Selecting Exposure Classes for Durability and Requirements for Concrete

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August 16, 2023

NRMCA

BUILD WITH STRENGTH

Benefits of Improved Durability

- Longer service life
- Minimize maintenance
- Key to “Sustainability”
  - Reduce carbon footprint
  - Reduce waste
  - Conserve resources

Pantheon 118 - 135 A.D.

Achieving Durable Structures

- Understand durability mechanisms
- Assign exposure classes and establish concrete requirements (ACI 318 Building Code)
- Available local materials and practices

Achieving Durable Concrete

- Minimize permeability
- Minimize cracking
- Chemical issues
  - ASR
  - Sulfates
  - Other
- *w/cm*
- Use of SCMs
- Minimize paste volume
- Construction
- Curing

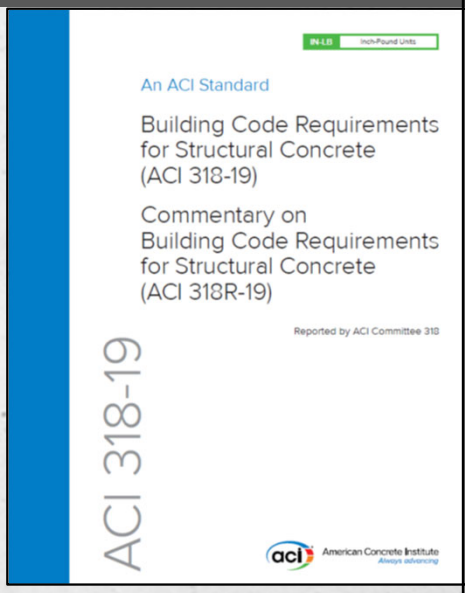
ACI 318-19 - A Design Standard

ACI 318 Building Code Requirements

- Chapter 19:
  - Concrete: Design & Durability Requirements
- Chapter 26:
  - Construction Documents and Inspection

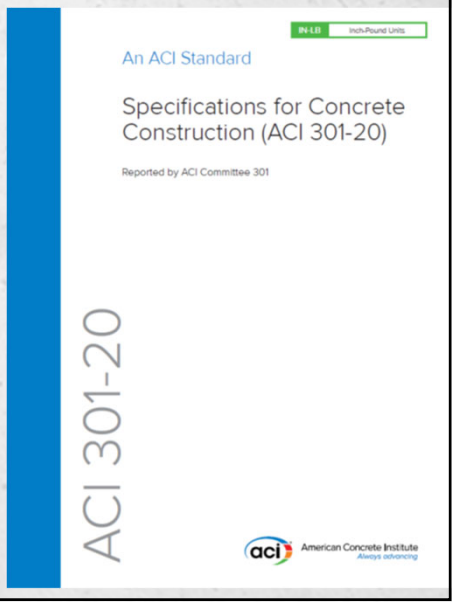
Minimum requirements for materials, design, and detailing

Covers strength, serviceability, durability



ACI 301 Specification for Structural Concrete

- Stand-alone reference specification with specific defaults
  - Written to comply with ACI 318
- Durability addressed in Section 4



ACI 318-19 – Durability Requirements

Chapter 19

19.3.1.1

The **licensed design professional shall assign** exposure classes in accordance with the severity of the **anticipated exposure** of structural concrete members **for each exposure category** according to Table 19.3.1.1

Durability Requirements

Exposure Categories

- **F** – Freezing and thawing exposure
- **S** – Sulfate exposure
- **W** – Contact with water (ASR)
- **C** – Corrosion protection of reinforcement

Members not exposed (interior) – F0, S0, W0, C0 – no applicable concrete requirements

Exposure Categories Durability (ACI 318)

