

Specifying Concrete Inspection and Quality

What Engineers Should Know

By George R. Wargo

Not every engineer has the knowledge and experience to develop structural concrete specifications that correctly and clearly express proper requirements for concrete materials and inspection practices. College engineering curriculums seldom provide instruction in these areas, so it can take years of on-the-job experience for a young engineer to become competent in specifying and managing all the requirements necessary to control quality concrete construction.

As an inspection/testing professional, my experience is that of the three major participants in jobsite construction quality activities (the engineer, the contractor, and the inspection agency), usually the inspection agency is most familiar with the information in ACI documents and in the material test standards referenced in the contract documents. Additionally, the inspection agency usually has a more complete collection of the various ACI and material test standards referenced. For these reasons, inspection agencies/inspectors often function as a reference source for the contractor and the engineer whenever issues or problems arise with the concrete or concrete material quality.

This arrangement is usually quite beneficial, provided that the inspector (or agency) is competent and that the engineer and the contractor are willing to seek information and assistance when needed.

In the same spirit of cooperation often exercised in the field, this article presents comments and tips for the engineer responsible for specifying and managing quality requirements for concrete materials and inspection/testing activities. More detailed information can be found in ACI documents, most notably, SP-2, *Manual of Concrete Inspection*.

Many of the following topics are essentially covered in most specifications by a general reference to ACI 318, *Building Code Requirements for Structural Concrete* and ACI 301, *Specifications for Structural Concrete*. However, since many contractor field offices do not maintain copies of these and other referenced standards, I recommend that project specifications be specific in identifying concrete quality requirements.



Consultation between the inspector, contractor and the engineer is often a key element in understanding and solving concrete quality problems

Qualification of Laboratories and Inspection Personnel

DO... require laboratories to provide evidence of compliance to ASTM E 329, *Standard Specification for Agencies Engaged in the Testing and/or Inspection of Materials Used in Construction* or ASTM C 1077, *Standard Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation*. Conformance to ASTM C 1077 includes regular inspection of the laboratory's facilities and procedures by an independent evaluation authority such as the CCRL. Preferably, laboratories should also be accredited by AASHTO, A2LA, NVLAP or other recognized accrediting body. Accreditation programs involve an in-depth verification and assessment of the laboratories internal quality system programs as well as evaluation of laboratory compliance to the ASTM C 1077 standard.

DON'T... require laboratory compliance to ASTM E 548, *Practice for Preparation of Criteria for Use in the Evaluation of Testing Laboratories and Inspection Bodies*. ASTM E 548 is a withdrawn standard which was never really applicable to testing laboratory activities.

DO... require concrete field testing personnel to be certified as ACI Concrete Field Testing Technicians—Grade 1, or equivalent. Equivalent certification programs must provide for both written and performance examinations, comparable to corresponding ACI programs.

Concrete inspectors and concrete laboratory technicians should also be certified to applicable ACI certification programs, or equivalent. Use of an accredited laboratory generally assures that inspection and testing personnel provided by the laboratory have been tested and/or evaluated and qualified for all applicable activities for which they are assigned.

Concrete Mix Requirements and Submittals

DO... require minimum limits for concrete durability given in Chapter 4 of ACI 318. Specify a compressive strength which is reflective of the water to cementitious materials ratio (w/cm) selected; for example, 4500 psi for 0.45 w/cm and 5000 psi for 0.40 w/cm. Many specifications often list a 0.40 or 0.45 w/cm requirement but couple this with a 4000 psi (air entrained) strength requirement. As a result, in-place production concrete often fails to meet the specified w/cm.

DON'T... specify unrealistic or unnecessarily low w/cm values. The w/cm limits given in Table 4.2.2 of ACI 318 are sufficient to provide the durability needed for various exposure conditions.

DO... specify minimum cementitious materials factors for concrete used in floors as given in Table 4.2.2.1 of ACI 301.

