CHAPTER 4 — DURABILITY REQUIREMENTS

In 2008, the provisions of Chapter 4 were revised and renumbered to present durability requirements in terms of exposure categories; therefore, change bars are not shown.

CODE

COMMENTARY

4.1 — General

R4.1 — General

Chapters 4 and 5 of earlier editions of the Code were reformatted in 1989 to emphasize the importance of considering durability requirements before selecting f'_c and concrete cover over the reinforcing steel. In 2008, the format of Chapter 4 was revised extensively by introducing exposure categories and classes with applicable durability requirements for concrete in a unified format.

4.1.1 —The value of f'_c shall be the greatest of the values required by (a) 1.1.1, (b) for durability in Chapter 4, and (c) for structural strength requirements and shall apply for mixture proportioning in 5.3 and for evaluation and acceptance of concrete in 5.6. Concrete mixtures shall be proportioned to comply with the maximum water-cementitious material ratio (*w*/*cm*) and other requirements based on the exposure class assigned to the concrete structural member. All cementitious materials specified in 3.2.1 and the combinations of these materials shall be included in calculating the *w*/*cm* of the concrete mixture.

R4.1.1 — Maximum water-cementitious material ratios (*w*/*cm*) of 0.40 to 0.50 that may be required for concretes exposed to freezing and thawing, sulfate soils or waters, or for corrosion protection of reinforcement will typically be equivalent to requiring an f'_c of 35 to 28 MPa, respectively. Generally, the required average compressive strengths, f'_{cr}, will be 3.5 to 5 MPa higher than the specified compressive strength, f'_c. Because it is difficult to accurately determine the *w*/*cm* of concrete, the f'_c specified should be reasonably consistent with the *w*/*cm* required for durability. Selection of an f'_c that is consistent with the maximum permitted *w*/*cm* for durability will help ensure that the maximum *w*/*cm* is not exceeded in the field. For example, a maximum *w*/*cm* of 0.45 and f'_c of 21 MPa should not be specified for the same concrete mixture. Because the usual emphasis during inspection is on concrete compressive strength, test results substantially higher than the specified compressive strength may lead to a lack of concern for quality and could result in production and delivery of concrete that exceeds the maximum *w*/*cm*.

4.1.2 — The maximum *w*/*cm* limits in Chapter 4 do not apply to lightweight concrete.

R4.1.2 — Maximum *w*/*cm* is not specified for lightweight concrete because of the uncertainty in determining the amount of mixing water that is absorbed by lightweight aggregates before concrete sets. This makes the calculation of the *w*/*cm* uncertain. The use of a minimum specified compressive strength, f'_c, will ensure the use of a high-quality cement paste. For normalweight concrete, the use of both minimum strength and maximum *w*/*cm* provide additional assurance that the paste is of high quality.

4.2 — Exposure categories and classes

R4.2 — Exposure categories and classes

Exposure categories defined in Table 4.2.1 are sub-divided into exposure classes depending on the severity of the exposure. Associated requirements for concrete relative to the exposure classes are provided in 4.3.

The Code does not include provisions for especially severe exposures, such as acids or high temperatures, and is not concerned with aesthetic considerations such as surface

CODE

4

4.2.1 — The licensed design professional shall assign exposure classes based on the severity of the anticipated exposure of structural concrete members for each exposure category according to Table 4.2.1.

TABLE 4.2.1 — EXPOSURE CATEGORIES AND CLASSES

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

COMMENTARY

finishes. These items are beyond the scope of the Code and should be covered specifically in the project specifications. Concrete ingredients and proportions are to be selected to meet the minimum requirements stated in the Code and the additional requirements of contract documents.

R4.2.1 — The Code addresses four exposure categories that affect the requirements for concrete to ensure adequate durability:

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 as defined in 4.2.1.

Exposure Category P applies to concrete in contact with water requiring low permeability.