Table 19.3.1.1—Exposure categories and classes

Category	Class	Condition	
Freezing and thawing (F)	F0	Concrete not exposed to freezing-and-thawing cycles	
	F1	Concrete exposed to freezing-and-thawing cycles with limited exposure to water	
	F2	Concrete exposed to freezing-and-thawing cycles with frequent exposure to water	
	F3	Concrete exposed to freezing-and-thawing cycles with frequent exposure to water and exposure to deicing chemicals	
Sulfate (S)		Water-soluble sulfate (SO_4^{2-}) in soil, percent by mass[1]	Dissolved sulfate (SO_4^{2-}) in water, ppm[2]
	S0	$SO_4^{2-} < 0.10$	$SO_4^{2-} < 150$
	S1	$0.10 \le SO_4^{2-} < 0.20$	$150 \le SO_4^{2-} < 1500$ or seawater
	S2	$0.20 \le SO_4^{2-} \le 2.00$	$1500 \le SO_4^{2-} \le 10{,}000$
	S3	$SO_4^{2-} > 2.00$	$SO_4^{2-} > 10{,}000$
In contact with water (W)	W0	Concrete dry in service	
	W1	Concrete in contact with water where low permeability is not required	
	W2	Concrete in contact with water where low permeability is required	
Corrosion protection of reinforcement (C)	C0	Concrete dry or protected from moisture	
	C1	Concrete exposed to moisture but not to an external source of chlorides	
	C2	Concrete exposed to moisture and an external source of chlorides from deicing chemicals, salt, brackish water, seawater, or spray from these sources	

Table 19.3.2.1—Requirements for concrete by exposure class

Exposure class		Maximum w/cm[1,2]	Minimum f'_c, psi	Additional requirements			Limits on cementitious materials
				Air content			
F0		N/A	2500	N/A			N/A
F1		0.55	3500	Table 19.3.3.1 for concrete or Table 19.3.3.3 for shotcrete			N/A
F2		0.45	4500	Table 19.3.3.1 for concrete or Table 19.3.3.3 for shotcrete			N/A
F3		0.40[3]	5000[3]	Table 19.3.3.1 for concrete or Table 19.3.3.3 for shotcrete			26.4.2.2(b)
				Cementitious materials[4] — Types			Calcium chloride admixture
				ASTM C150	ASTM C595	ASTM C1157	
S0		N/A	2500	No type restriction	No type restriction	No type restriction	No restriction
S1		0.50	4000	II[5][6]	Types with (MS) designation	MS	No restriction
S2		0.45	4500	V[6]	Types with (HS) designation	HS	Not permitted
S3	Option 1	0.45	4500	V plus pozzolan or slag cement[7]	Types with (HS) designation plus pozzolan or slag cement[7]	HS plus pozzolan or slag cement[7]	Not permitted
	Option 2	0.40	5000	V[8]	Types with (HS) designation	HS	Not permitted
W0		N/A	2500	None			
W1		N/A	2500	26.4.2.2(d)			
W2		0.50	4000	26.4.2.2(d)			
				Maximum water-soluble chloride ion (Cl^-) content in concrete, percent by mass of cementitious materials[9,10]			
				Nonprestressed concrete	Prestressed concrete	Additional provisions	
C0		N/A	2500	1.00	0.06	None	
C1		N/A	2500	0.30	0.06		
C2		0.40	5000	0.15	0.06	Concrete cover[11]	

Freezing and Thawing

- Expansion of water when freezing in saturated concrete causes internal expansion and damage
- Sometimes due to non-durable aggregates
- Surface scaling

Avoiding Freeze-Thaw Damage

- Adequate entrained air void system
- Lower *w/cm* to minimize saturation
- Durable aggregates
- Max SCM limits – deicing salts – hand-finished concrete

ACI 318 – Exposure Category F

EC	Examples
F0	• Warm regions; Inside structures • Concrete below the frost line
F1	• Members not subject to snow and ice accumulation; slabs not in direct contact with soil • Foundation walls if saturation is unlikely
F2	• Subject to snow and ice accumulation/buildup (exterior elevated slabs, foundation or basement walls) • Members in direct contact with soil
F3	• Exposed to deicing chemicals – directly or as accumulation of snow and ice with deicing chemicals

