NOTES: This version of Chapter 5 includes the following:
1. Approved version of 27 July 2011.
2. Changes approved for ACI 318-11.
3. Technical changes approved under CA 116.
4. Editorial changes approved under CA 115.
5. Commentary as approved on 318 LB 12-4.
6. Technical changes as approved under CA 120.
7. Section renumbering changes to make the chapter consistent.

CHAPTER 2 (partial) – NOTATION AND TERMINOLOGY

2.2 – Notation

\( f_{cm} \) = measured average compressive strength of concrete, psi

\( f_{ct} \) = measured average splitting tensile strength of lightweight concrete, psi

CHAPTER 5 — CONCRETE: DESIGN AND DURABILITY REQUIREMENTS

5.1 — Scope

5.1.1 — The provisions of this Chapter shall apply to the design properties and durability requirements for concrete.

5.2 — Concrete design properties

5.2.1 — Specified compressive strength

5.2.1.1 — The value of \( f_c \) shall be specified in contract documents and shall be in accordance with (a), (b), and (c): <1.1.1> <4.1.1> <19.3.1> <21.1.4.2> <21.1.4.3> <22.2.3> <5.1.1>

(a) Limits in Table 5.2.1.1;

(b) Durability requirements in Table 5.3.2.1;

(c) Structural strength requirements.
### Table 5.2.1.1 — Limits for $f_c$

<table>
<thead>
<tr>
<th>Application</th>
<th>Concrete</th>
<th>Minimum $f_c$, psi</th>
<th>Maximum $f_c$, psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td>Normalweight and lightweight</td>
<td>2500</td>
<td>None</td>
</tr>
<tr>
<td>Special moment frames and special structural walls</td>
<td>Normalweight</td>
<td>3000</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Lightweight</td>
<td>3000</td>
<td>5000*</td>
</tr>
</tbody>
</table>

*The limit is permitted to be exceeded where demonstrated by experimental evidence that members made with lightweight concrete provide strength and toughness equal to or exceeding those of comparable members made with normalweight concrete of the same strength. <21.1.4.3>*

### 5.2.1.2 — The specified compressive strength shall be used for mixture proportioning in 22.4 and for testing and acceptance of concrete in 22.5. <5.1.1>

### 5.2.1.3 — Unless otherwise specified, $f_c$ shall be based on 28-day tests. If other than 28 days, test age for $f_c$ shall be indicated in the contract documents. <5.1.3>

### R5.2.1 – Specified compressive strength

Requirements for concrete mixtures are based on the philosophy that concrete should provide both adequate strength and durability. The Code defines a minimum value of $f_c$ for structural concrete. There is no limit on the maximum value of $f_c$ except as required by specific Code provisions. <R5.1, Code 1.1.1>

Concrete mixtures proportioned in accordance with 22.4 should achieve an average compressive strength that exceeds the value of $f_c$ used in the structural design calculations. The amount by which the average strength of concrete exceeds $f_c$ is based on probabilistic concepts. When concrete is designed to achieve a strength level greater than $f_c$, it ensures that the concrete strength tests will have a high probability of meeting the strength acceptance criteria in 22.5. The durability requirements prescribed in Table 5.3.2.1 are to be satisfied in addition to meeting the minimum $f_c$ of 5.2.1. Under some circumstances, durability requirements may dictate a higher $f_c$ than that required for structural purposes. <R5.1.1>
For design of special moment frames and special structural walls used to resist earthquake forces, the Code limits the maximum specified compressive strength of lightweight concrete to 5000 psi. This limit is imposed primarily because of a paucity of experimental and field data on the behavior of members made with lightweight concrete subjected to displacement reversals in the nonlinear range. <R21.1.4>

5.2.2 — Modulus of elasticity

5.2.2.1 — Modulus of elasticity, $E_c$, for concrete shall be permitted to be calculated as (a) or (b). <8.5.1>

