NOTES: This version of Chapter 22 includes the following:

1. Approved version of 11/07/28.
2. Changes approved for ACI 318-11.
3. Technical changes approved under CA026.
4. Editorial changes approved under CA114.
5. Commentary as approved on 318 LB12-03.

CHAPTER 2 (partial) — NOTATION AND TERMINOLOGY

2.2—Notation

\[ w/cm = \text{water-cementitious materials ratio.} \]

\[ f'_{cu} = \text{required average compressive strength of concrete used as the basis for selection of concrete proportions, psi, Chapter 5} \]

2.3—Terminology

**water-cementitious materials ratio** — the ratio of the mass of water, excluding that absorbed by the aggregate, to the mass of cementitious materials in a mixture, stated as a decimal.

CHAPTER 3 (partial) – REFERENCED STANDARDS

3.3 – American Concrete Institute (ACI)

3.3.x -- Article 4.2.3 of “Specifications for Structural Concrete (ACI 301-10)” is declared to be part of this Code as if fully set forth herein, for the purposes cited in 22.4.1.2. <~>

R3.3.x -- Article 4.2.3 of ACI 301-10 is referenced for the method of mixture proportioning. <~>

CHAPTER 22 — REQUIREMENTS FOR CONCRETE AND GROUT

22.1 — Scope

22.1.1 — The provisions of this Chapter shall apply to materials and proportioning for concrete, materials and proportioning for grout for bonded tendons, and acceptance of concrete. <~>
22.2 — General

22.2.1 — The licensed design professional shall include in construction documents the applicable requirements for concrete and grout for bonded tendons.

22.2.2 — The provisions of this Chapter shall apply to acceptance testing of concrete.

22.3 — Materials for concrete

22.3.1 — Cementitious materials

22.3.1.1 — Cementitious materials shall conform to the specifications in Table 22.3.1.1.

<table>
<thead>
<tr>
<th>Cementitious material</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portland cement</td>
<td>ASTM C150</td>
</tr>
<tr>
<td>Blended hydraulic cements</td>
<td>ASTM C595, excluding Type IS ($\geq 70$)*</td>
</tr>
<tr>
<td>Expansive hydraulic cement</td>
<td>ASTM C845</td>
</tr>
<tr>
<td>Hydraulic cement</td>
<td>ASTM C1157</td>
</tr>
<tr>
<td>Fly ash and natural pozzolan</td>
<td>ASTM C618</td>
</tr>
<tr>
<td>Slag cement</td>
<td>ASTM C989</td>
</tr>
<tr>
<td>Silica fume</td>
<td>ASTM C1240</td>
</tr>
</tbody>
</table>

*Type IS ($\geq 70$) is not intended as principal cementing constituent of structural concrete.

22.3.1.2 — All cementitious materials specified in 22.3.1 and the combinations of these materials shall be included in calculating the $w/cm$ of the concrete mixture.

22.3.2 — Aggregates

22.3.2.1 — Aggregates shall conform to the following specifications:

(a) Normalweight aggregate: ASTM C33

(b) Lightweight aggregate: ASTM C330
22.3.2.2—Aggregates not meeting the specifications in 22.3.2.1 are permitted if they have been shown by test or actual service to produce concrete of adequate strength and durability and are approved by the building official.  <3.3.1> 

**R22.3.2.2** -- Aggregates conforming to ASTM specifications are not always economically available and, in some instances, noncomplying materials may have a documented history of satisfactory performance under similar exposure. Such nonconforming materials are permitted if acceptable evidence of satisfactory performance is provided. If possible, aggregates conforming to the designated specifications should be used.  <R3.3.1> 

22.3.2.3 — Nominal maximum size of coarse aggregate shall not exceed the least of (a), (b), and (c):

(a) 1/5 the narrowest dimension between sides of forms;

(b) 1/3 the depth of slabs;

(c) 3/4 the minimum clear spacing between individual reinforcing bars or wires, bundles of bars, individual tendons, bundled tendons, or ducts.