Exposure Category C applies to reinforced 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 when the exposure severity has negligible effect or does not apply to the structural 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 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. An example is 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

CODE

COMMENTARY

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: Structural members should be assigned to **Exposure Class P0** when there are no specific permeability requirements. **Exposure Class P1** is assigned on the basis of the need for concrete to have a low permeability to water when the permeation of water into concrete might reduce durability or affect the intended function of the structural member. Exposure Class P1 should typically be assigned when other exposure classes do not apply. 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 reinforced and prestressed concrete members depending on the degree of exposure to external sources of moisture and chlorides in service. Examples of external sources of chlorides include concrete in direct contact with deicing chemicals, salt, salt water, brackish water, seawater, or spray from these sources.

4.3 — Requirements for concrete mixtures

4.3.1 — Based on the exposure classes assigned from Table 4.2.1, concrete mixtures shall comply with the most restrictive requirements according to Table 4.3.1.

R4.3 — Requirements for concrete mixtures

R4.3.1 — Table 4.3.1 gives the requirements for concrete on the basis of the assigned exposure classes. When a structural concrete member is assigned more than one exposure class, 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 35 MPa, respectively. In this case, the requirement for corrosion protection is more restrictive than the requirement for resistance to freezing and thawing.

Exposure Classes F1, F2, and F3: In addition to complying with a maximum *w*/*cm* limit and a minimum strength requirement, concrete for structural members subject to freezing-and-thawing exposures should be air entrained in accordance with 4.4.1. Structural members assigned to Exposure Class F3 are additionally required to comply with the limitations on the quantity of pozzolans and slag in the composition of the cementitious materials as given in 4.4.2.

Exposure Classes S1, S2, and S3: Concrete exposed to injurious concentrations of sulfates from soil and water should be made with sulfate-resisting cement. Table 4.3.1 lists the appropriate types of cement and the maximum *w*/*cm* and minimum specified compressive strengths for various exposure conditions. In selecting cement for sulfate resistance,

CODE

TABLE 4.3.1 — REQUIREMENTS FOR CONCRETE BY EXPOSURE CLASS

Exposure Class	Max. *w/cm**	Min. f'_c, MPa	Additional minimum requirements			
			Air content			Limits on cementitious materials
F0	N/A	17	N/A			N/A
F1	0.45	31	Table 4.4.1			N/A
F2	0.45	31	Table 4.4.1			N/A
F3	0.45	31	Table 4.4.1			Table 4.4.2
			Cementitious materials†—types			Calcium chloride admixture
			ASTM C150	ASTM C595	ASTM C1157	
S0	N/A	17	No Type restriction	No Type restriction	No Type restriction	No restriction
S1	0.50	28	II‡	IP(MS), IS (<70) (MS)	MS	No restriction
S2	0.45	31	V§	IP (HS) IS (<70) (HS)	HS	Not permitted
S3	0.45	31	V + pozzolan or slag‖	IP (HS) + pozzolan or slag‖ or IS (<70) (HS) + pozzolan or slag‖	HS + pozzolan or slag‖	Not permitted
P0	N/A	17	None			
P1	0.50	28	None			
			Maximum water-soluble chloride ion (Cl^-) content in concrete, percent by weight of cement#			
			Reinforced concrete	Prestressed concrete	Related provisions	
C0	N/A	17	1.00	0.06	None	
C1	N/A	17	0.30	0.06		
C2	0.40	35	0.15	0.06	7.7.6, 18.16**	