(a) For values of $w_c$ between 90 and 160 lb/ft$^3$

$$E_c = w_c^{0.533} \sqrt{f_c'} \text{ (in psi)} \quad (5.2.2.1.a)$$

(b) For normalweight concrete

$$E_c = 57,000 \sqrt{f_c'} \text{ (in psi)} \quad (5.2.2.1.b)$$

Studies leading to the expression for modulus of elasticity of concrete in 5.2.2 are summarized in Reference 5.1 where $E_c$ was defined as the slope of the line drawn from a stress of zero to a compressive stress of 0.45 $f_c'$. The modulus of elasticity for concrete is sensitive to the modulus of elasticity of aggregate and mixture proportions of the concrete. Measured elastic modulus values can range from 80 to 120 percent of calculated values. ASTM C469 provides a test method for determining the modulus of elasticity for concrete in compression. <R8.5.1>

5.2.3 — Modulus of rupture

5.2.3.1 — Modulus of rupture, $f_r$, for concrete shall be calculated by:

$$f_r = 7.5\lambda\sqrt{f_c'} \quad (5.2.3.1)$$

where the value of $\lambda$ is in accordance with 5.2.4. <~>

5.2.4 — Lightweight concrete

5.2.4.1 — To account for the properties of lightweight concrete, a modification factor $\lambda$ is used as a multiplier of $\sqrt{f_c'}$ in all applicable provisions of this Code. The value of $\lambda$ shall be based on the composition of the aggregate in the concrete mixture in accordance with Table 5.2.4.1 or as permitted in 5.2.4.2. <8.6.1> <22.5.6.1>
Table 5.2.4.1 — Modification factor $\lambda$

<table>
<thead>
<tr>
<th>Concrete</th>
<th>Composition of aggregates</th>
<th>$\Lambda$</th>
</tr>
</thead>
<tbody>
<tr>
<td>All-lightweight</td>
<td>Fine: ASTM C330</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>Coarse: ASTM C330</td>
<td></td>
</tr>
<tr>
<td>Lightweight, fine blend</td>
<td>Fine: Combination of ASTM C330 and C33</td>
<td>0.75 to 0.85*</td>
</tr>
<tr>
<td></td>
<td>Coarse: ASTM C330</td>
<td></td>
</tr>
<tr>
<td>Sand-lightweight</td>
<td>Fine: ASTM C33</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>Coarse: ASTM C330</td>
<td></td>
</tr>
<tr>
<td>Sand-lightweight, coarse blend</td>
<td>Fine: ASTM C33</td>
<td>0.85 to 1.00†</td>
</tr>
<tr>
<td></td>
<td>Coarse: Combination of ASTM C330 and C33</td>
<td></td>
</tr>
<tr>
<td>Normalweight</td>
<td>Fine: ASTM C33</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>Coarse: ASTM C330</td>
<td></td>
</tr>
</tbody>
</table>

*Linear interpolation from 0.75 to 0.85 is permitted based on the absolute volume of normalweight fine aggregate as a fraction of the total absolute volume of fine aggregate.

†Linear interpolation from 0.85 to 1.00 is permitted based on the absolute volume of normalweight coarse aggregate as a fraction of the total absolute volume of coarse aggregate. <8.6.1>

5.2.4.2 — If the measured average splitting tensile strength of lightweight concrete, $f_{ct}$, is used to calculate $\lambda$, laboratory tests shall be conducted in accordance with ASTM C330 to establish the value of $f_{ct}$ and corresponding value of $f_{cm}$ and $\lambda$ shall be calculated by: <5.1.4> <8.6.1>

$$\lambda = \frac{f_{ct}}{6.7\sqrt{f_c}} \leq 1.0$$ (5.2.4.2)

**NOTE:** replace $f'_{c}$ with $f_{cm}$ in this equation.

The concrete mixture tested in order to calculate $\lambda$ shall be representative of that to be used in the work.

R5.2.4 — Lightweight concrete

The modification factor $\lambda$ is used to account for the lower tensile-to-compressive strength ratio of lightweight concrete compared with normalweight concrete. For design using lightweight concrete, shear strength, friction properties, splitting resistance, bond between concrete and
reinforcement, and development length requirements are not taken as equivalent to normalweight concrete of the same compressive strength. <R8.6.1>

Two alternative procedures are provided to determine \( \lambda \). The first alternative is based on the assumption that, for equivalent compressive strength levels, the tensile strength of lightweight concrete is a fixed fraction of the tensile strength of normalweight concrete. The multipliers used for \( \lambda \) are based on data from tests on concrete made with many types of structural lightweight aggregate. <R8.6.1>

