Modifications to ACI 301

Significant additions and modifications boost the power of the reference specification for structural concrete

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This is the second of three articles discussing ACI 301-10, "Specifications for Structural Concrete." The first article summarized the major modifications to ACI 301, including additional chapters on industrial floor slabs, tilt-up construction, precast concrete, and architectural precast concrete. This article provides a detailed review of some of the modifications made to default requirements that have existed in previous versions of ACI 301. Only a few of the modifications and additions to ACI 301 are described in this article; therefore, design and construction teams should thoroughly review ACI 301-10 to be aware of all the changes. The third article will discuss how ACI 301-10 can be used as a part of the specifications for a project.

FUNDAMENTALS

ACI 301-10 was developed by a dedicated committee comprised of consultants; structural, materials, and construction engineers; academics; contractors; concrete producers; and material suppliers. The committee was well balanced in terms of individuals responsible for developing project specifications and those using project specifications. This balance was essential for the committee to meet its primary goal—to produce a specification that would meet the intent of design teams and be usable by construction teams.

Project specifications are typically written by the Architect/Engineer (A/E) and the decision to incorporate ACI 301 into the project specifications is the A/E's choice. ACI 301-10 is a document written in mandatory language that is intended to be used by the A/E as a document that can be referenced. It's important to note that if the A/E does not incorporate ACI 301 into the project specifications, it does not have direct control on a project. It's equally important to know that once ACI 301-10 is referenced in the project specifications, it becomes part of those specifications and its requirements are part of the project requirements.

CHANGES RELATIVE TO PREVIOUS VERSIONS

The major changes in ACI 301-10 are new sections on industrial floors, tilt-up construction, precast concrete, and architectural precast concrete. For the first time, ACI 301 contains default requirements for these special construction types, so many of their requirements can be communicated to the contractor by reference to ACI 301 rather than by providing special sections within the contract documents. Other changes to ACI 301 are summarized in the following sections.

Professional services

ACI 318-08 designates the Licensed Design Professional (LDP) as the engineer who has responsible charge of the structural design. As a result of this, there has been a tendency to call any licensed engineer working on construction projects the LDP; however, the definition ACI 318 provides does not adequately describe all of the licensed engineers that work on a construction project. ACI 301-10 has added the term Licensed Design Engineer (LDE)—defined as the engineer who provides services to the contractor. Reviewing the definitions between the

two terms shows that there are significant differences in responsibilities of the LDP (the engineer responsible for the design of the structure) and the LDE (the engineer who provides services to the contractor).

Construction projects require the services of engineers who are involved in both the design phase and the construction phase of the project. ACI 301-10 requires that the contractor must use an LDE for specific tasks such as formwork design, structural design of post-tensioning, tilt-up drawings, structural design of precast elements, or other engineering duties that the contractor may require. In many parts of ACI 301-10, the LDE is required to submit his/her work to the LDP for acceptance.

Concrete compressive strength limits

One of the realities of cast-in-place concrete is that the strength of the concrete is not known until 28 days after the concrete has been cast in the structure. When compressive strength test results do not meet the specifications, the entire concrete design and construction team typically feels the impact as the effects of the low compressive strengths are analyzed and addressed. This doesn't happen with other materials used in the structure. For example, if a reinforcing bar manufacturer determines that a production lot has inadequate strength, the problem is resolved before the bars are shipped. The rest of the construction team has no knowledge of the problem, and there is no need for their input or help in determining what caused the low-strength material. This is definitely not the case for low-strength concrete test results.

Due to a widespread misconception that all compressive strength tests must exceed the specified strength f'_c, reported low compressive strength test results are probably the most overinvestigated items on a concrete project. The actual acceptance criteria are provided in ACI 301-10, Section 1.6.6.1 (Fig. 1). These criteria match those in Sections 5.6.3.3 and 5.6.3.4 of ACI 318-08. Note, however, that Sections 1.7.4.1 and 1.7.5.1 of ACI 301-10 specify that strength and durability of a structure, respectively, may be considered deficient only if the concrete fails to meet the limits provided in Section 1.6.6.1.b.

