Conference*. Pre installation conference is desirable for major and/or complex concrete installations. Decisions made should be documented. These meetings help minimize misunderstandings and allow for a review of specification requirements or project conditions and facilitate resolution of problems 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.

PART 2 – PRODUCTS

2.5 CONCRETE MATERIALS

A. Cementitious Materials: use materials meeting the following requirements.
   1. Hydraulic Cement: ASTM C150, ASTM C1157 or ASTM C595
   2. Fly Ash or Natural Pozzolan: ASTM C618
   3. Slag Cement: ASTM C989
   4. Silica Fume: ASTM C1240

- ASTM C 150 is the specification for portland cement that defines 5 types. ASTM C 595 is a specification for blended cements defining 2 types, with fly ash or pozzolan and slag cement. The quantity of the blended material varies and is indicated in the type designation. ASTM C 1157 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 – rather than use blended cement.
- 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 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 often 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.
- 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 obtain LEED credits. 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 Class N pozzolan, such as calcined clay is also used. 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 due to shipping 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. Slurry form is no longer available in the United States. 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.

B. Normal-weight Aggregate: ASTM C33

1. Nominal maximum size of coarse aggregate: *<indicate the size as per design requirements for each class of concrete>*
2. Local aggregates not complying with ASTM C33 but that have shown by test or service record to produce concrete of adequate strength/durability is permitted when acceptable to the Engineer of Record
3. Alkali Silica Reactivity: Aggregate shall be considered non-reactive with a documented satisfactory service record for a minimum ten year period used in concrete with similar cementitious materials or with an alkali (Na_2O eq.) content in concrete equal or higher than that in the proposed mixture. In the absence of service record the aggregate shall be tested and will be considered non-reactive if it passes one of the following two requirements – ASTM C1260 14-day expansion less than or equal to 0.10% or ASTM C1293 1-year expansion less than or equal to 0.040%. For aggregate that do not meet these criteria, mitigation measures shall apply in accordance with Section 2.12

- 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. See 2.12. 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 supplies in some regions of the country will not comply with some requirements in ASTM C33.
- Service records of aggregate use in concrete 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.
- 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. ASTM C1260 is more 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.
- Mitigation measures for alkali aggregate reactions are pertinent to structural members that will be wet in service and when there is a history of deleterious ASR cracking in the region. There is considerable guidance on ASR. One reference is Guide Specification for Concrete Subject to Alkali-Silica Reactions, developed by the PCA Durability Subcommittee and available from NRMCA. Specification requirements are addressed in 2.12 C
- Combined aggregate grading requirements such as Coarseness Factor - Workability Factor charts or the 8-18 grading criteria are good concrete mixture optimization tools that should be used by the concrete producer when appropriate for the application. Invoking these requirements should be avoided in project specifications 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 2.12 D.
- Use of aggregate that does not meet a coarse aggregate gradation size number within ASTM C33 but would otherwise meet all of 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.

C. Lightweight Aggregate: ASTM C330

D. Heavyweight Aggregate: ASTM C637

E. Water: ASTM C1602

- 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 invoked only when applicable.

F. Chemical Admixtures:

1. Air Entraining: ASTM C260
2. Water reducing, accelerating and retarding: ASTM C494
3. Admixtures for flowing concrete: ASTM C1017
4. Admixtures for corrosion inhibition: ASTM C1582
5. Admixtures with no standard (ASTM or other) designation 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.
- 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 2.12 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.

G. Fibers: ASTM C1116

2.12 CONCRETE MIXTURES

A. Prepare design mixtures for each class of concrete on the basis of laboratory trial mixtures or field test data, or both according to ACI 301. Design mixtures shall meet the specified strength requirements listed below
<provide a schedule for different classes of concrete required for the structure. Include detailed requirements pertinent to exposure classes as per ACI 318.>

Class	Location	Nominal Max. Aggregate Size	Exposure Classes	f'_c, psi	Requirements for Exposure Classes

- 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 318-08 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 P – Concrete in contact with water requiring low permeability
  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.

B. Contractor is responsible for preparation of design mixtures for each class of concrete used in construction.

- 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 – 3.3 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 elements.

- 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.
- 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. 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 included as cementitous material in the calculation of w/cm. Referring a water cement ratio based on the mass of only portland cement is misleading.
- 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. 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 ± tolerances in C 94 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. 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 301 and 302 recommend minimum cementitious material content (not cement) for floor slabs only, primarily to improve finishability. There is no technical reason to include minimum cementitious materials content for other structural elements provided the performance requirements are achieved. 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.
- 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. 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 ± 3°F apply. If hot weather job concreting has to be simulated in the laboratory the approach suggested in ACI 305 for lab trial batches could be adopted. In any event, the established acceptance criteria for the project must apply.

