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Surfside Florida Building Collapse of June 2021 and ACI 318 Building Code Requirements for Structural Concrete

PART 2 OF 4

ICC INTERNATIONAL CODE COUNCIL®

Surfside, Florida Building Collapse of June 2021 and ACI 318 Building Code Requirements for Structural Concrete: Part 2 of 4

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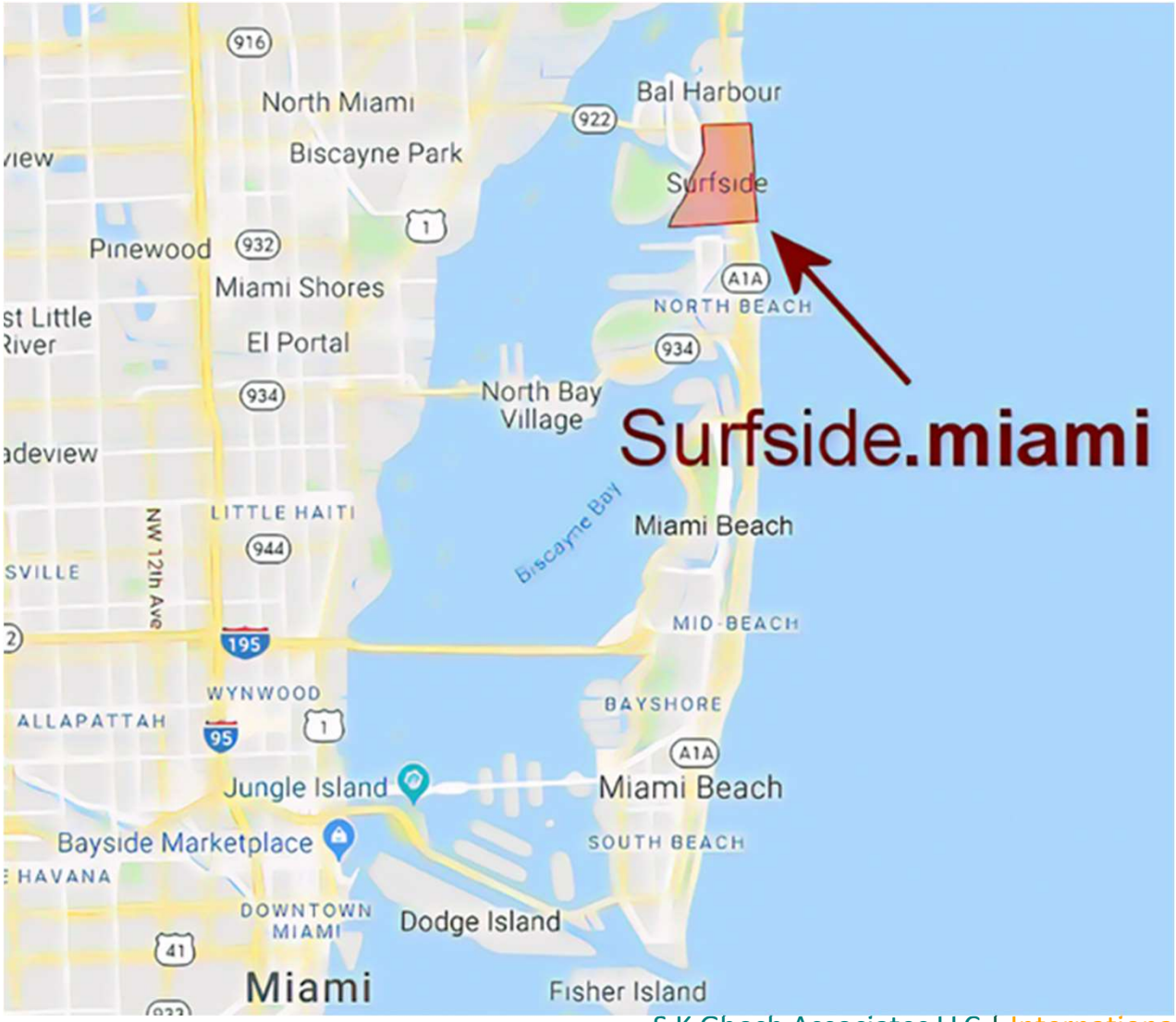
The Event

On **Thursday, June 24, 2021**, at approximately 1:25 a.m. EDT, Champlain Towers South, a 12-story beachfront condominium in the Miami suburb of Surfside, Florida, partially collapsed. Ninety-eight people died.