The second alternative procedure to determine \( \lambda \) is based on laboratory tests of lightweight concrete with aggregate source and compressive strength representative of that to be used in the Work. The laboratory tests performed in accordance with ASTM C330 provide a measured average splitting tensile strength \( f_{ct} \) and a measured average compressive strength \( f_{cm} \) for the lightweight concrete. The value of \( \lambda \) is determined using Eq. 5.2.4.2, which is based on the assumption that the average splitting tensile strength of normalweight concrete is equal to \( 6.7 \sqrt{f_{cm}} \).<R8.6.1>

### 5.3 — Concrete durability requirements

#### 5.3.1 — Exposure categories and classes

5.3.1.1 -- The licensed design professional shall assign exposure classes in accordance with the severity of the anticipated exposure of members for each exposure category in Table 5.3.1.1. <4.2.1>
### Table 5.3.1.1 — Exposure categories and classes

<table>
<thead>
<tr>
<th>Category</th>
<th>Severity</th>
<th>Class</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freezing and thawing (F)</td>
<td>Not applicable</td>
<td>F0</td>
<td>Concrete not exposed to freezing-and-thawing cycles</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>F1</td>
<td>Concrete exposed to freezing-and-thawing cycles and occasional exposure to moisture</td>
</tr>
<tr>
<td></td>
<td>Severe</td>
<td>F2</td>
<td>Concrete exposed to freezing-and-thawing cycles and in continuous contact with moisture</td>
</tr>
<tr>
<td></td>
<td>Very severe</td>
<td>F3</td>
<td>Concrete exposed to freezing-and-thawing cycles and in continuous contact with moisture and exposed to deicing chemicals</td>
</tr>
<tr>
<td>Sulfate (S)</td>
<td>Not applicable</td>
<td>S0</td>
<td>$\text{SO}_4^{2-} &lt; 0.10$</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>S1</td>
<td>$0.10 \leq \text{SO}_4^{2-} &lt; 0.20$</td>
</tr>
<tr>
<td></td>
<td>Severe</td>
<td>S2</td>
<td>$0.20 \leq \text{SO}_4^{2-} \leq 2.00$</td>
</tr>
<tr>
<td></td>
<td>Very severe</td>
<td>S3</td>
<td>$\text{SO}_4^{2-} &gt; 2.00$</td>
</tr>
<tr>
<td>Requiring low permeability (P)</td>
<td>Not applicable</td>
<td>P0</td>
<td>In contact with water where low permeability is not required</td>
</tr>
<tr>
<td></td>
<td>Required</td>
<td>P1</td>
<td>In contact with water where low permeability is required</td>
</tr>
<tr>
<td>Corrosion protection of reinforcement (C)</td>
<td>Not applicable</td>
<td>C0</td>
<td>Concrete dry or protected from moisture</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>C1</td>
<td>Concrete exposed to moisture but not to an external source of chlorides</td>
</tr>
<tr>
<td></td>
<td>Severe</td>
<td>C2</td>
<td>Concrete exposed to moisture and an external source of chlorides from deicing chemicals, salt, brackish water, seawater, or spray from these sources</td>
</tr>
</tbody>
</table>

* Percent sulfate by mass in soil shall be determined by ASTM C1580
† Concentration of dissolved sulfates in water in ppm shall be determined by ASTM D516 or ASTM D4130

#### 5.3.2 — Requirements for concrete mixtures

5.3.2.1 -- Based on the exposure classes assigned from Table 5.3.1.1, concrete mixtures shall conform to the most restrictive requirements in Table 5.3.2.1. <4.3.1>
R5.3 — Concrete durability requirements

Durability of concrete is impacted by the resistance to fluid penetration. This is primarily affected by \( w/cm \) and the composition of cementitious materials used in concrete. For a given \( w/cm \), the use of fly ash, slag cement, silica fume, or a combination of these materials will typically increase concrete’s resistance to fluid penetration and thus improve concrete durability. The Code places emphasis on \( w/cm \) for achieving low permeability to meet durability requirements. ASTM C1202 can be used to provide an indication of concrete’s resistance to fluid penetration. <R4.1, R4.3.1>