These limitations shall not apply if, in the judgment of the licensed design professional, workability and methods of consolidation are such that concrete can be placed without honeycombs or voids.  <3.3.2> 

**R22.3.2.3** — The size limitations on aggregates are provided to facilitate placement of concrete around the reinforcement without honeycombing due to blockage by closely-spaced reinforcement.  <R3.3.2.> 

22.3.3 — Water

22.3.3.1 — Mixing water shall conform to ASTM C1602.  <3.4.1> 

**R22.3.3.1** — Almost any natural water that is drinkable (potable) and has no pronounced taste or odor is satisfactory as mixing water for making concrete. Excessive impurities in mixing water may affect setting time, concrete strength, and volume stability (length change), and may also cause efflorescence or corrosion of reinforcement.  < R 3.4.1> 

Salts or other deleterious substances contributed from the aggregate or admixtures add to those that might be contained in the mixing water. These additional amounts are to be considered in establishing the total impurities that may be present in the concrete.  < R 3.4.1> 

ASTM C1602 allows the use of potable water without testing and includes methods for qualifying nonpotable sources of water, such as from concrete production operations, with consideration of effects on setting time and strength. Testing frequencies are established to ensure continued monitoring of water quality.  < R 3.4.1> 

ASTM C1602 includes optional limits for chlorides, sulfates, alkalis, and solids in mixing water that can be invoked if appropriate.  < R 3.4.1>
22.3.3.2 — Mixing water, including that portion of mixing water contributed in the form of free moisture on aggregates, for prestressed concrete, for concrete that will contain aluminum embedments, or for concrete cast against stay-in-place galvanized steel forms shall not contain deleterious amounts of chloride ion. <3.4.2>

22.3.4 — Admixtures

22.3.4.1 — Admixtures shall conform to the following specifications: <3.6.1> <3.6.2>

(a) For water reduction and setting time modification: ASTM C494;

(b) For producing flowing concrete: ASTM C1017;

(c) For air entrainment: ASTM C260.

22.3.4.2 — Admixtures that do not conform to the specifications listed in 22.3.4.1 shall be subject to prior approval by the licensed design professional. <3.6.3>

22.3.4.3 — Calcium chloride or admixtures containing chloride from sources other than impurities in admixture ingredients shall not be used in prestressed concrete, in concrete containing embedded aluminum, or in concrete cast against stay-in-place galvanized steel forms. <3.6.4>

R22.3.4.3 — Calcium chloride is prohibited from use in prestressed concrete because corrosion of prestressing steel is generally of greater concern than corrosion of non-prestressed reinforcement (ACI 222R). Because of the possibility of local reduction in the cross section and failure of the prestressing steel may result in fracture of the steel (ACI 222R). The presence of chloride ions may cause corrosion of embedded aluminum (e.g., conduit), especially if the aluminum is in contact with embedded steel and the concrete is in a humid environment. Protection requirements for embedded aluminum are given in 23.6. Corrosion of galvanized steel sheet and galvanized steel stay-in-place forms may occur, especially in humid environments or where drying is inhibited by the thickness of the concrete or coatings or impermeable coverings. Specific limits on chloride ion concentration in concrete are given in 5.3. <R3.6.4>

22.3.4.4 — Admixtures used in concrete containing expansive cements conforming to ASTM C845 shall be compatible with the cement and produce no deleterious effects. <3.6.5>

R22.3.4.4 — In some cases, the use of admixtures in concrete containing ASTM C845 expansive cements has resulted in reduced levels of expansion or increased shrinkage values. See ACI 223. <R3.6.5>

22.3.5 — Steel fiber reinforcement

22.3.5.1 — Steel fiber reinforcement shall be deformed and conform to ASTM A820. Steel fibers shall have a length-to-diameter ratio not smaller than 50 and not greater than 100. <3.5.8>

R22.3.5.1 — Deformations in steel fibers enhance mechanical anchorage with the concrete. The lower and upper limits for the fiber length-to-diameter ratio are based on available test data. <R3.5.8>
22.4 — Proportioning of concrete mixtures

R22.4 — Proportioning of concrete mixtures

The 2014 edition of the Code does not include the statistical requirements for proportioning concrete that were in previous editions. The Committee considers that this information is inappropriate in the Code because it is not a responsibility of the licensed design professional to proportion concrete mixtures. Further, this information is available in other ACI documents, such as ACI 301 and ACI 214R.

Finally, the quality control procedures of some concrete producers allow meeting the acceptance criteria of the Code without following the exact process included in previous editions of the Code.