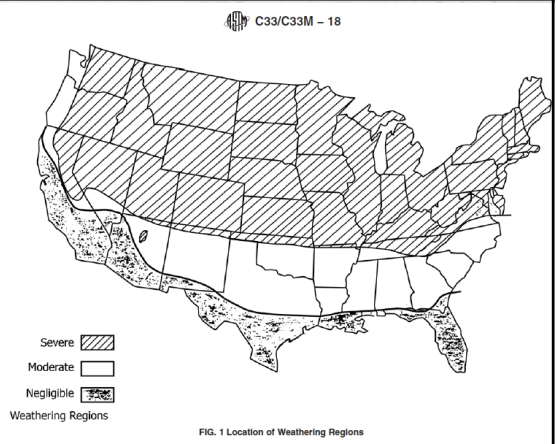


FIG. 1 Location of Weathering Regions

ACI 318 – Exposure Category F

- Classes: F0, F1, F2, F3
- Max *w/cm*; Min f'_c
- Air content
  - Lower air for F1
  - Based on size of coarse aggregate
  - Reduce air content by 1% for $f'_c \geq 5000$ psi
  - Tolerance is ± 1.5%
- Max SCM limits for F3 (minimize scaling)

ACI 318-19 Exposure Category F, Freezing and thawing

Class	Condition
F0	Concrete not exposed to FT cycles
F1	Concrete exposed to FT cycles with limited exposure to water
F2	Concrete exposed to FT cycles with frequent exposure to water
F3	F2 + exposure to deicing chemicals

w/cm	Air	CM	f'_c	Relat. CO2
NA	NA	450	NA	100
0.55	4.5	525	3500	115
0.45	6.0	645	4500	139
0.40	6.0	725	5000	155

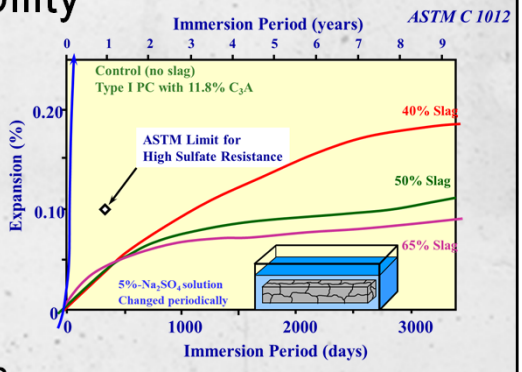
- A more restrictive FT exposure selection results in higher GWP
  - Foundations – F0 by ACI 332 (Residential), F0 or F1 or F2 (by ACI 318)
  - Interior elements during construction

Sulfates

- Sulfates in soil or water react with aluminates (C_3A in portland cement)
- Ettringite formation – expansion and cracking
- Gypsum formation – loss of cementitious properties

Mitigating Sulfate Attack

- Lower *w/cm* – reduced permeability
- Sulfate-resisting cementitious material
  - Type II, V (lower C_3A content)
  - Blended - Types IP, IS, IT, IL with MS or HS
  - Higher C_3A encapsulates chlorides
- Use of SCMs
  - Class C fly ash not effective



ACI 318 – Exposure Category S

- Classes: S0, S1, S2, S3
- Max *w/cm*; Min f'_c
- Types of cementitious materials
  - Qualification testing by ASTM C1012 with criteria
- Two alternative options for S3
- Sea water listed as S1 (chloride binding)
- Prohibits calcium chloride admix for S2 & S3

ACI 318 – Exposure Category W

- Concrete in contact with water
- Classes: W0, W1, W2
- Exposure Class W2 – requires low permeability
  - Max *w/cm*; Min f'_c
- Address alkali aggregate reactions for W1 & W2