1.6.6 *Acceptance of concrete strength*

1.6.6.1 *Standard molded and cured strength specimens*—The strength of concrete is satisfactory provided that the criteria of 1.6.6.1.a and 1.6.6.1.b are met.

1.6.6.1.a Every average of three consecutive strength tests equals or exceeds the specified compressive strength f'_c.

1.6.6.1.b No strength test result falls below f'_c by more than 500 psi when f'_c is 5000 psi or less, or by more than $0.10f'_c$ when f'_c is more than 5000 psi. These criteria also apply to accelerated strength testing unless another basis for acceptance is specified in Contract Documents.

Fig. 1: Definitions of satisfactory concrete strength test results. Per Sections 1.7.4.1 and 1.7.5.1, concrete work is subject to rejection when Section 1.6.6.1.b is not met

Section 1.6.6.1 requires that steps be taken to make adjustments to increase the overall average compressive strength when the average of three consecutive strength tests is less than f'_c or when an individual strength test is less than (f'_c – 500 psi) or $0.9f'_c$ when f'_c is greater than 5000 psi. ACI 318 does not require the structural adequacy to be investigated when the three-test average is below the specified strength. ACI 318 only requires structural adequacy to be investigated if the individual strength test is less than (f'_c – 500 psi) or $0.9f'_c$ when the compressive strength is greater than 5000 psi. It should also be noted that in many cases, though a single strength test may fall below f'_c, the strength or durability of the structure is acceptable.

Material testing

When low strength test results are reported, the construction team may devote significant resources to investigate the claims. In some cases, the concrete strengths are actually low. Many investigations will reveal, however, that the testing agency performed the tests improperly and reported inaccurate results.

Due to this, ACI 301-10 contains requirements related to qualifications for the testing agency and technicians. ACI 301-10 is not written to the testing agency, but it provides minimum requirements that provide assurance to the contractor that the testing agency is qualified to properly conduct testing. ACI 301-10 also requires that the testing agency meets the requirements in ASTM C1077 and that the technicians be certified with the appropriate ACI certification programs.

Previous versions of ACI 301 required the contractor to provide and maintain adequate facilities on the project site for the testing agency to use for the initial curing of the concrete test cylinders. In some cases, it was not clear as to what type of facility was required to meet the initial curing requirements specified in ASTM C31. To avoid this confusion, ACI 301-10 requires only that the contractor provides space and electrical power for the sole use of the testing agency. This clarifies that the owners' testing agency has the responsibility of maintaining adequate field curing conditions.

Reinforcement

ACI 301 has requirements pertaining to reinforcement. Some projects have experienced problems during placement of the reinforcing bars because of congestion associated with embedments, openings, and other items. Section 3.3.2.2 of ACI 301-10 requires that if reinforcement must be located outside of placing tolerances, the A/E has to be contacted for approval. Tolerances for reinforcement are provided in ACI 117.

One of the more confusing words that we use in the concrete industry is the word minimum. The *American Heritage Dictionary* defines minimum as the least possible; however, in previous ACI documents, when minimum was used pertaining to concrete cover of reinforcing bars, it didn't mean least possible. In ACI 318-08, ACI Committee 318 changed the term from minimum to specified tolerances, allowing a more clear association with ACI 117, which provides tolerances that permit a reduction in the cover as stated in project specifications. ACI Committee 301 has made parallel changes in ACI 301-10, which now requires the contractor to place reinforcement to the specified tolerance. Cover for reinforcement must be in accordance with Table 3.3.2.3 of ACI 301-10. As with previous versions of ACI 301, values in this table are in agreement with ACI 318 requirements, and the headings within the table have been clarified to better match the cover requirements stated in ACI 318.

ACI 318-08 includes two types of reinforcement that were not described in previous versions of ACI 318. These reinforcement types—headed shear stud reinforcement and steel fiber—are included in ACI 301-10 (Fig. 2).