Because it is difficult to verify accurately the \( w/cm \) of concrete, the selected value of \( f'c \) should be consistent with the maximum \( w/cm \) required for durability. Selection of an \( f'c \) that is consistent with the maximum permitted \( w/cm \) required for durability will permit results of strength tests to be used as a surrogate for \( w/cm \), and thus help ensure that the maximum \( w/cm \) is not exceeded in the field. <R4.1.1>

As stated in the footnote to Table 5.3.2.1, maximum \( w/cm \) limits are not specified for lightweight concrete because the amount of mixing water that is absorbed by the lightweight aggregates makes calculation of \( w/cm \) uncertain. Therefore, the requirement for a minimum \( f'c \), is used to ensure a high-quality cement paste. <R4.1.2>

Exposure categories defined in Table 5.3.1.1 are subdivided into exposure classes depending on the severity of the exposure. Associated requirements for concrete relative to the exposure classes are provided in 5.3.2. <R4.2.1>

The Code does not include provisions for especially severe exposures, such as acids or high temperatures. <R4.2>

R5.3.1 — Exposure categories and classes

The Code addresses four exposure categories that affect the requirements for concrete to ensure adequate durability: <All in R5.3.1 from R4.2.1>

**Exposure Category F** applies to exterior concrete that is exposed to moisture and cycles of freezing and thawing, with or without deicing chemicals.

**Exposure Category S** applies to concrete in contact with soil or water containing deleterious amounts of water-soluble sulfate ions.

**Exposure Category P** applies to concrete in contact with water where low permeability is required.

**Exposure Category C** applies to nonprestressed and prestressed concrete exposed to conditions that require additional protection against corrosion of reinforcement.
Severity of exposure within each category is defined by classes with increasing numerical values representing increasingly severe exposure conditions. A classification of “0” is assigned if the exposure severity has negligible effect (is benign) or the exposure category does not apply to the member.

**Exposure Category F** is subdivided into four exposure classes: Exposure Class F0 is assigned to concrete that will not be exposed to cycles of freezing and thawing. Exposure Class F1 is assigned to concrete exposed to cycles of freezing and thawing and that will be occasionally exposed to moisture before freezing. Examples of Exposure Class F1 are exterior walls, beams, girders, and slabs not in direct contact with soil. Exposure Class F2 is assigned to concrete exposed to cycles of freezing and thawing that is in continuous contact with moisture before freezing. Examples are an exterior water tank or vertical members in contact with soil. Exposure Classes F1 and F2 are conditions where exposure to deicing salt is not anticipated. Exposure Class F3 is assigned to concrete exposed to cycles of freezing and thawing, in continuous contact with moisture, and where exposure to deicing chemicals is anticipated. Examples are horizontal members in parking structures.

**Exposure Category S** is subdivided into four exposure classes: Exposure Class S0 is assigned for conditions where the water-soluble sulfate concentration in contact with concrete is low and injurious sulfate attack is not a concern. Exposure Classes S1, S2, and S3 are assigned for structural concrete members in direct contact with soluble sulfates in soil or water. The severity of exposure increases from Exposure Class S1 to S3 based on the more critical value of measured water-soluble sulfate concentration in soil or the concentration of dissolved sulfate in water. Sea water exposure is classified as Exposure Class S1.

**Exposure Category P** is subdivided into two exposure classes: Members are assigned to Exposure Class P0 if they are dry in service, exposed to moisture or in contact with water, but there are no specific requirements for low permeability. Exposure Class P1 is assigned if there is need for concrete with low permeability to water when the permeation of water into concrete might reduce durability or affect the intended function of the member. An example is an interior water tank.

**Exposure Category C** is subdivided into three exposure classes: Exposure Class C0 is assigned when exposure conditions do not require additional protection against the initiation of corrosion of reinforcement. Exposure Classes C1 and C2 are assigned to nonprestressed and prestressed concrete members depending on the degree of exposure to external sources of moisture and chlorides in service. Examples of exposures to external sources of chlorides include concrete in direct contact with deicing chemicals, salt, salt water, brackish water, seawater, or spray from these sources.
### Table 5.3.2.1 — Requirements for concrete by exposure class