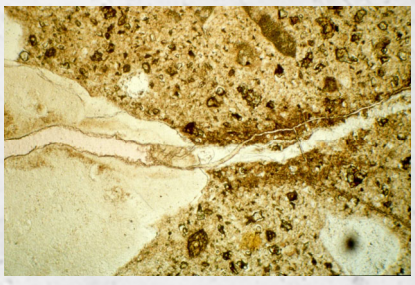
Alkali Aggregate Reactions

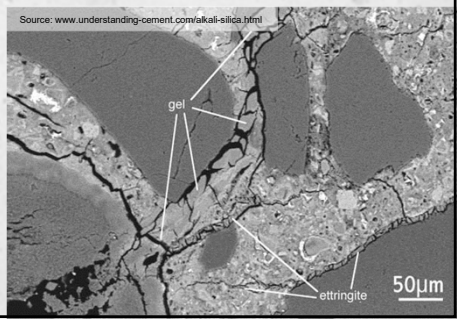
- Two types
  - Alkali Carbonate (ACR)
  - Alkali Silica (ASR)
- Alkali carbonate reactive rocks are rare
  - Should not be used in concrete
- Alkali silica reactions
  - Guidance in ASTM C1778

Alkali-Silica Reaction (ASR)

Factors that Affect ASR:

- Aggregate with reactive silica
- Alkalis (sodium / potassium) from cement
- Exposure to Moisture





Reaction between aggregate and alkaline liquid forms gel, causes expansion leading to cracking and pop outs

ACI 301: ASR

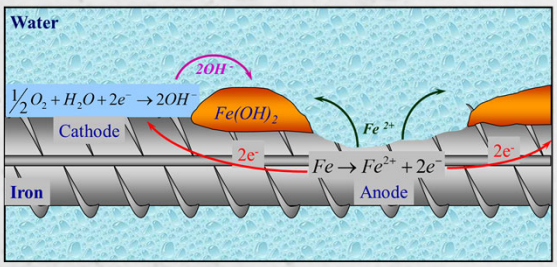
- Aggregate reactivity
  - ASTM C1293 ≤ 0.04% at 1 yr
- Mitigation
  - ASTM C1567 ≤ 0.10% at 14 days
    - Include C1260 with aggregate expansion > 0.10%
  - Alkali loading limit (cement alkalis only)
    - Max 3 lb/yd^3 or 4 lb/yd^3

Corrosion

Corrosion is the #1 cause of deterioration of concrete structures

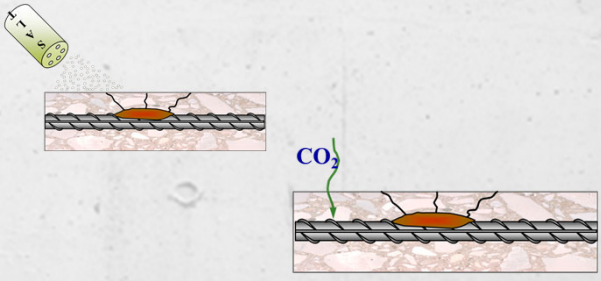
Impacts safety and cost

- Electrical circuit
- Moisture
- Oxygen



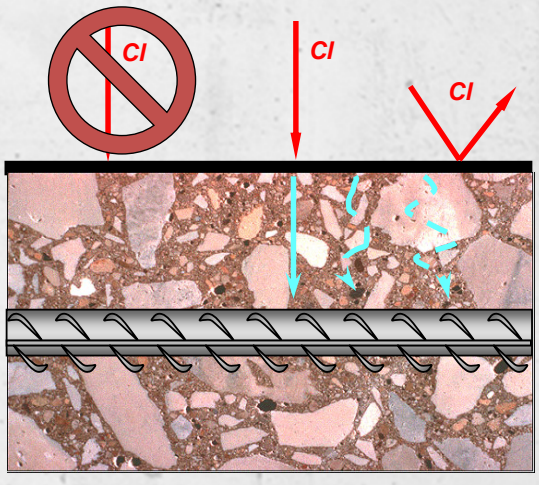
High pH in concrete passivates steel until…