Exposure Category F – Freezing and Thawing

- ACI 318 requires a minimum specified strength, f'_c, of 4500 psi and a max w/cm of 0.45 for all categories when freezing conditions are anticipated.
- 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 above 5000 psi, the air content is permitted to be reduced by 1.0%.
- 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. ASTM C33 provides a map of the US where the severity of freezing conditions is outlined. 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. Air content of concrete for slabs with 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.

- ACI 318 does not provide a reference standard to measure the concentration on water soluble sulfates in soil or water which establishes the severity of exposure. The following methods are currently available: 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.
- 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 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. Suppliers of fly ash or slag cement might have this 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 Class S2 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 content in cements for this condition.
- A minimum cementitious material content is not needed for exposure to water-soluble sulfates.

- If exposure to sulfates is not pertinent, do not include these limitations.

Exposure Category P – Concrete requiring low permeability in direct contact with water

- 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.
- When Exposure Class P1 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 P1.
- If this exposure class P1 does 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 permeation of chloride ions from external sources.
- Chloride ion limits for concrete mixtures are based on ACI 318. The chloride ion content, expressed as a percent by weight of cement, can be documented by a calculation of the water-soluble chloride ions contributed by all ingredients in the mixture or tested on hardened concrete specimens by 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.
- 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 attain the improved performance. Corrosion inhibiting admixtures are also used successfully.
- 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, P and C, ACI 318 includes prescriptive w/cm provisions for concrete. These provisions are incorporated 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. An alternative performance-based requirement might be considered by the design professional.
- ASTM C1202 is a standard test method for rapid indication of concrete's ability to resist chloride ion penetration. By requiring a low ASTM C1202 coulomb level the engineer ensures that the concrete mixture has reduced "permeability" property. 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. A recommended accelerated curing procedure used by at least one state highway agency is to use standard curing for the test specimens for 7 days 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** and not invoked with the limit on 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

  For structures governed by the local building code, these alternatives may need approval from the building official.

- 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. Hence, 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.

C. Alkali silica reactivity – For structural concrete members that will be moist in service and when it is determined as per Section 2.2B that the aggregate source used needs to include mitigative measures, submit documentation demonstrating that the proposed cementitious materials used with the aggregates by ASTM C1567 tests with an expansion after 14 days of exposure less than or equal to 0.1%.

- 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, silica fume, and slag are used in concrete mixtures as mitigative measures for ASR. Generally 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 25% Fly ash A shows expansion below 0.1% the concrete supplier should use at least 25% of that fly ash in the concrete mixture proportions.
- ASTM C1293 is a more reliable test method for evaluating the potential reactivity of aggregates or for determining mitigation of combination of cementitious materials with the aggregates. For determining mitigation effectiveness, it is recommended to conduct ASTM C1293 for a period of 2 years. This time period is not practical for project schedules in specifications. In general ASTM C1567 provides a conservative indication of mitigation measures in shorter time period.
- A minimum cementitious materials content is not needed for mitigating deleterious expansions due to ASR.

D. 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 28 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 etc. that can impact the results and pose a high risk of rejection of acceptable concrete. Knowledge of local materials shrinkage characteristics, or a willingness to include shrinkage reducing admixtures may allow for a lower specified shrinkage than the value recommended.
- Establishing specification requirements on grading limits of aggregates does not always assure reduced aggregate voids, lower paste content and thereby lower shrinkage.
- A low w/cm does not assure reduced shrinkage.

E. 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 notified to the Engineer of Record in the submittal.

- 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.

F. 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. The changes in mixture proportions might include changes in the quantities of cementitious materials, admixture dosage and aggregates. Requiring a re-submittal with 28-day strength data on relatively minor adjustments is not practical and will delay construction schedules. The design professional might consider obtaining an original submittal stated in acceptable ranges of ingredient quantities. 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.

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.

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.

- 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.
- It is recommended that the specification should not include more restrictive delivery time limits than specified in ASTM C94. Judicious use of water reducing and retarding admixtures and methods for reducing concrete temperature can generally ensure that the concrete will meet the project requirements for placing and finishing at the stated delivery time of 90 minutes. 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 most often exceed 95°F and delivery at 90 minutes is successfully accomplished with the use of retarding admixtures. The restriction on maximum number of revolutions (300) in ASTM C94 is generally not a concern for most aggregates and should be waived if the slump is adequate at the time of placement.