<table>
<thead>
<tr>
<th>Exposure Class</th>
<th>Max. w/cm</th>
<th>Min $f'c$, psi</th>
<th>Additional requirements</th>
<th>Limits on cementitious materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>F0</td>
<td>N/A</td>
<td>2500</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>F1</td>
<td>0.45</td>
<td>4500</td>
<td>Table 5.3.3.1</td>
<td>N/A</td>
</tr>
<tr>
<td>F2</td>
<td>0.45</td>
<td>4500</td>
<td>Table 5.3.3.1</td>
<td>N/A</td>
</tr>
<tr>
<td>F3</td>
<td>0.45</td>
<td>4500</td>
<td>Table 5.3.3.1</td>
<td>Table 5.3.3.2</td>
</tr>
</tbody>
</table>

**Cementitious materials† - Types**

<table>
<thead>
<tr>
<th>ASTM C150</th>
<th>ASTM C595</th>
<th>ASTM C1157</th>
<th>Calcium chloride admixture</th>
</tr>
</thead>
<tbody>
<tr>
<td>S0</td>
<td>N/A</td>
<td>2500</td>
<td>No Type restriction</td>
</tr>
<tr>
<td>S1</td>
<td>0.50</td>
<td>4000</td>
<td>II§</td>
</tr>
<tr>
<td>S2</td>
<td>0.45</td>
<td>4500</td>
<td>V§</td>
</tr>
<tr>
<td>S3</td>
<td>0.45</td>
<td>4500</td>
<td>V plus pozzolan or slag cement&quot;</td>
</tr>
</tbody>
</table>

| P0 | N/A | 2500 | None |
| P1 | 0.50 | 4000 | None |

**Maximum water-soluble chloride ion (Cl\(^{-}\)) content in concrete, percent by weight of cement"**

<table>
<thead>
<tr>
<th>Nonprestressed concrete</th>
<th>Prestressed concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>C0</td>
<td>N/A</td>
</tr>
<tr>
<td>C1</td>
<td>N/A</td>
</tr>
<tr>
<td>C2</td>
<td>0.40</td>
</tr>
</tbody>
</table>

* The maximum w/cm limits in Table 5.3.2.1 do not apply to lightweight concrete. <4.1.2>
†Alternative combinations of cementitious materials to those listed in Table 5.3.2.1 are permitted when tested for sulfate resistance and meeting the criteria in 5.3.4.1. <Table 4.3.1>

‡For seawater exposure, other types of portland cements with tricalcium aluminate (C₃A) contents up to 10 percent are permitted if the \( w/cm \) does not exceed 0.40. <Table 4.3.1>

§Other available types of cement such as Type I or Type III are permitted in Exposure Classes S1 or S2 if the C₃A contents are less than 8 percent for Exposure Class S1 or less than 5 percent for Exposure Class S2. <Table 4.3.1>

¶The amount of the specific source of the pozzolan or slag cement to be used shall be at least the amount that has been determined by service record to improve sulfate resistance when used in concrete containing Type V cement. Alternatively, the amount of the specific source of the pozzolan or slag cement to be used shall be at least the amount tested in accordance with ASTM C1012 and meeting the criteria in 5.3.4.1. <Table 4.3.1>

#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. <Table 4.3.1>

**Concrete cover shall be in accordance with 6.10.5. <Table 4.3.1>

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**R5.3.2 — Requirements for concrete mixtures**

Table 5.3.2.1 provides the requirements for concrete on the basis of the assigned exposure classes. The most restrictive requirements are applicable. For example, a prestressed concrete member assigned to Exposure Class C2 and Exposure Class F3 would require concrete to comply with a maximum \( w/cm \) of 0.40 and minimum \( f_{c}^{'} \) of 5000 psi. In this case, the requirement for corrosion protection (C2) is more restrictive than the requirement for resistance to freezing and thawing. <All in R5.3.2 from R4.3.1>

**Exposure Classes F1, F2, and F3:** In addition to complying with a maximum \( w/cm \) limit and a minimum \( f_{c}^{'} \), concrete for members subject to freezing-and-thawing exposures is to be air entrained in accordance with 5.3.3.1. Members assigned to Exposure Class F3 are additionally required to comply with the limitations on the quantity of pozzolans and slag cement in the composition of the cementitious materials as given in 5.3.3.4.