- Chlorides exceed threshold
- Carbonation to level of steel



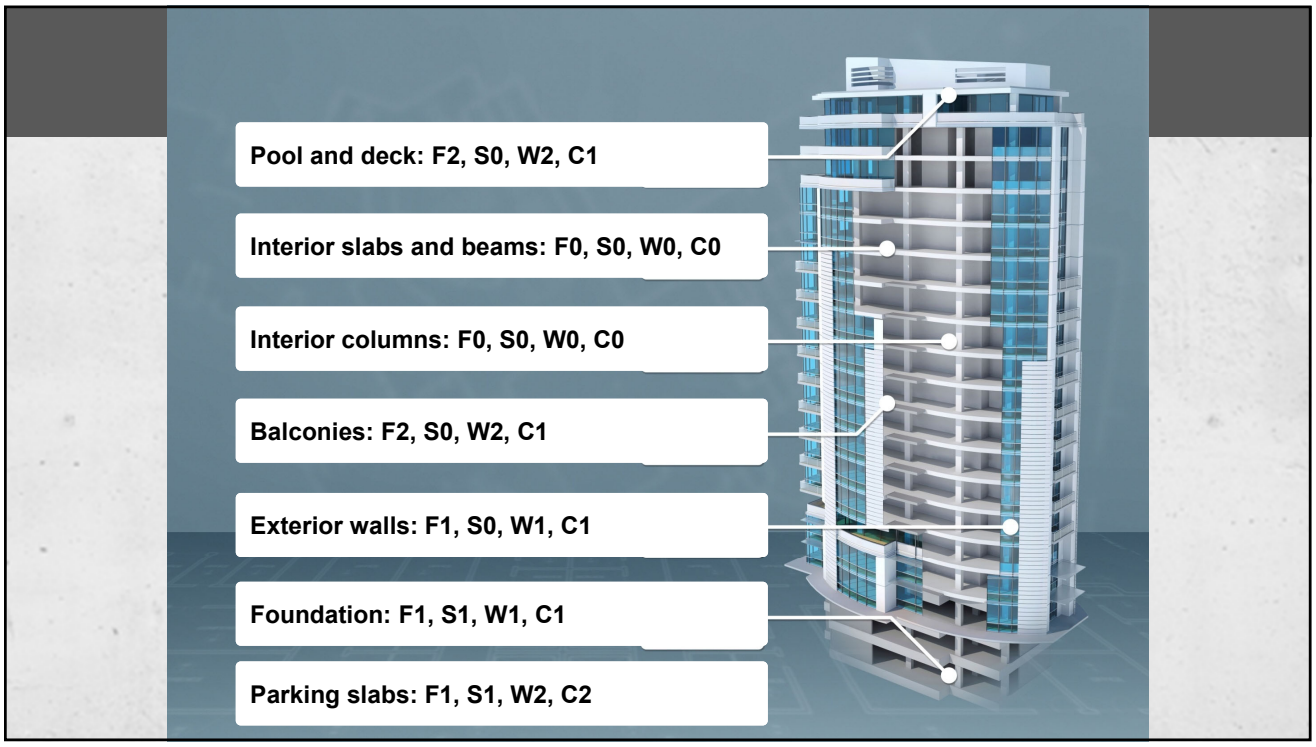
Mitigating Steel Corrosion

- Avoid external chlorides
- Minimize internal chlorides
- Low permeability concrete
- Adequate cover
- Corrosion inhibiting admixtures
- Minimize cracks
- Membranes/sealers
- Steel coatings
- Noncorrosive metal reinforcement
- Cathodic protection



ACI 318 – Exposure Category C

- Classes: C0, C1, C2
- Chloride limits for concrete mixtures
  - Water-soluble chlorides, % of cementitious materials
- Exposure Class C2 – requires low permeability
  - Max *w/cm*; Min f'_c
  - Cover