22.4.1 — Selection of concrete proportions

R22.4.1 — Selection of concrete proportions

This section provides requirements for developing mixture proportions. The concrete has to be workable and it has to meet the durability and strength requirements of the Code. The term "without segregation" is intended to provide for a cohesive mixture in which aggregates remain well distributed while the concrete is in its fresh state. It is recognized that some segregation in the form of bleeding will occur. The required workability will depend on reinforcement congestion, member geometry, and the placement and consolidation methods to be used. Construction requirements of the contractor should be considered in establishing required workability of the concrete.

The Code does not include provisions for especially severe exposures, such as chemical contact, high temperatures, temporary freezing and thawing conditions during the construction period, abrasive conditions, alkali-aggregate reactions, or other unique durability considerations pertinent to the structure. The Code also does not address aesthetic considerations such as surface finishes. If applicable, these items should be covered specifically in the construction documents.

22.4.1.1 — Concrete mixture proportions shall be established so that the concrete satisfies (a) through (c):

(a) Can be placed readily without segregation into forms and around reinforcement under placement conditions to be used;

(b) Meets requirements for assigned exposure classes of Chapter 5;

(c) Conforms to strength test requirements of 22.5.

R22.4.1.1 — Concrete mixture proportions shall be established in accordance with Article 4.2.3 of ACI 301 or by an alternative method acceptable to the licensed design professional. Alternative methods shall have a probability of satisfying the requirements of 22.5.3.2 that meets or exceeds the probability associated with the method in Article 4.2.3 of ACI 301.

R22.4.1.2 — Article 4.2.3 of ACI 301 contains the statistical procedures for selecting the required average strength that were included previously in the Code. Alternatively, the concrete producer is permitted to
provide evidence acceptable to the licensed design professional that the concrete can be proportioned by an alternative method to meet the project requirements and the acceptance criteria of 22.5. The Code presumes that the probability of not meeting the acceptance criteria in 22.5.3.2 is not more than 1 in 100. Following the method of proportioning in ACI 301 will maintain this level of risk. A key factor in evaluating any proposed alternative proportioning method would be its ability to preserve this presumed level of risk. Refer to ACI 214R for additional information. <Mostly new and R5.3.2.1>

22.4.1.3 — Concrete materials used in the Work shall correspond to those used to develop concrete mixture proportions. <3.2.2>

22.4.1.4 — If different concrete mixtures are to be used for different portions of proposed Work, each mixture shall comply with 22.4.1.1. <5.2.2>

R22.4.1.4 — If more than one concrete mixture is used for the project, each mixture is required to satisfy Code requirements. A change in concrete constituents, such as sources or types of cementitious materials, aggregates, or admixtures, is considered a different mixture. A minor change in mixture proportions made in response to field conditions is not considered a new mixture. <~>

22.4.2 – Documentation of concrete mixture characteristics

22.4.2.1 – Documentation of concrete mixture characteristics shall be reviewed by the licensed design professional before the mixture is used and before making changes to mixtures already in use. Evidence of the ability of the proposed mixture to comply with the requirements of 22.4.1.1 shall be included in the documentation. The evidence shall be based on field test records or laboratory trial batches. Field or laboratory data shall be based on materials intended to be used in the proposed Work. Field test records shall represent conditions similar to those anticipated during the proposed Work. <~>

R22.4.2.1 – Review of the proposed concrete mixture is necessary to ensure that it is appropriate for the project and meets all of the requirements as established by the licensed design professional for strength and durability. The licensed design professional typically reviews the documentation on a proposed concrete mixture to evaluate the likelihood that the concrete will meet the acceptance requirements of 22.5 and that acceptable materials are used. The statistical principles discussed in ACI 214R can be useful in evaluating the likelihood that a proposed mixture will meet the requirements of 22.5. <~>

22.4.2.2 – If field or laboratory data are not available, and $f'_c$ is not greater than 5,000 psi, concrete proportions shall be based on other experience or information, if approved by the licensed design professional. If $f'_c$ exceeds 5,000 psi, test data documenting the characteristics of the proposed mixtures are required. <based on 5.4.1>

