ACI 318 Durability Requirements

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Specifications

Often a project will have specifications prescribed by an engineer to ensure adequate concrete performance for the specific requirements of that project. Sometimes these specifications make sense, sometimes they don't, but at least they set a baseline of minimum quality to be achieved on a job. But what if there are no specifications? If we are left to our own devices, how do we know we are using the proper mix design and materials to provide a quality, lasting product for the conditions of our project?

In large part, the answers can be found in ACI 318, Chapter 19. This is a guide to different exposures concrete can face, and what strengths, w/cm ratios, SCM replacements, cement types and air contents are appropriate for each of those exposures. It must be noted, that ACI 318, chapter 19 does not identify the specific load bearing requirements that may influence the need for higher strengths. Typically, if such load concerns were present, engineering must be done to determine the necessary strength.

Exposure Types

How ACI 318-22.19 works is by defining different levels of four different kinds of exposures. **F** - Freezing/Thawing, **S** - Sulfates, **W** - Contact with Water, and **C** - Corrosion protection of reinforcement.

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	

[1]Percent sulfate by mass in soil shall be determined by ASTM C1580.

[2]Concentration of dissolved sulfates in water, in ppm, shall be determined by ASTM D516 or ASTM

The above replication of table 19.3.1.1 defines each exposure class and the different levels of exposure that are reasonably common. We think about the working environment of our concrete member and apply those conditions to the levels of exposure in the above chart. Once we know our exposure levels for each class, we can apply them to the below replication of table 19.3.2.1

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]		Additional provisions
			Nonprestressed concrete	Prestressed concrete	
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]

[1]The *w/cm* is based on all cementitious and supplementary cementitious materials in the concrete mixture.

[2]The maximum *w/cm* limits do not apply to lightweight concrete.

[3]For plain concrete, the maximum w/cm shall be 0.45 and the minimum f_c' shall be 4500 psi.

[4]Alternative combinations of cementitious materials to those listed are permitted for all sulfate exposure classes when tested for sulfate resistance and meeting the criteria in 26.4.2.2(c).

[5]For seawater exposure, other types of portland cements with tricalcium aluminate (C_3A) contents up to 10 percent are permitted if the *w/cm* does not exceed 0.40.

[6]Other available types of cement such as Type I or Type III are permitted in Exposure Classes S1 or S2 if the C_3A contents are less than 8 percent for Exposure Class S1 or less than 5 percent for Exposure Class S2.

[7]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 26.4.2.2(c).

[8]If Type V cement is used as the sole cementitious material, the optional sulfate resistance requirement of 0.040 percent maximum expansion in ASTM C150 shall be specified.

[9]The mass of supplementary cementitious materials used in determining the chloride content shall

We also have to consider the appropriate air content. using our exposure levels from the replication of Table 19.3.1.1 we can apply them to the replication of table 19.3.3.1 (below) to determine target air content.

Table 19.3.3.1—Total air content for concrete exposed to cycles of freezing and thawing

Nominal maximum aggregate size, in.	Target air content, percent	
	F1	F2 and F3
3/8	6.0	7.5
1/2	5.5	7.0
3/4	5.0	6.0
1	4.5	6.0
1-1/2	4.5	5.5
2	4.0	5.0
3	3.5	4.5

Finally, we have to make sure we are using the appropriate contents of SCMs. The below replication of table 24.4.2.2(b) helps with this.

Table 26.4.2.2(b)—Limits on cementitious materials for concrete assigned to Exposure Class F3

Supplementary cementitious materials	Maximum percent of total cementitious materials by mass
Fly ash or natural pozzolans conforming to ASTM C618	25
Slag cement conforming to ASTM C989	50
Silica fume conforming to ASTM C1240	10
Total of fly ash or natural pozzolans and silica fume	35
Total of fly ash or natural pozzolans, slag cement, and silica fume	50

Ok that's a lot of tables and much to digest. Let's make it easy with an example. Assume we are pouring an elevated exterior concrete deck in our climate. Since it's a thin topping, we are going to use a 3/8" chip aggregate. Let's consider what our exposures are. It's outside, but isn't intended to be used during the winter months. We can assume that it will be exposed to water, but due to no use in the winter, it isn't likely to be salted. We'll choose exposure class F2. As an elevated slab, it is not subject to sulfates in the soil (which isn't really a problem in this area anyway), so we select S0. Concrete will be exposed to rain and snow and thus could be wet in service, and we are very concerned with water intrusion into the room below the deck. We select W2. There is rebar in our deck, and it is exposed to moisture, but not chlorides. We select C1. Now we build the mix design requirements. F2 specifies a maximum .45 w/cm ratio and minimum 4500psi strength. S0 requires just 2500psi, but that is superseded by the F2 requirements. W2 requires a .50 w/c and 4000psi, again superseded by the F2 requirements. Finally C1 requires a 2500psi and limits to the chloride contents of our materials. We can select admixtures with low - to no chloride contents and again, the 2500psi is superseded by the F2 requirements. Table 19.3.3.1 tells us that for F2 exposure and 3/8" aggregate, we should target 7.5% air. 26.4.2.2 is irrelevant in this case.

So now we have a great starting spot for the specifications of our project: a 3/8' maximum nominal aggregate size, with a maximum .45 w/cm ratio, 4500psi minimum strength, and target 7.5% air. We can be reasonably confident that concrete that conforms to these specs, with quality materials, will be appropriate and long lasting in service to our project.

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Hahn Ready Mix
3636 West River Drive, Davenport, IA 52802