Durability

The portion of ACI 301 that applies to concrete mixtures has been rewritten to be in agreement with ACI 318-08 requirements pertaining to durability. An item in the mandatory requirements checklist requires that the A/E designate which portion of the structure will be subject to each or a combination of the durability conditions listed in ACI 318-08 and ACI 301-10. Corresponding specification requirements are provided in ACI 301-10, including tables showing the required cementitious material types, water-cementitious material ratio, compressive strength, and air content.

ACI 301 has always contained limits on the minimum and maximum temperatures of delivered concrete for both hot and cold weather concrete applications. Previous versions specified a maximum concrete temperature of 90°F. ACI 301-10 specifies a maximum temperature of 95°F. There are also other requirements in ACI 301-10 related to both the maximum and minimum temperatures.

Section 4.2.3.4 covers documentation required to verify that a proposed concrete mixture design will produce an average compressive strength meeting or exceeding the required average strength. Section 4.2.3.4.a covers field test data representing historical strength tests, and Section 4.2.3.4.b covers laboratory trial mixture requirements, including the requirement that the temperature of a freshly mixed trial mixture is to be within 10°F of the intended maximum temperature of the concrete delivered in the field.

ACI 301-10 continues to require that the concrete be air-entrained as the default requirement. Using air-entrained concrete for hard-troweled concrete floors increases the chances of delamination. The optional requirement checklist advises the A/E to specify non-air-entrained concrete when the floor will be hard-troweled.

As-cast concrete finishes

In previous versions of ACI 301, terms describing concrete finishes have created confusion. The term smooth, as in smooth form finishes, has been especially problematic. Many people interpret smooth as the term that is defined in the *American Heritage Dictionary* as free from projections or unevenness of surface. As a result, there have been disputes regarding the acceptability of surface air voids. To clarify the intent of the specifications, surface finishes are now defined using surface finish (SF) classes (Fig. 3). It should be noted that while a mockup of the concrete surface appearance and texture is an optional requirement for an SF-2.0 finish, such a mockup is a mandatory requirement for an SF-3.0 finish.

ACI 301-10 provides detailed definitions for the acceptable appearance of each of the finishes, including descriptions of acceptable void sizes. If the A/E does not specify a finish, then the default finish is SF-1.0 for surfaces not exposed to public view and SF-2.0 for surfaces exposed to public view.

Architectural concrete

Section 6 of ACI 301-10 provides requirements for architectural concrete. As stated in Section 6.1.1.1 and in the mandatory item checklist, this section is invoked only for areas designated as architectural concrete in the contract documents. Many of the requirements for architectural concrete also apply to other finishes and are included in Sections 1 through 5 of ACI 301-10. Section 6, however, contains more stringent requirements.

Section 6 also contains an optional requirement for a field mockup to be constructed on site (Fig. 4). The mockup will remain on site to be used as a comparative sample for judging the appearance of completed work as the project progresses.

Lightweight concrete

Lightweight concrete, typically made with lightweight aggregates meeting ASTM C330 (rather than ASTM C33, which applies to normalweight aggregates), is used on

3.2.1.8 *Headed shear stud reinforcement*—Headed studs and headed stud assemblies shall conform to ASTM A1044/A1044M.

3.2.1.9 *Steel fiber reinforcement*—When required, steel fiber reinforcement shall be deformed and conform to ASTM A820/A820M. Length-diameter ratio of fibers shall be between 50 and 100.

Fig. 2: Two new types of reinforcement are included in ACI 301-10

(a) **2.2.1.1** *Form-facing materials*—Unless otherwise specified or permitted, form face material in contact with concrete shall be lumber, plywood, tempered concrete-form-grade hardboard, metal, plastic, or paper that creates specified appearance and texture of concrete surface.