3.17 FIELD QUALITY ASSURANCE

A. CONCRETE FIELD TESTS:

1. Concrete Test Samples: Samples for acceptance tests on concrete shall be obtained in accordance with ASTM C172.
2. Compressive Strength Tests on concrete:
   a. Samples for concrete compressive strength tests of each class of concrete placed each day shall be taken not less than once per day, nor less than once for each 150 yd^3 of concrete, nor less than once for each 5000 ft^2 surface area for slabs or walls. 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 made from at least five randomly selected batches or from each batch if fewer than five batches are used.
   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 318 chapter 5.6.4 Investigation of low-strength test results.

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 from the discharge of 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 engineer 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 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.
- Consider longer periods before strength testing 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 318-08. 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.
- 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.
- 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 5.6.4, 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 generally the contractor's responsibility to provide facilities and space for testing and storage of specimens during the initial curing period at the jobsite. The initial curing period is very critical for later age acceptance test results such as strength. One of the most frequent reasons for low acceptance test results are the lack of proper initial curing (temperature and humidity) of the cylinders as defined for "standard curing" in ASTM C31. It is emphasized that the testing lab should be responsible for ensuring that the initial curing temperatures are within the stated range according to ASTM C31 for standard curing conditions. If the contractor does 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.
- 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.

- 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 ≥ 0.85 f'_c, and
  - each individual core ≥ 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 testing agency should be required to bear the expense for subsequent tests and evaluation.

3. Air Content: ASTM C231. Test when concrete is sampled for strength tests. ASTM C173 for structural lightweight concrete or when local practice dictates due to characteristics of aggregates used.
   a. Air content tests shall be performed on concrete at least at the same frequency as compressive strength testing.
   b. The provisions of ASTM C94 shall apply for acceptance of air content of concrete.
   c. For critical applications, the air content of concrete shall be measured at greater frequencies than that required for strength tests during the initial part of the project, as stated in contract documents.

- Only use air content testing as an acceptance criterion for concrete that has an air content requirement in the specification. It might be 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 ±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.
- For some projects when it is critical to ensure that the correct quantity of air content is being delivered, the design professional might chose to verify the air content more frequently than the frequency used for strength tests and defer back to the frequency of strength tests once it is assured that the required air content is consistently being delivered.

4. Slump: ASTM C143; one test when concrete is sampled for strength tests. For mixtures approved as self consolidating concrete, measure slump flow at the same frequency as above in accordance with ASTM C1611.

- Concrete contractor and concrete supplier might 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. Use compliance with target slump established by the producer and contractor as a means of verifying uniformity.
- If engineer chooses to specify slump, it should be specified as a target limit, where the appropriate ± 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.

5. Temperature: ASTM C1064; one test when concrete is sampled for strength tests.

- A commonly used temperature limit specified is 90°F or 95°F, primarily to ensure 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 are available. CIP 42 from NRMCA discusses thermal cracking and prevention.

6. Density: ASTM C138; one test when concrete is sampled for strength tests.

- Density is specified and used as an acceptance criterion only for lightweight or heavyweight concrete. However, even for normal weight concrete it is highly 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.

7. Test results shall be reported by the testing laboratory to the architect, engineer, concrete producer, and concrete contractor within 48 hours of testing.

- 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 318-08

TABLE 4.2.1 — EXPOSURE CATEGORIES AND CLASSES

Category	Severity	Class	Condition	
F Freezing and thawing	Not applicable	F0	Concrete not exposed to freezing-and-thawing cycles	
	Moderate	F1	Concrete exposed to freezing-and-thawing cycles and occasional exposure to moisture	
	Severe	F2	Concrete exposed to freezing-and-thawing cycles and in continuous contact with moisture	
	Very severe	F3	Concrete exposed to freezing-and-thawing and in continuous contact with moisture and exposed to deicing chemicals	
S Sulfate			**Water-soluble sulfate (SO_4) in soil, percent by weight**	**Dissolved sulfate (SO_4) in water, ppm**
	Not applicable	S0	$SO_4 < 0.10$	$SO_4 < 150$
	Moderate	S1	$0.10 \le SO_4 < 0.20$	$150 \le SO_4 < 1500$ Seawater
	Severe	S2	$0.20 \le SO_4 \le 2.00$	$1500 \le SO_4 \le 10{,}000$
	Very severe	S3	$SO_4 > 2.00$	$SO_4 > 10{,}000$
P Requiring low permeability	Not applicable	P0	In contact with water where low permeability is not required	
	Required	P1	In contact with water where low permeability is required.	
C Corrosion protection of reinforcement	Not applicable	C0	Concrete dry or protected from moisture	
	Moderate	C1	Concrete exposed to moisture but not to external sources of chlorides	
	Severe	C2	Concrete exposed to moisture and an external source of chlorides from deicing chemicals, salt, brackish water, seawater, or spray from these sources	