Follow ACI 302.1R *Guide for Concrete Floor and Slab Construction* recommendations for specifying use of non-air entrained concrete in floor slabs which will receive a steel trowel finish (unless other considerations such as exposure to severe weather during construction requires the use of air entrained concrete). Air entrained concrete bleeds at a slower rate than non-air entrained concrete, increasing the possibility of late rising bleed water being trapped under the steel troweled surface, leading to subsequent scaling of the surface.

Table 4.2.2 - Requirements for special exposure conditions

Exposure Condition	Maximum water cementitious materials ratio, by weight, normal weight aggregate concrete	Minimum f'_c normal weight and light weight aggregate concrete, psi
Concrete intended to have low permeability when exposed to water	0.50	4000
Concrete exposed to freezing and thawing in a moist condition or to deicing chemicals	0.45	4500
For corrosion protection of reinforcement in concrete exposed to chlorides from deicing chemicals, salt, salt water, brackish water, seawater, or spray from these sources	0.40	5000

Table 4.2.2.1 - Minimum cementitious materials content requirements for floors

Nominal maximum size of aggregate, in.	Minimum cementitious materials content, lb/yd ³
1-1/2	470
1	520
3/4	540
3/8	610

Note: When fly ash is used, quantity shall not be less than 15% nor more than 25% by weight of total cementitious materials.

Industry experience has generally shown that steel troweled, air entrained, lightweight concrete does not appear to develop finish related scaling problems as readily as normal weight concrete. Since a 6 to 7 percent air is usually integral to achieving the density requirement, it is generally impractical to impose the ACI 302.1R recommendations for use of non-air concrete in floor slabs when lightweight concrete is employed.

DON'T... specify low w/cm ratios for non-air entrained (non-exposed) concrete unless required for special conditions. For most non-air entrained concrete, desired quality can usually be achieved by simply specifying the strength required and, when applicable, the minimum cement content needed. Typical proportioning for a 4000 psi, non-air entrained concrete containing 1-inch maximum size aggregate will generally require a w/cm in the range of 0.50 to 0.53 to produce a 4-inch slump (depending upon the type and amounts of admixtures employed).

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Requirements for location and minimum lengths for splicing of reinforcement must be provided by the engineer

DO... specify the methods that may be employed to qualify mix proportions. Both ACI 318 and ACI 301 require proportioning based upon either field experience or trial mixtures. Be specific in identifying the type of supporting documentation which must accompany concrete mix proportion submittals. For example, all submittals should be accompanied by material certifications to appropriate ASTM standards for all proposed mix ingredients.

Field experience test data should be traceable to the specific batch plant that will produce concrete for the project. Statistical data for average strength and standard deviation must show that the proposed proportions will meet or exceed the “required average strength” (a value in excess of the specified strength as calculated per ACI 318 and ACI 301).

Laboratory trial mixtures should be developed with at least three different w/cm ratios to produce a range of strengths encompassing the required average strength. By plotting compressive strength versus w/cm ratio for each of the trial mixes, a curve can be drawn and used to develop concrete proportions corresponding to a specific desired strength value anywhere along the curve. Once again, a strength level must be selected which meets or exceeds the required average strength, and the corresponding w/cm must not exceed the maximum value specified.

In the absence of suitable data from field experience or trial mixtures, ACI 318 also permits the engineer to approve proportions based upon “other information,” provided that the specified strength of concrete is not more than 5000 psi and that the proportions proposed for use will produce a strength at least 1200 psi greater than the specified strength. What constitutes other information is not defined, but one example of a recommended method would be to have a qualified independent laboratory conduct a trial mix verification using the materials and proportions proposed for the work.

DON'T... wait until field tests of production concrete fall below specified strength levels to make inquiries regarding lower than expected quality performance of the concrete. Once production concrete commences, carefully review initial reports of concrete test results and compare performance of concrete to that presented in the concrete mix submittal. If actual performance is significantly below expected (even though minimum requirements for acceptance are still being met), demand investigations to determine the corrective action needed.