R22.4.2.2 — If $f'_c$ is not greater than 5000 psi and test data are not available, concrete mixture proportions should be established to produce a sufficiently high average strength such that the likelihood that the concrete would not meet the strength acceptance criteria would be acceptably low. Guidance on an appropriate average strength is provided in ACI 214R. The purpose of this provision is to allow work to continue when there is an unexpected interruption in concrete supply and there is not sufficient time for testing and evaluation or for a small project where the cost of trial mixture data is not justified. <R5.4.1>
22.4.2.3. — As data become available during construction, it shall be permitted to modify a mixture that consistently exceeds the acceptance criteria of 22.5, provided that acceptable evidence is furnished to the licensed design professional to demonstrate that the modified mixture will comply with the requirements of 22.4.1.1. <based on 5.5>

**R22.4.2.3** — Often, at the beginning of a project, concrete mixtures will be proportioned conservatively to ensure passing the acceptance criteria. As test data showing actual variability become available, it may be appropriate to proportion the mixture less conservatively. See ACI 214 R22.4 for guidance. <~>

### 22.5 — Evaluation and acceptance of concrete

#### 22.5.1 — General

**22.5.1.1** — A strength test shall be the average of the strengths of at least two 6 x 12 in. cylinders or at least three 4 x 8 in. cylinders made from the same sample of concrete and tested at 28 days or at test age designated for \( f'_{c} \). <5.6.2.4>

**R22.5.1.1** — Casting and testing more than the minimum number of specimens may be desirable in case it becomes necessary to discard an outlying individual cylinder strength in accordance with ACI 214R.22.4 If individual cylinder strengths are discarded in accordance with ACI 214R, a strength test is valid provided at least two individual 6 by 12 in. cylinder strengths or at least three 4 by 8 in. cylinders are averaged. All individual cylinder strengths that are not discarded in accordance with ACI 214R are to be used to calculate the average strength. The size and number of specimens representing a strength test should be the same for each class of concrete. <R5.6.2.4>

Testing three instead of two 4 by 8 in. cylinders preserves the confidence level of the average strength because 4 by 8 in. cylinders tend to have approximately 20 percent higher within-test variability than 6 by 12 in. cylinders.22.3 <R5.6.2.4>

**22.5.1.2** — The testing agency performing acceptance testing shall comply with ASTM C1077.

**R22.5.1.2** — ASTM C1077 defines the duties, responsibilities, and minimum technical requirements of testing agency personnel and defines the technical requirements for equipment used in testing concrete and concrete aggregates. Agencies that test cylinders or cores to determine compliance with Code requirements should be accredited or inspected for conformance to the requirement of ASTM C1077 by a recognized evaluation authority. <R5.6.1>

**22.5.1.3** — Qualified field testing technicians shall perform tests on fresh concrete at the job site, prepare specimens for standard curing, prepare specimens for field curing, if required, and record the temperature of the fresh concrete when preparing specimens for strength tests. <5.6.1>

**R22.5.1.3** — Technicians can establish qualifications by becoming certified through certification programs. Field technicians in charge of sampling concrete; testing for slump, unit weight, yield, air content, and temperature; and making and curing test specimens should be certified in accordance with...
22.5.1.4 — Qualified laboratory technicians shall perform required laboratory tests. <5.6.1>

**R22.5.1.4**—Concrete testing laboratory personnel should be certified in accordance with the requirements of the ACI Concrete Laboratory Testing Technician – Level 1 Certification Program, the ACI Concrete Strength Testing Technician Certification Program, the requirements of ASTM C1077, or an equivalent program. <R5.6.1>

22.5.1.5 – All reports of acceptance tests shall be provided to the licensed design professional, contractor, concrete producer, and, when requested, to the owner and the building official. <5.6.1>

**R22.5.1.5**—The Code requires testing reports to be distributed to the parties responsible for the design, construction, and approval of the Work. Such distribution of test reports should be indicated in contracts for inspection and testing services. Prompt distribution of testing reports allows for timely identification of either compliance or the need for corrective action. A complete record of testing allows the concrete producer to reliably establish appropriate mixture proportions for future Work. <R5.6.1>

22.5.2 — Frequency of testing

22.5.2.1 — Samples for preparing strength test specimens of each class of concrete placed each day shall be taken in accordance with (a), (b), and (c): <5.6.2.1>

(a) At least once a day;

(b) At least once for each 150 yd$^3$ of concrete;

(c) At least once for each 5000 ft$^2$ of surface area for slabs or walls.