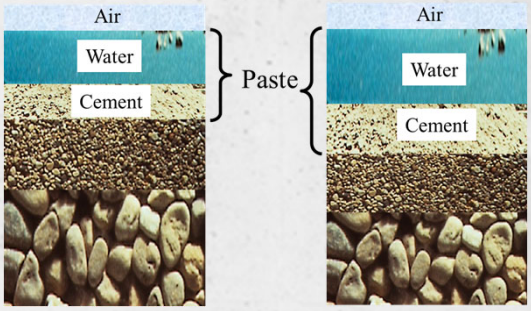


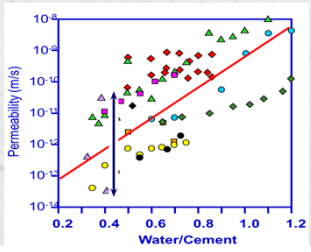
Requirements for Concrete (partial)

Concrete Mixtures				
Members	**Exposure**	**f'_c load/dur**	***w/cm***	**NMSA**
Pool and deck	F2, S0, W2, C1	4,000 / 4,500	0.45	¾-in.
Interior slabs and beams	F0, S0, W0, C0	4,000 / n/a	n/a	¾-in.
Interior columns	F0, S0, W0, C0	8,000 / n/a	n/a	¾-in.
Balconies	F2, S0, W2, C1	4,000 / 4,500	0.45	¾-in.
Exterior walls	F1, S0, W1, C1	3,500 / 3,500	0.55	1-in.
Foundation	F1, S1, W1, C1	3,000 / 4,000	0.50	1-in.
Parking Slabs	F1, S1, W2, C2	3,000 / 5,000	0.40	¾-in.

Specifying *w/cm*

- Paste volume impact
- No "credit" for SCMs
- Wide range of permeability
- Lower is not always better
  - Impacts sustainability, constructability

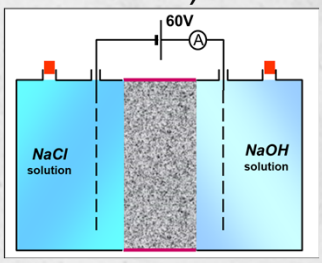




(Adapted from Hearn et al, 1996)

Performance Alternative: Permeability

- For ASTM C1202 (accelerated curing for mixtures with SCM):
  - *w/cm* = 0.55 → Maximum 3000 coulombs
  - *w/cm* = 0.50 → Maximum 2500 coulombs
  - *w/cm* = 0.45 → Maximum 2000 coulombs
  - *w/cm* = 0.40 → Maximum 1500 coulombs
- For ASTM C1876 (resistivity) (56 day):
  - *w/cm* = 0.55 → Minimum 60 Ω-m
  - *w/cm* = 0.50 → Minimum 75 Ω-m
  - *w/cm* = 0.45 → Minimum 90 Ω-m
  - *w/cm* = 0.40 → Minimum 120 Ω-m