*For lightweight concrete, see 4.1.2.
†Alternative combinations of cementitious materials of those listed in Table 4.3.1 shall be permitted when tested for sulfate resistance and meeting the criteria in 4.5.1.
‡For seawater exposure, other types of portland cements with tricalcium aluminate (C_3A) contents up to 10 percent are permitted is the *w/cm* does not exceed 0.40.
§Other available types of cement such as Type III or Type I are permitted in Exposure Classes S1 or S2 if the C_3A contents are less than 8 or 5 percent, respectively.
‖The amount of the specific source of the pozzolan or slag to be used shall not be less than the amount that has been determined by service record to improve sulfate resistance when used in concrete containing Type V cement. Alternatively, the amount of the specific source of the pozzolan or slag to be used shall not be less than the amount tested in accordance with ASTM C1012 and meeting the criteria in 4.5.1.
#Water-soluble chloride ion content that is contributed from the ingredients including water, aggregates, cementitious materials, and admixtures shall be determined on the concrete mixture by ASTM C1218M at age between 28 and 42 days.
**Requirements of 7.7.6 shall be satisfied. See 18.16 for unbonded tendons.

COMMENTARY

the principal consideration is its tricalcium aluminate (C_3A) content. For Exposure Class S1 (moderate exposure), Type II cement is limited to a maximum C_3A 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 C1157 is Type MS. For Exposure Class S2 (severe exposure), Type V cement with a maximum C_3A content of 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 C_3A 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 cover all special cases.

The use of fly ash (ASTM C618, Class F), natural pozzolans (ASTM C618, Class N), silica fume (ASTM C1240), or ground-granulated blast-furnace slag (ASTM C989) also has been shown to improve the sulfate resistance of concrete.[4.1-4.3] ASTM C1012 can be used to evaluate the sulfate resistance of mixtures using combinations of cementitious materials as determined in 4.5.1. For Exposure Class S3, the alternative in ACI 318-05 allowing use of Type V plus pozzolan, based on records of successful service, instead of meeting the testing requirements of 4.5.1, still exists and has been expanded to consider the use of slag and the blended cements.

Table 4.3.1 lists seawater under Exposure Class S1 (moderate exposure), even though it generally contains more than 1500 ppm SO_4. Portland cement with higher C_3A content improves binding of chlorides present in seawater and the Code permits other types of portland cement with C_3A up to 10 percent if the maximum *w/cm* is reduced to 0.40.

In addition to the proper selection of cementitious materials, other requirements for durable concrete exposed to water-soluble sulfate are essential, such as low *w/cm*, strength, adequate air entrainment, 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 and where the other exposure conditions defined in Table 4.2.1 do not apply. The primary means to obtain low permeability is to use a low *w/cm*. Low permeability can be also achieved by optimizing the cementitious materials used in the concrete mixture. One standard method that provides a performance-based indicator of low permeability of concrete is ASTM C1202, which is more reliable in laboratory evaluations than for field-based acceptance.

CODE

COMMENTARY

Exposure Class C2: For reinforced 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 in structures where chlorides may be applied should be evaluated, such as in parking structures where chlorides may be tracked in by vehicles, or in structures near seawater. Epoxy- or zinc-coated bars or cover greater than the minimum required in 7.7 may be desirable. Use of slag 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 C494M, Types F and G, or ASTM C1017M can also provide additional protection.[4.4] The use of ASTM C1202[4.5] to test concrete mixtures proposed for use will provide additional information on the performance of the mixtures.

Exposure Classes C0, C1, and C2: For Exposure Classes C0, C1, and C2, the chloride ion limits apply. For reinforced concrete, the permitted maximum amount of water-soluble chloride ions incorporated into the concrete, measured by ASTM C1218M at ages between 28 and 42 days, depend 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 weight of cement applies regardless of exposure.

Additional information on the effects of chlorides on the corrosion of reinforcing steel is given in ACI 201.2R,[4.6] which provides guidance on concrete durability, and ACI 222R,[4.7] 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 4.3.1, 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 C1218M.

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 4.3.1 are to be applied to chlorides contributed from the concrete ingredients, not those from the environment surrounding the concrete. For reinforced concrete that will be dry in service (Exposure Class C0), a limit of 1 percent has been included to control the water-soluble chlorides introduced by concrete-making materials. Table 4.3.1 includes limits of 0.30 and 0.15 percent for reinforced concrete subject to Exposure Classes C1 and C2, respectively.