**Exposure Classes S1, S2, and S3:** Table 5.3.2.1 lists the appropriate types of cement and the maximum \( w/cm \) and minimum specified compressive strengths for various sulfate exposure conditions. In selecting cement for sulfate resistance, the principal consideration is its tricalcium aluminate (C₃A) content. For Exposure Class S1 (moderate exposure), Type II cement is limited to a maximum C₃A content of 8.0 percent under ASTM C150. The blended cements under ASTM C595 with the MS designation are appropriate for use in Exposure Class S1. The appropriate types under ASTM C595 are IP(MS) and IS(<70)(MS) and under ASTM C1157 it is Type MS. For Exposure Class S2 (severe exposure), Type V cement with a C₃A content of up to 5 percent is specified. Blended cements Types IP (HS) and IS (<70) (HS) under ASTM C595 and Type HS under ASTM C1157 can also be used. In certain areas, the C₃A content of other available types such as Type III or Type I may be less than 8 or 5 percent and are usable in moderate or severe sulfate exposures. Note that sulfate-resisting cement will not increase resistance to some chemically aggressive solutions, for example, sulfuric acid. The project specifications should explicitly cover all cases.
The use of fly ash (ASTM C618, Class F), natural pozzolans (ASTM C618, Class N), silica fume (ASTM C1240), or slag cement (ASTM C989) also has been shown to improve the sulfate resistance of concrete. ASTM C1012 can be used to evaluate the sulfate resistance of mixtures using combinations of cementitious materials as determined in 5.3.4. For Exposure Class S3, the alternative allows the use of Type V plus pozzolan, slag cement, or blended cement, based on records of successful service, instead of meeting the testing requirements of 5.3.4.

Seawater is listed under Exposure Class S1 (moderate exposure) in Table 5.3.1.1, even though it generally contains more than 1500 ppm SO₄. Portland cement with higher C₃A content improves binding of chlorides present in seawater and the Code permits other types of portland cement with C₃A up to 10 percent if the maximum $w/cm$ is limited to 0.40 (see footnote to the table.)

In addition to the proper selection of cementitious materials, other requirements for durable concrete exposed to water-soluble sulfates are essential, such as low $w/cm$, strength, adequate consolidation, uniformity, adequate cover of reinforcement, and sufficient moist curing to develop the potential properties of the concrete.

**Exposure Class P1:** The Code includes an Exposure Class P1 for concrete that needs to have a low permeability when in direct contact with water. The primary means to obtain low permeability is to use a low $w/cm$. For a given $w/cm$, permeability can be reduced by optimizing the cementitious materials used in the concrete mixture.

**Exposure Class C2:** For nonprestressed and prestressed concrete in Exposure Class C2, the maximum $w/cm$, minimum specified compressive strength, and minimum cover are the basic requirements to be considered. Conditions should be evaluated for structures exposed to chlorides, such as in parking structures where chlorides may be tracked in by vehicles, or in structures near seawater. Coated reinforcement, corrosion-resistant steel reinforcement, and cover greater than the minimum required in 6.11.5 can provide additional protection under such conditions. Use of slag cement meeting ASTM C989 or fly ash meeting ASTM C618 and increased levels of specified compressive strength provide increased protection. Use of silica fume meeting ASTM C1240 with an appropriate high-range water reducer, ASTM C494, Types F and G, or ASTM C1017 can also provide additional protection. The use of ASTM C1202 to test concrete mixtures proposed for use will provide additional information on the performance of the mixtures.

**Chloride Limits for Exposure Category C:** For Exposure Classes C0, C1, and C2, the chloride ion limits apply. For nonprestressed concrete, the permitted maximum amount of water-soluble chloride ions incorporated into the concrete, measured by ASTM C1218 at ages between 28 and 42 days, depends on the degree of exposure to an anticipated external source of moisture and chlorides. For prestressed concrete, the same limit of 0.06 percent chloride ion by mass of cement applies regardless of exposure.

Additional information on the effects of chlorides on the corrosion of steel reinforcing is given in ACI 201.2R, which provides guidance on concrete durability, and ACI 222R, which
provides guidance on factors that impact corrosion of metals in concrete. An initial evaluation of the chloride ion content of the proposed concrete mixture may be obtained by testing individual concrete ingredients for total chloride ion content. If total chloride ion content, calculated on the basis of concrete proportions, exceeds those permitted in Table 5.3.2.1, it may be necessary to test samples of the hardened concrete for water-soluble chloride ion content. Some of the chloride ions present in the ingredients will either be insoluble in water or will react with the cement during hydration and become insoluble under the test procedures described in ASTM C1218.