**R22.5.2.1**—Samples for strength tests are to be taken on a strictly random basis if they are to measure properly the acceptability of the concrete. To be representative within the period of placement, the choice of times of sampling, or the batches of concrete to be sampled, is to be made on the basis of chance alone. Batches are not sampled on the basis of appearance, convenience, or other possibly biased criterion, because the statistical analyses will lose their validity. ASTM D3665$^{22.6}$ describes procedures for random selection of the batches to be tested. Specimens for only one strength test (as defined in 22.5.1.1.) are to be made from a single batch, and water may not be added to the concrete after the sample is taken. <R5.6.2.2>

**R22.5.2.1(c)**—In calculating surface area, only one side of the slab or wall is considered. Criterion (c) will require more frequent sampling than once for each 150 yd$^3$ placed if average wall or slab thickness is less than 9-3/4 in. <R5.6.2.1>

22.5.2.2 — On a given project, if total volume of concrete is such that frequency of testing required by 22.5.2.1 would provide less than five strength tests for a given class of concrete,
strength test specimens shall be made from at least five randomly selected batches or from each batch if fewer than five batches are used. <5.6.2.2>

22.5.2.3—If total quantity of a given class of concrete is less than 50 yd³, strength tests are not required when evidence of satisfactory strength is submitted to and approved by the building official. <5.6.2.3>

22.5.3 — Acceptance criteria for standard-cured specimens

22.5.3.1 — Specimens for acceptance tests shall be in accordance with (a) and (b):

(a) Sampling of concrete for strength test specimens shall be in accordance with ASTM C172; <5.6.3.1>

(b) Cylinders for strength tests shall be made and standard-cured in accordance with ASTM C31 and tested in accordance with ASTM C39. Cylinders shall be 4 x 8 in. or 6 x 12 in. <5.6.3.2>

R22.5.3.1—The cylinder size should be agreed upon by the owner, licensed design professional, and testing agency before construction. <R5.6.3.2>

22.5.3.2 — Strength level of an individual class of concrete shall be acceptable if (a) and (b) are satisfied: <5.6.3.3>

(a) Every arithmetic average of any three consecutive strength tests equals or exceeds $f'_{c}$;

(b) No strength test falls below $f'_{c}$ by more than 500 psi if $f'_{c}$ is 5000 psi or less; or by more than 0.10 $f'_{c}$ if $f'_{c}$ is greater than 5000 psi.

R22.5.3.2—Evaluation and acceptance of the concrete can be judged immediately as test results are received during the course of the Work. Strength tests failing to meet these criteria will occur occasionally (probably about once in 100 tests) even though concrete strength and uniformity are satisfactory. Allowance should be made for such statistically expected variations in deciding whether the strength level being produced is adequate. <R5.6.3.3>

22.5.3.3 — If the requirements of 22.5.3.2 are not satisfied, steps shall be taken to increase the average of subsequent strength test results. <5.6.3.4>

R22.5.3.3—The steps taken to increase the average level of subsequent strength test results will depend on the particular circumstances, but could include one or more of the following:

(a) Increase in cementitious materials content;
(b) Reduction in or better control of water content;
(c) Use of a water-reducing admixture to improve the dispersion of cementitious materials;
(d) Other changes in mixture proportions;
(e) Reduction in delivery time;
(f) Closer control of air content;
(g) Improvement in the quality of the testing, including strict compliance with ASTM C172, ASTM C31, and ASTM C39. <R5.6.3.4>
Such changes in operating procedures, or small changes in cementitious materials content, or water content should not require a formal resubmission; however, changes in sources of cement, aggregates, or admixtures need to be accompanied by evidence that the average strength level will be improved. <R5.6.3.4>

22.5.3.4 — Requirements of 22.5.6 shall apply if 22.5.3.2(b) is not satisfied. <5.6.3.4>

22.5.4 — Field-cured specimens for curing adequacy

22.5.4.1 — If required by the building official or licensed design professional, results of strength tests of cylinders cured in accordance with (a) and (b) shall be provided in addition to standard-cured cylinder strength tests required by 22.5.3: <5.6.4.1> <5.11.4>

(a) Field-cured test cylinders shall be molded at the same time and from the same samples as standard-cured test cylinders<5.6.4.3>

(b) Field-cured cylinders shall be cured under field conditions in accordance with ASTM C31. <5.6.4.2>