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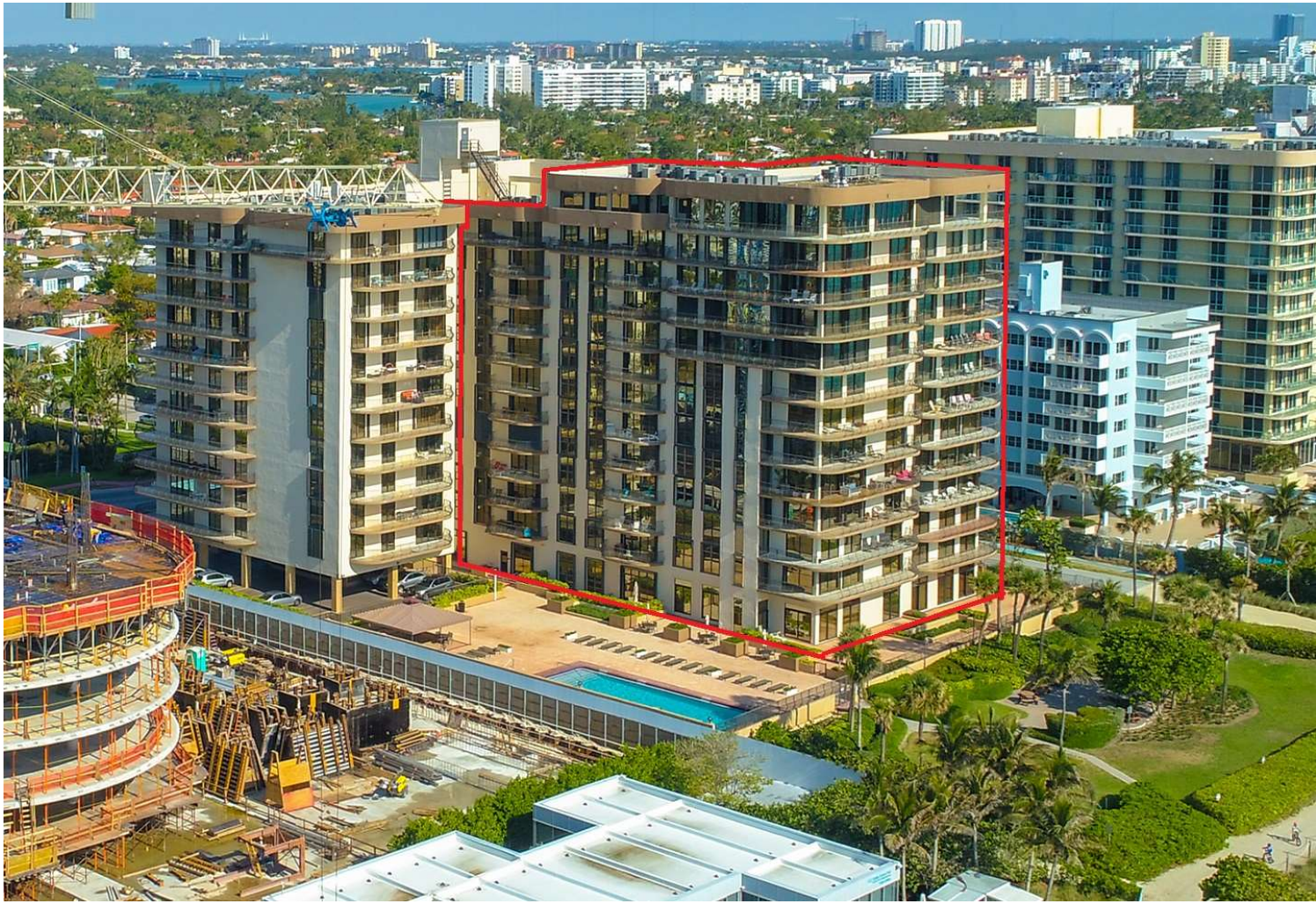
Champlain Tower South Before Collapse



Before and After Collapse

Critical Improvements in ACI 318 since Building Was Designed

The building was likely designed under the early or mid-1970s Florida Building Code and ACI 318-71 or ACI 318-77. ACI 318 provisions for concrete durability, reinforcement durability, structural integrity, and flat plate – column frame design are critical areas of improvements that engineers, architects, and building officials must be familiar with for safe performance of concrete buildings.