Volume Change

Concrete reduces volume after its placed
Restraint causes cracking

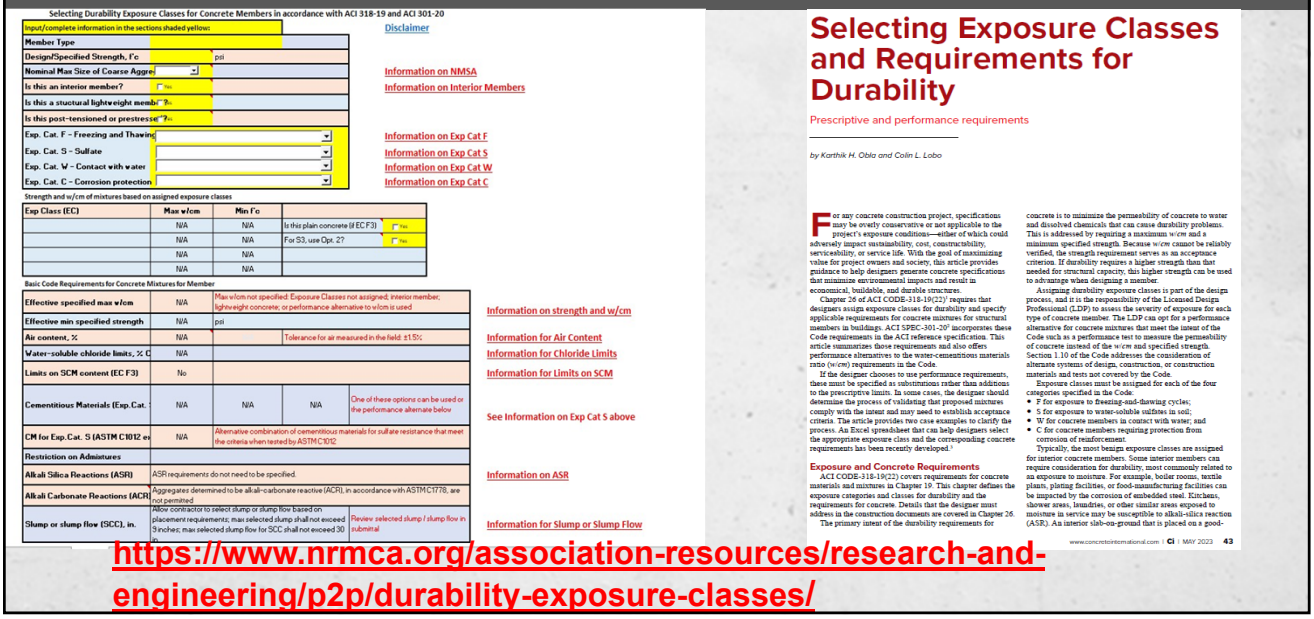
- Minimize paste volume
- Shrinkage Reducing Admixtures
- Fibers
- Reinforcement - Keep cracks tight
- Jointing

Performance: Drying Shrinkage

Not required by ACI 318

- ASTM C157
  - Preapproval
  - Specimen size 3 x 3 x 10 in (larger with 1 ½ in. agg)
  - Cured in limewater for 7 days and dried for 28 days
  - Length change criteria - 0.04 or 0.05%

Demonstration



Selecting Durability Exposure Classes for Concrete Members in accordance with ACI 318-19 and ACI 301-20

Input/complete information in the sections shaded yellow:

Disclaimer

Member Type		
Design/Specified Strength, f'c	psi	
Nominal Max Size of Coarse Aggre		Information on NMSA
Is this an interior member?	No	Information on Interior Members
Is this a structural lightweight membr		
Is this post-tensioned or prestresse		
Exp. Cat. F – Freezing and Thawing		Information on Exp Cat F
Exp. Cat. S – Sulfate		Information on Exp Cat S
Exp. Cat. W – Contact with water		Information on Exp Cat W
Exp. Cat. C – Corrosion protection		Information on Exp Cat C

Strength and w/cm of mixtures based on assigned exposure classes

Exp Class (EC)	Max w/cm	Min f'c	
	N/A	N/A	Is this plain concrete (if EC F3) No
	N/A	N/A	For S3, use Opt. 2? No
	N/A	N/A	
	N/A	N/A	

Basic Code Requirements for Concrete Mixtures for Member

Effective specified max w/cm	N/A	Max w/cm not specified: Exposure Classes not assigned; interior member, lightweight concrete, or performance alternative to w/cm is used		Information on strength and w/cm
Effective min specified strength	N/A	psi		
Air content, %	N/A		Tolerance for air measured in the field: ±1.5%	Information for Air Content
Water-soluble chloride limits, % C	N/A			Information for Chloride Limits
Limits on SCM content (EC F3)	No			Information for Limits on SCM
Cementitious Materials (Exp.Cat.	N/A	N/A	N/A	One of these options can be used or the performance alternate below
CM for Exp.Cat. S (ASTM C1012 ex	N/A	Alternative combination of cementitious materials for sulfate resistance that meet the criteria when tested by ASTM C1012.		See Information on Exp Cat S above
Restriction on Admixtures				
Alkali Silica Reactions (ASR)	ASR requirements do not need to be specified.			Information on ASR
Alkali Carbonate Reactions (ACR)	Aggregates determined to be alkali-carbonate reactive (ACR), in accordance with ASTM C1778, are not permitted			
Slump or slump flow (SCC), in.	Allow contractor to select slump or slump flow based on placement requirements; max selected slump shall not exceed 9 inches; max selected slump flow for SCC shall not exceed 30		Review selected slump / slump flow in submittal	Information for Slump or Slump Flow