When concretes are tested for water-soluble chloride ion content, the tests should be made at an age of 28 to 42 days. The limits in Table 5.3.2.1 are to be applied to chlorides contributed from the concrete ingredients, not those from the environment surrounding the concrete. For nonprestressed concrete that will be dry in service (Exposure Class C0), a limit of 1.00 percent has been included to control the water-soluble chlorides introduced by concrete-making materials.

5.3.3 — Additional requirements for freezing and thawing exposure

5.3.3.1 — Normalweight and lightweight concrete subject to freezing and thawing Exposure Classes F1, F2, or F3 shall be air entrained with air content indicated in Table 5.3.3.1. <4.4.1>

5.3.3.2 – Tolerance on air content as delivered is ± 1.5 percentage points. <4.4.1>

5.3.3.3 – For $f'_c$ exceeding 5000 psi, reduction of air content indicated in Table 5.3.3.1 by 1.0 percentage point is permitted. <4.4.1>

Table 5.3.3.1 — Total air content for concrete exposed to cycles of freezing and thawing

<table>
<thead>
<tr>
<th>Nominal maximum aggregate size,* in.</th>
<th>Target air content, percent</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>F1</td>
<td>F2 and F3</td>
</tr>
<tr>
<td>3/8</td>
<td></td>
<td>6</td>
<td>7.5</td>
</tr>
<tr>
<td>1/2</td>
<td></td>
<td>5.5</td>
<td>7</td>
</tr>
<tr>
<td>3/4</td>
<td></td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>4.5</td>
<td>6</td>
</tr>
<tr>
<td>1-1/2</td>
<td></td>
<td>4.5</td>
<td>5.5</td>
</tr>
<tr>
<td>2†</td>
<td></td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>3†</td>
<td></td>
<td>3.5</td>
<td>4.5</td>
</tr>
</tbody>
</table>

*Refer to 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. Air content of the total mixture is calculated from value measured on the sieved fraction passing the 1-1/2 in. sieve in accordance with ASTM C231. The tolerance on air content as delivered applies to this value.

**R5.3.3 — Additional requirements for freezing and thawing exposure**

R5.3.3.1 — A table of required air contents for concrete to resist damage from cycles of freezing and thawing is included in the Code, based on guidance provided for proportioning concrete mixtures in ACI 211.1.\(^{5,12}\) Entrained air will not protect concrete containing coarse aggregates that undergo disruptive volume changes when frozen in a saturated condition. <R4.4.1>

R5.3.3.3 – This section permits a 1.0 percentage point lower air content for concrete with \(f'\)c greater than 5000 psi. Such higher strength concretes, which have a lower \(w/cm\) and porosity, have greater resistance to cycles of freezing and thawing. <R4.4.1>

**5.3.3.4 — The maximum percentage of pozzolans, including fly ash, silica fume, and slag cement in concrete subject to Exposure Class F3, shall be in accordance with Table 5.3.3.4. <4.4.2>**

**Table 5.3.3.4 — Limits on cementitious materials for concrete subject to Exposure Class F3**

<table>
<thead>
<tr>
<th>Cementitious materials</th>
<th>Maximum percent of total cementitious materials by weight*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fly ash or other pozzolans conforming to ASTM C618</td>
<td>25</td>
</tr>
<tr>
<td>Slag cement conforming to ASTM C989</td>
<td>50</td>
</tr>
<tr>
<td>Silica fume conforming to ASTM C1240</td>
<td>10</td>
</tr>
<tr>
<td>Total of fly ash or other pozzolans and silica fume</td>
<td>35†</td>
</tr>
<tr>
<td>Total of fly ash or other pozzolans, slag cement,</td>
<td>50†</td>
</tr>
<tr>
<td>and silica fume</td>
<td></td>
</tr>
</tbody>
</table>

*The total cementitious material also includes ASTM C150, C595, C845, and C1157 cement. The maximum percentages above include:

(a) Fly ash or other pozzolans in Type IP, blended
cement, ASTM C595, or ASTM C1157;
(b) Slag cement used in the manufacture of an IS
blended cement, ASTM C595, or ASTM C1157; and
(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 mass of
the cementitious materials.