R22.5.4.1 — Strength tests of cylinders cured under field conditions may be required to evaluate the adequacy of curing and protection of concrete in the structure. <R5.6.4.1>

The Code provides a specific criterion in 22.5.4.2 for judging the adequacy of field curing. For a reasonably valid comparison to be made, field-cured cylinders and companion standard-cured cylinders are made from the same sample. Field-cured cylinders are cured under the same conditions as the structure. <R5.11.4>

Cylinders related to members not directly exposed to weather should be cured adjacent to those members and provided with the same degree of protection and method of curing. The field cylinders should not be treated more favorably than the structural members they represent. < R5.11.4>

In evaluating test results of field-cured cylinders, it should be recognized that even if cylinders are protected in the same manner as the structure they may not experience the same temperature history as the concrete in the structure. This different temperature history occurs because heat of hydration may be dissipated differently in a cylinder compared with the structural member. <~>

R22.5.4.2 — Guidance is provided in the Code concerning the interpretation of tests of field-cured cylinders. Research22.7 has shown that the strength of cylinders protected and cured to simulate good field practice should be at least about 85 percent of standard-cured cylinders if both are tested at the age designated for \( f'_c \). Thus a value of 85 percent has been set as a rational basis for judging the adequacy of field curing. The comparison is made between the measured strengths of companion field-cured and standard-cured cylinders, not between the strength of field-cured cylinders and the specified value of \( f'_c \).

However, test results for the field-cured cylinders are considered satisfactory if the strength of field-cured
cylinders exceed the $f'_c$ by more than 500 psi, even though they fail to reach 85 percent of the strength of companion standard-cured cylinders. <R5.6.4.4>

The 85 percent criterion is based on the assumption that concrete is maintained above 50 °F and in a moist condition for at least the first 7 days after placement, or high-early-strength concrete is maintained above 50 °F and in a moist condition for at least the first 3 days after placement. <based upon R5.11.4>

If the field-cured cylinders do not provide satisfactory strength by this comparison, steps need to be taken to improve the curing. If the tests indicate a possible serious deficiency in strength of concrete in the structure, core tests may be required, with or without supplemental wet curing, to evaluate the structural adequacy, as provided in 22.5.6. <R5.11.4>

22.5.5 — Investigation of low strength-test results

Requirements are provided if strength tests have failed to meet the specified acceptance criteria, specifically 22.5.3.2(b) or 22.5.4.1. These requirements are applicable only for evaluation of in-place strength at the time of construction. Strength evaluation of existing structures is covered by Chapter 24. The building official should apply judgment as to the significance of low test results and whether they indicate need for concern. If further investigation is deemed necessary, such investigation may include in-place tests as described in ACI 228.1R or, in extreme cases, strength tests of cores taken from the structure. <R5.6.5>

In-place tests of concrete, such as by probe penetration (ASTM C803), rebound hammer (ASTM C805), or pullout test (ASTM C900), may be useful in determining whether a portion of the structure actually contains low-strength concrete. Unless these in-place tests have been correlated with standard strength test results for the concrete in the structure, they are of value primarily for comparisons within the same structure rather than as quantitative estimates of strength. <R5.6.5>

For cores, if required, conservative acceptance criteria are provided in 22.5.6.4 that should ensure structural adequacy for virtually any type of construction. Lower strength may be tolerated under many circumstances, but this is a matter of judgment on the part of the licensed design professional and building official. If the strengths of cores obtained in accordance with 22.5.6.3 fail to comply with 22.5.6.4, it may be practical, particularly in the case of floor or roof systems, for the building official to require a load test (Chapter 24). Short of load tests, if time and conditions permit, an effort may be made to improve the strength of the concrete in place by supplemental wet curing. Effectiveness of supplemental curing should be verified by further strength evaluation using procedures previously discussed. <R5.6.5>

The Code, as stated, concerns itself with assuring structural safety, and the requirements in 22.5.5 are aimed at that objective. It is not the function of the Code to assign responsibility for strength deficiencies. <R5.6.5>

Under the requirements of this section, it is recognized that cores taken to confirm structural adequacy will usually be taken at ages later than those specified for $f'_c$. <R5.6.5>

22.5.5.1 — If any strength test of standard-cured cylinders falls below $f'_c$ by more than the values given in 22.5.3.2(b) or if tests of field-cured cylinders in accordance with 22.5.4 indicate
deficiencies in protection and curing, steps shall be taken to ensure that structural capacity of the structure is not jeopardized. <5.6.5.1>

R22.5.5.1 — If the strength of field-cured cylinders does not conform to 22.5.4.2, steps need to be taken to improve the curing. If supplemental in-place tests (see R22.5.6) confirm a possible deficiency in strength of concrete in the structure, core tests may be required to evaluate structural adequacy.