(b) **5.3.3.3** *As-cast finishes*—Use form-facing materials meeting the requirements of 2.2.1.1. Produce as-cast formed finishes in accordance with Contract Documents and 5.3.3.3.a through 5.3.3.3.c.

5.3.3.3.a *Surface finish-1.0 (SF-1.0):*

- No formwork facing material is specified;
- Patch voids larger than 1-1/2 in. wide or 1/2 in. deep;
- Remove projections larger than 1 in.;
- Tie holes need not be patched;
- Surface tolerance Class D as specified in ACI 117; and
- Mockup not required.

5.3.3.3.b *Surface finish-2.0 (SF-2.0):*

- Patch voids larger than 3/4 in. wide or 1/2 in. deep;
- Remove projections larger than 1/4 in.;
- Patch tie holes;
- Surface tolerance Class B as specified in ACI 117; and
- Unless otherwise specified, provide mockup of concrete surface appearance and texture.

5.3.3.3.c *Surface finish-3.0 (SF-3.0):*

- Patch voids larger than 3/4 in. wide or 1/2 in. deep;
- Remove projections larger than 1/8 in.;
- Patch tie holes;
- Surface tolerance Class A as specified in ACI 117; and
- Provide mockup of concrete surface appearance and texture.

Fig. 3: As-cast finishes can be specified using surface finish classes: (a) permitted form-facing materials; and (b) requirements for surface finish classes (SF-1.0, SF-2.0, and SF-3.0)

projects to reduce the dead load or increase fire resistance of the structural systems. The requirements for lightweight concrete are invoked only when the A/E specifies the equilibrium density of the concrete—the density determined after the concrete has dried to a constant weight. Because it can take a considerable length of time for the moisture content to stabilize, ASTM C567 includes an analytical method among the three different methods allowed for determining the equilibrium density. Unless the A/E directly specifies another method, the equilibrium density is determined using the calculated method in ASTM C567. The acceptance criterion for density is based on a fresh bulk density correlated with the specified equilibrium density (Fig. 5).

If lightweight aggregates are not conditioned (that is, prewetted) properly, there is a greater probability of excessive slump loss and erratic air content. Previous versions of ACI 301 contained

6.1.3.4 *Field mockup*

6.1.3.4.a When required, construct field mockups using same procedures, equipment, and materials that will be used for production of cast-in-place architectural concrete. Field mockups shall be used as a sample of acceptable quality of finished product. Construct field mockups at an acceptable location on site. Provide a simulated repair area to determine an acceptable repair procedure. Repair procedure shall be suitable to provide an acceptable color and texture match. Maintain and protect the mockups until final acceptance of architectural concrete.

6.1.3.4.b For walls, include vertical, horizontal, and rustication joints. Demonstrate methods of repair, curing, aggregate exposure, sealers, and coating. Construct mockup to include a minimum of two lifts having heights planned for placement of architectural concrete.

6.1.3.4.c For flatwork, construct minimum 10 x 10 ft mockup for review and acceptance using same materials and procedures detailed for architectural concrete.

Fig. 4: Field mockups provide samples that define acceptable quality of finished product and repair procedures

prescriptive requirements for the conditioning method. Prescriptive requirements, however, may not meet the intent of the specification. Further, the concrete producer may not need to conform to the prescribed requirements to meet the intent of the specification. ACI 301-10 requires that the aggregate moisture conditions be such that the concrete will maintain the required slump.

As with previous versions, ACI 301-10 requires that the slump and air content of normalweight concrete be measured at the point of delivery. ACI 301-10 requires that the slump and air content of lightweight concrete be measured at the point of placement (Sections 7.2.2.1 and 7.2.2.2). Given the many different types of lightweight aggregates, it would be difficult to place concrete if the slump were measured at the point of delivery. For example, if the air content of a lightweight concrete were measured and controlled at the point of delivery, the concrete may not meet the requirements at the end of the pump.