TABLE 4.3.1 — REQUIREMENTS FOR CONCRETE BY EXPOSURE CLASS

Exposure Class	Max. w/cm	Min. f'_c, psi	Additional minimum requirements			
			Air content			Limits on cementitious materials
F0	N/A	2500	N/A			N/A
F1	0.45	4500	Table 4.4.1			N/A
F2	0.45	4500	Table 4.4.1			N/A
F3	0.45	4500	Table 4.4.1			Table 4.4.2
			Cementitious materials*—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†‡	IP(MS), IS (<70) (MS)	MS	No restriction
S2	0.45	4500	V‡	IP (HS) IS (<70) (HS)	HS	Not permitted
S3	0.45	4500	V + pozzolan or slag§	IP (HS) + pozzolan or slag§ or IS (<70) (HS) + pozzolan or slag§	HS + pozzolan or slag§	Not permitted
P0	N/A	2500	None			
P1	0.50	4000	None			
			Maximum water-soluble chloride ion (Cl^-) content in concrete, percent by weight of cement‖		Related provisions	
			Reinforced concrete	Prestressed concrete		
C0	N/A	2500	1.00	0.06	None	
C1	N/A	2500	0.30	0.06		
C2	0.40	5000	0.15	0.06	7.7.6, 18.16#	

*Alternative combinations of cementitious materials of those listed in Table 4.3.1 shall be permitted when tested for sulfate resistance and meeting the criteria in 4.5.1.
†For seawater exposure, other types of portland cements with tricalcium aluminate (C_3A) contents up to 10 percent are permitted is the *w/cm* does not exceed 0.40.
‡Other available types of cement such as Type III or Type I are permitted in Exposure Classes S1 or S2 if the C_3A contents are less than 8 or 5 percent, respectively.
§The amount of the specific source of the pozzolan or slag to be used shall not be less than 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 to be used shall not be less than the amount tested in accordance with ASTM C1012 and meeting the criteria in 4.5.1.
‖Water-soluble chloride ion content that is contributed from the ingredients including water, aggregates, cementitious materials, and admixtures shall be determined on the concrete mixture by ASTM C1218 at age between 28 and 42 days.
#Requirements of 7.7.6 shall be satisfied. See 18.16 for unbonded tendons.

TABLE 4.4.1 — TOTAL AIR CONTENT FOR CONCRETE EXPOSED TO CYCLES OF FREEZING AND THAWING

Nominal maximum aggregate size, in.*	Air content, percent	
	Exposure Class F1	Exposure Classes F2 and F3
3/8	6	7.5
1/2	5.5	7
3/4	5	6
1	4.5	6
1-1/2	4.5	5.5
2†	4	5
3†	3.5	4.5

*See ASTM C33 for tolerance on oversize for various nominal maximum size designations.
†Air contents apply to total mixture. When testing concretes, however, aggregate particles larger than 1-1/2 in. are removed by sieving and air content is measured on the sieved fraction (tolerance on air content as delivered applies to this value). Air content of total mixture is computed from value measured on the sieved fraction passing the 1-1/2 in. sieve in accordance with ASTM C231.

TABLE 4.4.2 — REQUIREMENTS FOR CONCRETE SUBJECT TO EXPOSURE CLASS F3

Cementitious materials	Maximum percent of total cementitious materials by weight*
Fly ash or other pozzolans conforming to ASTM C618	25
Slag conforming to ASTM C989	50
Silica fume conforming to ASTM C1240	10
Total of fly ash or other pozzolans, slag, and silica fume	50†
Total of fly ash or other pozzolans and silica fume	35†

*The total cementitious material also includes ASTM C150, C595, C845, and C1157 cement.
The maximum percentages above shall include:
(a) Fly ash or other pozzolans in Type IP, blended cement, ASTM C595, or ASTM C1157;
(b) Slag used in the manufacture of an IS blended cement, ASTM C595, or ASTM C1157;
(c) Silica fume, ASTM C1240, present in a blended cement.
†Fly ash or other pozzolans and silica fume shall constitute no more than 25 and 10 percent, respectively, of the total weight of the cementitious materials.

TABLE 4.5.1 — REQUIREMENTS FOR ESTABLISHING SUITABILITY OF CEMENTITIOUS MATERIALS COMBINATIONS EXPOSED TO WATER-SOLUBLE SULFATE

Exposure Class	Maximum expansion when tested using ASTM C1012		
	At 6 months	At 12 months	At 18 months
S1	0.10 percent		
S2	0.05 percent	0.10 percent*	
S3			0.10 percent

*The 12-month expansion limit applies only when 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*