22.5.5.2 — If the likelihood of low-strength concrete is confirmed and calculations indicate that load-carrying capacity is significantly reduced, tests of cores drilled from the area in question in accordance with ASTM C42 shall be permitted. In such cases, three cores shall be taken for each strength test that falls below the values given in 22.5.3.2(b). <5.6.5.2>

22.5.5.3 — Cores shall be obtained, moisture-conditioned by storage in watertight bags or containers, transported to the laboratory, and tested in accordance with ASTM C42. Cores shall be tested between 48 hours and 7 days after coring unless approved by the licensed design professional. The specifier of tests referenced in ASTM C42 shall be the licensed design professional. <5.6.5.3>

R22.5.5.3 — The use of a water-cooled bit results in a core with a moisture gradient between the exterior surface and the interior. This gradient lowers the apparent compressive strength of the core. The requirement of at least 48 hours between the time of coring and testing provides a minimum time for the moisture gradient to be reduced. The maximum time between coring and testing is intended to ensure timely testing of cores if strength of concrete is in question. <R5.6.5>

Research has also shown that other moisture conditioning procedures, such as soaking or air drying, affect measured core strengths and result in conditions that are not representative of the in-place concrete. Thus, to provide reproducible moisture conditions that are representative of in-place conditions, a standard moisture conditioning procedure that permits dissipation of moisture gradients is prescribed for cores. ASTM C42 permits the specifier of tests to modify the default duration of moisture conditioning before testing. <R5.6.5>

22.5.5.4 — Concrete in an area represented by core tests shall be considered structurally adequate if (a) and (b) are satisfied:

(a) The average of three cores is equal to at least 85 percent of \( f'_{c} \);

(b) No single core is less than 75 percent of \( f'_{c} \). <5.6.5.4>

R22.5.5.4 — An average core strength of 85 percent of the specified strength is realistic. It is not realistic, however, to expect the average core strength to be equal to \( f'_{c} \), because of differences in the size of specimens, conditions of obtaining specimens, degree of consolidation, and curing conditions. The acceptance criteria for core strengths have been established with consideration that cores for investigating low strength test results will typically be extracted at an age later than specified for \( f'_{c} \). For the purpose of satisfying 22.5.5.4, this Code does not intend that core strengths be adjusted for the age of the cores. <R5.6.5 plus ~>

22.5.5.4.1 — Additional testing of cores extracted from locations represented by erratic core strength results shall be permitted. <5.6.5.4>
22.5.5.5 — If criteria of 22.5.6.4 are not met and if the structural adequacy remains in doubt, the responsible authority shall be permitted to order a strength evaluation in accordance with Chapter 24 for the questionable portion of the structure or take other appropriate action.

22.5.6 — Acceptance of steel fiber-reinforced concrete

22.5.6.1 — Steel fiber-reinforced concrete shall conform to ASTM C1116. <5.1.6>

22.5.6.2 — Acceptance of steel fiber-reinforced concrete used for shear resistance in beams shall be determined by testing in accordance with ASTM C1609. In addition, fiber-reinforced concrete shall satisfy the compressive strength test requirements of 22.5.3. <5.6.6.1>

22.5.6.3 — Steel fiber-reinforced concrete shall be considered acceptable for shear resistance if conditions (a), (b), and (c) are satisfied:

(a) There are at least 100 lb of deformed steel fibers per cubic yard of concrete; <5.6.6.2a>

(b) The residual strength obtained from flexural testing in accordance with ASTM C1609 at a midspan deflection of 1/300 of the span length is at least 90 percent of the measured first-peak strength obtained from a flexural test or 90 percent of the strength corresponding to $f_r$ from Eq. (5.2.2.1), whichever is greater; <5.6.6.2b>

(c) The residual strength obtained from flexural testing in accordance with ASTM C1609 at a midspan deflection of 1/150 of the span length is at least 75 percent of the measured first-peak strength obtained from a flexural test or 75 percent of the strength corresponding to $f_r$ from Eq.(5.2.2.1), whichever is greater. <5.6.6.2c>