Placement Related Inspection Activities

DO... specify that concrete production facilities be inspected and certified to the NRMCA Plant Certification Program. When this is impractical, require that a plant meet the requirements of ASTM C 94 *Standard Specification for Ready-Mixed Concrete*, and have a survey conducted by a qualified engineer or independent inspection agency. Independent inspection of batching facilities and operations during production is recommended, especially at the start of projects and whenever questions or concerns for the performance of the concrete develop. Additional information on batch plant inspection is provided in ACI 311.5R, *Guide for Concrete Plant Inspection and Testing of Ready-Mixed Concrete*.

Specify independent inspection of forms and reinforcement prior to concrete placement. Inspection and testing of subgrade and subbase materials by qualified geotechnical personnel may also need to be addressed by the engineer.

Prestressing material and operations should be inspected on a continuous basis by certified personnel. Strands should be inspected for location, securement, anchorage, cleanliness and damage. Calculations of stressing force and related strand elongation need to be conducted under the supervision of a qualified engineer. Stressing operations should be witnessed and documented by a certified independent inspector with all observations and elongation measurements submitted to the structural engineer immediately following the activity.

DON'T... forget to identify minimum lap lengths for splicing reinforcement and any restrictions concerning location of splices. Also, don't forget to specify a maximum height for the free-fall of concrete.

Testing of Concrete and Concrete Materials

DO... specify pre-construction and in-process production sampling and testing of concrete materials by an independent testing agency. The scope and frequency of testing depends on the project size. The specifier should consult ACI publications SP-2 and ACI 311.4R, *Guide for Inspection of Concrete*, for guidance.

Specify requirements for daily field testing of concrete for slump, air content, temperature, casting of strength specimens, and other tests applicable to the work. Frequency of testing should meet the minimum requirements given in ACI 301.

It is a good idea to instruct the contractor in the project specification to:

1. Provide at least 24 hour advance notification to the testing agency prior to all concrete operations so that arrangements for inspection and testing can be made,
2. Assist the testing agency in obtaining and handling samples at the project site or at the source of materials, and
3. Provide on-site facilities for the safe storage and initial curing of test specimens, as required by ASTM C 31, *Standard Practice for Making and Curing Concrete Test Specimens in the Field*.

DON'T... specify excessive testing frequencies, such as sampling and testing each truck for slump and air content. The testing frequencies given in ACI 301 are adequate for documenting and controlling the quality of concrete production. Excessive testing frequencies are not only unnecessary but can also be counterproductive as they may delay the placement process, as well as reduce the performance level of testing being conducted.



Field testing of concrete is a key element of quality control. Excessive testing, however, does not add to quality and can be counterproductive

If strength tests of concrete cylinders fail to demonstrate satisfactory strength, concrete cores may be drilled and obtained from the structure and tested in accordance with ASTM C 42, *Method of Obtaining and Testing Drilled Cores and Sawed Beams of Concrete*. Three cores should be obtained and tested for each strength test in question. Per ACI 318, concrete in an area represented by core tests shall be considered structurally adequate if the average strength of three cores is equal to at least 85 percent of the specified strength and no individual core is less than 75 percent of the specified strength.

DON'T... permit nondestructive tests, such as impact hammer, probe penetration, pull-out or ultrasonic velocity to be used as the sole basis of acceptance or rejection of concrete. Evaluation of concrete by nondestructive methods should involve calibration of the nondestructive method by experimental testing, such as correlating measurements against compressive test results of cores taken from the same area where nondestructive measurements were performed.

Nondestructive testing is very useful in conducting comparison tests of like concrete from the same project and identifying locations of possible low-strength concrete. ■

Evaluation of Strength Results

DO... specify that the strength level of concrete will be considered satisfactory if the averages of all sets of three consecutive compressive strength results equal or exceed the specified strength, and no individual strength test result falls below the specified compressive strength by more than 500 psi (as given in ACI 318 and ACI 301).

George R. Wargo is the Manager of Civil/Structural Inspection and Testing at Construction Engineering Consultants, Inc. in Pittsburgh, PA and the chair of ACI Committee 311 "Inspection of Concrete". He can be reached at gw@cectesting.com

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