Selecting Exposure Classes and Requirements for Durability

Prescriptive and performance requirements

by Karthik H. Obla and Colin L. Lobo

For any concrete construction project, specifications may be overly conservative or not applicable to the project's exposure conditions—either of which could adversely impact sustainability, cost, constructability, serviceability, or service life. With the goal of maximizing value for project owners and society, this article provides guidance to help designers generate concrete specifications that minimize environmental impacts and result in economical, buildable, and durable structures.

Chapter 26 of ACI CODE-318-19(22)[1] requires that designers assign exposure classes for durability and specify applicable requirements for concrete mixtures for structural members in buildings. ACI SPEC-301-20[2] incorporates these Code requirements in the ACI reference specification. This article summarizes those requirements and also offers performance alternatives to the water-cementitious materials ratio (*w/cm*) requirements in the Code.

If the designer chooses to use performance requirements, these must be specified as substitutions rather than additions to the prescriptive limits. In some cases, the designer should determine the process of validating that proposed mixtures comply with the intent and may need to establish acceptance criteria. The article provides two case examples to clarify the process. An Excel spreadsheet that can help designers select the appropriate exposure class and the corresponding concrete requirements has been recently developed.[3]

Exposure and Concrete Requirements

ACI CODE-318-19(22) covers requirements for concrete materials and mixtures in Chapter 19. This chapter defines the exposure categories and classes for durability and the requirements for concrete. Details that the designer must address in the construction documents are covered in Chapter 26.

The primary intent of the durability requirements for concrete is to minimize the permeability of concrete to water and dissolved chemicals that can cause durability problems. This is addressed by requiring a maximum *w/cm* and a minimum specified strength. Because *w/cm* cannot be reliably verified, the strength requirement serves as an acceptance criterion. If durability requires a higher strength than that needed for structural capacity, this higher strength can be used to advantage when designing a member.

Assigning durability exposure classes is part of the design process, and it is the responsibility of the Licensed Design Professional (LDP) to assess the severity of exposure for each type of concrete member. The LDP can opt for a performance alternative for concrete mixtures that meet the intent of the Code such as a performance test to measure the permeability of concrete instead of the *w/cm* and specified strength. Section 1.10 of the Code addresses the consideration of alternate systems of design, construction, or construction materials and tests not covered by the Code.

Exposure classes must be assigned for each of the four categories specified in the Code:

- F for exposure to freezing-and-thawing cycles;
- S for exposure to water-soluble sulfates in soil;
- W for concrete members in contact with water; and
- C for concrete members requiring protection from corrosion of reinforcement.

Typically, the most benign exposure classes are assigned for interior concrete members. Some interior members can require consideration for durability, most commonly related to an exposure to moisture. For example, boiler rooms, textile plants, plating facilities, or food-manufacturing facilities can be impacted by the corrosion of embedded steel. Kitchens, shower areas, laundries, or other similar areas exposed to moisture in service may be susceptible to alkali-silica reaction (ASR). An interior slab-on-ground that is placed on a good-

https://www.nrmca.org/association-resources/research-and-engineering/p2p/durability-exposure-classes/

Summary

- Discussed durability mechanisms, mitigation and ACI 318 requirements
  - Freeze-thaw, Sulfate, Water, ASR, and Corrosion
- LDP assigns exposure classes, concrete requirements
- Rational interpretation of Codes and Standards important for low embodied carbon concrete
  - Max CM, SCM limits (only F3), *w/cm, air* (more restrictive)
- Can include performance requirements
  - RCP/resistivity (instead of *w/cm*), Shrinkage