The performance criteria are based on results from flexural tests conducted on steel fiber-reinforced concretes with fiber types and contents similar to those used in the tests of beams that served as the basis for 13.6.3.1. <R5.6.6.1>

The term “residual strength” is defined in ASTM C1609 and is related to the ability of cracked fiber-reinforced concrete to resist tension. <R5.6.6.2(b), (c)>

NOTE: Sub G is planning to rewrite, as new business, the provisions and commentary dealing with grout for bonded tendons. Those provisions and commentary, when available, will be proposed for replacing what is shown below.

22.6 — Grout for bonded tendons <18.18>

22.6.1 — Materials for grout <18.18.2>

Materials for Grout
Past success with grout for bonded tendons has been with portland cement. A blanket endorsement of all cementitious materials for use with this grout is inappropriate because of a lack of experience or tests with cementitious materials other than portland cement and a concern that some cementitious materials might introduce chemicals that are harmful to tendons. Use of finely graded sand in the grout should only be considered with large ducts having large void areas.

22.6.1.1 — Grout shall consist of portland cement and water; or portland cement, sand, and water.

22.6.1.2 — Materials for grout shall conform to the specifications listed in Table 22.6.1.2.

<table>
<thead>
<tr>
<th>Table 22.6.1.2 — Materials for grout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
</tr>
<tr>
<td>Portland cement</td>
</tr>
<tr>
<td>Water</td>
</tr>
<tr>
<td>Sand, if used</td>
</tr>
</tbody>
</table>

*Gradation shall be permitted to be modified as necessary to obtain satisfactory flowability.

22.6.1.3 — Admixtures conforming to 22.3.4 and known to have no injurious effects on grout, steel, or concrete shall be permitted. Calcium chloride or admixtures containing chloride from sources other than impurities in admixture ingredients shall not be used in grout for bonded tendons.

R22.6.1.3—Substances known to be harmful to tendons, grout, or concrete are chlorides, fluorides, sulfites, and nitrates. Aluminum powder or other expansive admixtures, if approved, should produce an unconfined expansion of 5 to 10 percent. Neat cement grout is used in almost all building construction.

22.6.2 — Selection of grout proportions

R22.6.2 — Selection of grout proportions

Grout proportioned in accordance with these provisions will generally lead to 7-day compressive strength on standard 2-in. cubes in excess of 2500 psi and 28-day strengths of about 4000 psi. The handling and placing properties of grout are usually given more consideration than strength when designing grout mixtures.

22.6.2.1 — Proportions of materials for grout shall be based on (a) or (b):

(a) Results of tests on fresh and hardened grout prior to beginning grouting operations;
(b) Prior documented experience with similar materials and equipment under comparable field conditions.

22.6.2.2 — Cement used in the Work shall correspond to that on which selection of grout proportions was based.
22.6.2.3 — Water content shall be minimum necessary for proper pumping of grout; however, w/c shall not exceed 0.45 by weight.

22.6.2.4 — Water shall not be added to increase grout flowability that has been decreased by delayed use of the grout.

End of current Chapter 22

Chapter 22 Commentary References

22.1. ACI Committee 222, “Protection of Metals in Concrete Against Corrosion (ACI 222R-01, Reapproved 2010),” American Concrete Institute, Farmington Hills, MI, 2010, 42 pp.

22.2. ACI Committee 223, “Guide for the Use of Shrinkage-Compensating Concrete (ACI 223R-10),” American Concrete Institute, Farmington Hills, MI, 2010, 16 pp.


22.4. ACI Committee 214, “Guide to Evaluation of Strength Test Results of Concrete (ACI 214R-11),” American Concrete Institute, Farmington Hills, MI, 2011, 16 pp.


22.8. ACI Committee 228, “In-Place Methods to Estimate Concrete Strength (ACI 228.1R-03),” American Concrete Institute, Farmington Hills, MI, 2003, 44 pp.


End of Commentary References

Note: The following are cited in the Commentary but are also cited in the Code in the sections shown.


22.4.1.2. ACI Committee 301, “Specifications for Structural Concrete (ACI 301-10),” American Concrete Institute, Farmington Hills, MI, 2011, 82 pp.