**R5.3.3.4** — To reduce the risk of deicer scaling, Table 5.3.3.4 establishes
limitations on the amount of fly ash, other pozzolans, silica fume, and slag cement
that can be included in concrete exposed to deicing chemicals (Exposure Class
F3) based on research studies. The limitations in Table 5.3.3.4 are not
applicable to members assigned to Exposure Class C2 unless those members are
also in Exposure Class F3. \(<R4.4.2>\)

### 5.3.4 — Alternative combinations of cementitious materials for sulfate
exposure

**5.3.4.1** — Alternative combinations of cementitious materials to those
listed in 5.3.2 are permitted when tested for sulfate resistance and
meeting the criteria in Table 5.3.4.1. \(<4.5.1>\)

**Table 5.3.4.1** — Requirements for establishing suitability of combinations
of cementitious materials exposed to water-soluble sulfate

<table>
<thead>
<tr>
<th>Exposure class</th>
<th>Maximum expansion strain when tested using ASTM C1012</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>At 6 months</td>
</tr>
<tr>
<td>S1</td>
<td>0.10 percent</td>
</tr>
<tr>
<td>S2</td>
<td>0.05 percent</td>
</tr>
<tr>
<td>S3</td>
<td>Not required</td>
</tr>
</tbody>
</table>

*The 12-month expansion limit applies only when the measured
expansion exceeds the 6-month maximum expansion limit.

**R5.3.4** — Alternative combinations of cementitious materials for sulfate
exposure

**R5.3.4.1** — ASTM C1012 is permitted to be used to evaluate the sulfate resistance of concrete
mixtures using alternative combinations of cementitious materials to those listed in Table 5.3.2.1
for all classes of sulfate exposure. More detailed guidance on qualification of such mixtures
using ASTM C1012 is given in ACI 201.2R. The expansion criteria in Table 5.3.4.1, for
testing according to ASTM C1012, are the same as those in ASTM C595 for moderate sulfate
resistance (Optional Designation MS) in Exposure Class S1 and for high sulfate resistance
(Optional Designation HS) in Exposure Class S2, and the same as in ASTM C1157 for Type MS
in Exposure Class S1 and Type HS in Exposure Class S2. <R4.5.1>

COMMENTARY REFERENCES

Chapter 5

5.1. Pauw, A., “Static Modulus of Elasticity of Concrete as Affected by Density,” ACI

5.2. ASTM C469/C469M-10, “Standard Test Method for Static Modulus of Elasticity and
Poisson’s Ratio of Concrete in Compression,” ASTM International, West Conshohocken, PA, 5
pp.

5.3. Ivey, D. L., and Buth, E., “Shear Capacity of Lightweight Concrete Beams,” ACI

5.4. Hanson, J. A., “Tensile Strength and Diagonal Tension Resistance of Structural Lightweight

5.5. ASTM C1202-10, “Standard Test Method for Electrical Indication of Concrete’s Ability to
Resist Chloride Ion Penetration,” ASTM Book of Standards, Part 04.02, ASTM, West
Conshohocken, PA, 7 pp.

Diffusion of Fly Ash and Blended Cement Pastes,” Cement and Concrete Research, V. 16, No. 5,

5.6. ACI Committee 233, “Slag Cement in Concrete and Mortar (ACI 233R-03),” American
Concrete Institute, Farmington Hills, MI, 2003, 19 pp.

5.8. ACI Committee 234, “Guide for the Use of Silica Fume in Concrete (ACI 234R-06),”
American Concrete Institute, Farmington Hills, MI, 2006, 63 pp.

5.9. Ozyildirim, C., and Halstead, W., “Resistance to Chloride Ion Penetration of Concretes
Containing Fly Ash, Silica Fume, or Slag,” Permeability of Concrete, SP-108, American
Concrete Institute, Farmington Hills, MI, 1988, pp. 35-61.

5.10. ACI Committee 201, “Guide to Durable Concrete (ACI 201.2R-08),” American Concrete
5.11. ACI Committee 222, “Protection of Metals in Concrete Against Corrosion (ACI 222R-01),” American Concrete Institute, Farmington Hills, MI, 2001, 41 pp.


End of Commentary References, Chapter 5

The following are referenced in the commentary but are also referenced in the code.