Mass concrete

Mass concrete—concrete that requires careful control of maximum temperatures and temperature differentials—is widely encountered in present day concrete construction. Thick, large sections (such as in mat foundations) are common, and high-strength or high-performance concrete tends to generate greater heat during hydration. Previous versions of ACI 301 required that mass concrete be placed at a maximum temperature of 70°F unless otherwise specified, but it

7.3.3 *Field quality control*

7.3.3.1 *Density*—Acceptance of lightweight concrete in field will be based on fresh bulk density measured in accordance with ASTM C138/C138M. The fresh bulk density required shall correspond to the specified equilibrium density. When the fresh bulk density varies by more than plus or minus 3 lb/ft^3 from the required fresh bulk density, adjust the mixture as promptly as conditions permit to bring the density to the desired level. Do not use concrete for which fresh bulk density varies by more than plus or minus 4 lb/ft^3 from the required fresh bulk density.

7.3.3.2 *Air content*—Air content of lightweight concrete sample for each strength test will be determined in accordance with ASTM C173/C173M as specified in 7.2.2.1.

Fig. 5: Acceptance testing for lightweight concrete is based on fresh bulk density, but lightweight concrete is specified using the equilibrium density of the concrete

didn't require verification for the maximum concrete temperatures or temperature differentials. While a maximum temperature of 70°F was unnecessarily conservative in many cases, it didn't provide protection against excessive cracking caused by large temperature differentials. ACI 301-10 now requires a thermal control plan for mass concrete. A portion of the mass concrete requirements are shown in Fig. 6. This encourages the use of concrete mixtures that have lower initial temperature and a controlled and known rate of heat generation. It also encourages the use of insulation to maintain specified temperature differentials.

Post-tensioned concrete

Requirements for post-tensioned concrete, including materials, installation, stressing, and grouting, are contained in Section 9 of ACI 301-10. While the material requirements for bonded strands are specified in ACI 301-10, the latest version of ACI 301 refers to the requirements of ACI 423.7 for unbonded, single-strand tendons.

The installers of post-tensioning systems must be certified in accordance with the Post-Tensioning Institute's (PTI) Level 1 Field Installation programs for bonded and unbonded systems (Fig. 7). Inspections must be performed by a certified PTI Level 2 Unbonded PT Inspector.

Post-tensioning grout properties have changed significantly in ACI 301-10. New requirements cover the grout as well as the grout installation procedures. Required strength, water-cement ratio, setting time, flow rates, and bleed rates are defined. Bleed rates are to be measured using the wick-induced bleed test procedure defined in ACI 301-10. This procedure is a modification of the ASTM C940 test.

8.1.2 *General requirements*—Mass concrete shall comply with requirements of Sections 1 through 5, unless otherwise specified in this section or in Contract Documents.

Unless otherwise specified, the following criteria shall apply for mass concrete placements:

- The maximum temperature in concrete after placement shall not exceed 158°F; and
- The maximum temperature difference between center and surface of placement shall not exceed 35°F.

Fig. 6: Requirements for mass concrete

9.3—Execution

9.3.1 *Installer certification*—Unless otherwise specified or permitted, installation shall be performed by personnel certified by the Post-Tensioning Institute's training and certification program. For unbonded post-tensioning, personnel shall be certified in accordance with PTI's Level 1 Field Installation program. For bonded post-tensioning, personnel shall be certified in accordance with PTI's Level 1 Bonded PT—Field Installation program. Submit the qualifications of installation personnel.

Fig. 7: The installers of post-tensioning systems must be certified in accordance with the Post-Tensioning Institute's Level 1 Field Installation programs

A MORE POWERFUL SPECIFICATION

ACI 301-10 is a comprehensive reference specification for concrete construction. When incorporated by reference into contract documents, ACI 301-10 provides consistent, unambiguous instructions to the contractor. This is just a small sample of the modifications and additions to ACI 301-10; therefore, the entire team should thoroughly review ACI 301-10.

Note: Additional information on the ASTM standards discussed in this article can be found at **www.astm.org**.

Selected for reader interest by the editors.

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