CODE

4.4 — Additional requirements for freezing-and-thawing exposure

4.4.1 — Normalweight and lightweight concrete subject to Exposure Classes F1, F2, or F3 shall be air-entrained with air content indicated in Table 4.4.1. Tolerance on air content as delivered shall be ±1.5 percent. For f'_c greater than 35 MPa, reduction of air content indicated in Table 4.4.1 by 1.0 percent shall be permitted.

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

Nominal maximum aggregate size, mm*	Air content, percent	
	Exposure Class F1	Exposure Classes F2 and F3
9.5	6	7.5
12.5	5.5	7
19.0	5	6
25.0	4.5	6
37.5	4.5	5.5
50†	4	5
75†	3.5	4.5

*See ASTM C33 for tolerance on oversize for various nominal maximum size designations.
†Air contents apply to total mixture. When testing concretes, however, aggregate particles larger than 40 mm are removed by sieving and air content is measured on the sieved fraction (tolerance on air content as delivered applies to this value). Air content of total mixture is computed from value measured on the sieved fraction passing the 40 mm sieve in accordance with ASTM C231.

COMMENTARY

Table R4.3.1 — Chloride limits for new construction (adapted from Table 3.1 of ACI 222R[4.7])

Construction type and condition	Chloride limit, percent by mass		
	Test method		
	Acid soluble	Water soluble	
	ASTM C1152	ASTM C1218M	Soxhlet*
Prestressed concrete	0.08	0.06	0.06
Reinforced concrete wet in service	0.10	0.08	0.08
Reinforced concrete dry in service	0.20	0.15	0.15

*The Soxhlet test method is described in ACI 222.1.[4.8]

ACI 222R[4.7] has adopted slightly different categories and limits as shown in Table R4.3.1. ACI 201.2R[4.6] has adopted these same limits by referring to ACI 222R.

In Table 4.2.1, Exposure Classes C1 and C0 are similar to the categories for reinforced concrete under wet and dry conditions in service as described in ACI 222R. The recommended limit for prestressed concrete in this Code is same as in ACI 222R.

When epoxy- or zinc-coated bars are used, the limits in Table 4.3.1 may be more restrictive than necessary.

R4.4 — Additional requirements for freezing-and-thawing exposure

R4.4.1 — 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.[4.9] Target values are provided for Exposure Class F1 (moderate) and both Exposure Classes F2 and F3 (severe) exposures depending on the exposure to moisture or deicing salts. Entrained air will not protect concrete containing coarse aggregates that undergo disruptive volume changes when frozen in a saturated condition.

Section 4.4.1 permits 1 percent lower air content for concrete with f'_c greater than 35 MPa. Such high-strength concretes will have a lower *w*/*cm* and porosity and, therefore, improved resistance to cycles of freezing and thawing.

CODE

4.4.2 —The quantity of pozzolans, including fly ash and silica fume, and slag in concrete subject to Exposure Class F3, shall not exceed the limits in Table 4.4.2.

TABLE 4.4.2 — REQUIREMENTS FOR CONCRETE SUBJECT TO EXPOSURE CLASS F3

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

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

4.5 — Alternative cementitious materials for sulfate exposure

4.5.1 — Alternative combinations of cementitious materials to those listed in Table 4.3.1 shall be permitted when tested for sulfate resistance and meeting the criteria in Table 4.5.1.

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

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

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

COMMENTARY

R4.4.2 — Table 4.4.2 establishes limitations on the amount of fly ash, other pozzolans, silica fume, and slag that can be included in concrete exposed to deicing chemicals (Exposure Class F3) based on research studies.[4.10,4.11]

4

R4.5 — Alternative cementitious materials for sulfate exposure

R4.5.1 — In the 2008 version of the Code, 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 4.3.1 for all classes of sulfate exposure. More detailed guidance on qualification of such mixtures using ASTM C1012 is given in ACI 201.2R.[4.6] The expansion criteria in Table 4.5.1, 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.

Notes