Concrete Durability

Concrete Durability Requirements of ACI 318

Aspects of Concrete Durability:

- Freeze-Thaw Resistance
- Resistance to Sulfate Attack
- Low Permeability
- Corrosion Protection

ACI 318-71 – ACI 318-19

318-71 – Unidentified requirements in Chapter 4, Concrete Quality

318-77 – Requirements under the heading of Special Exposure Requirements in Chapter 4

318-89 – Chapter 4 titled: Durability Requirements

318-08 – Major changes; chapter completely rewritten; Exposure Categories and Classes introduced

318-14 – Reorganization; concrete durability requirements became part of Chapter 19, Concrete (Section 19.3)

318-19 – Only a couple of substantive changes

ACI 318-71 Chapter 4: Concrete Quality

4.2.5 – Concrete that, after curing, will be subject to freezing temperatures while wet shall contain entrained air within limits of Table 4.2.5.

For such concrete made with normal weight aggregate, the water-cement ratio shall not exceed 0.53 by weight.

When the concrete is made with lightweight aggregate, the specified compressive strength f_c' shall be at lest 3750 psi for exposure to fresh water and 4000 psi for exposure to seawater.

ACI 318-71 Chapter 4: Concrete Quality

TABLE 4.2.5 – CONCRETE AIR CONTENT FOR VARIOUS SIZES OF COARSE AGGREGATE

Nominal maximum Size of coarse Aggregate, in.	Total air content, Percent by volume
3/8	6 to 10
1/2	5 to 9
3/4	4 to 8
1	3.5 to 6.5
1-1/2	3 to 6
2	2.5 to 5.5
3	1.5 to 4.5

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ACI 318-71 Chapter 4: Concrete Quality

4.2.6 – When made with normal weight aggregate, concrete that is intended to be watertight shall have a maximum water-cement ratio of 0.48 for exposure to fresh water and 0.44 for exposure to sea water.

For concrete made with lightweight aggregate, specified compressive strength f_c' shall be at least 3750 psi for exposure to fresh water and 4000 psi for exposure to seawater.

ACI 318-71 Chapter 4: Concrete Quality

4.2.7 – Concrete that will be exposed to injurious concentrations of sulfate-containing solutions shall conform to Section 4.2.6 and be made with sulfate-resisting cement.

No corrosion protection (introduced in 1989)

ACI 318-77 Chapter 4: Concrete Quality

4.6 – Special exposure requirements

4.6.1~~2.5~~ – Concrete that, after curing, will be exposed~~subject~~ to freezing temperatures while wet shall contain entrained air within limits of Table 4.6.1~~4.2.5~~.

4.6.1.1 - For such concrete made with normal weight aggregate, the water-cement ratio shall not exceed 0.53 by weight.

4.6.1.2 - When the concrete is made with lightweight aggregate, the specified compressive strength f_c' shall be at lest 3000 psi~~3750 psi for exposure to fresh water and 4000 psi for exposure to seawater~~.

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ACI 318-77 Chapter 4: Concrete Quality

TABLE 4.6.1~~2.5~~ – CONCRETE AIR CONTENT FOR VARIOUS SIZES OF COARSE AGGREGATE

Same as ACI 318-71 Table 4.2.5

ACI 318-77 Chapter 4: Concrete Quality

4.6.2 – Concrete that is intended to be watertight shall conform to the following:

4.6.2.1~~2.6~~ – ~~When~~For concrete made with normal weight aggregate, ~~concrete that is intended to be watertight shall have a maximum~~ water-cement ratio shall not exceed~~of~~ 0.50~~48~~ by weight for exposure to fresh water and 0.45~~4~~ for exposure to sea water.

4.6.2.2 - For concrete made with lightweight aggregate, specified compressive strength f_c' shall be at least 3750 psi for exposure to fresh water and 4000 psi for exposure to seawater.

ACI 318-77 Chapter 4: Concrete Quality

4.6.3~~2.7~~ – Concrete that will be exposed to injurious concentrations of sulfate-containing solutions shall conform to Section 4.2.6 and be made with sulfate-resisting cement.

No corrosion protection (introduced in 1989)

ACI 318-08 Chapter 4: Durability Requirements

- Format of Chapter 4 extensively revised by introducing exposure categories and classes, with applicable durability requirements given for various classes in a unified format.

ACI 318-08 Chapter 4: Durability Requirements

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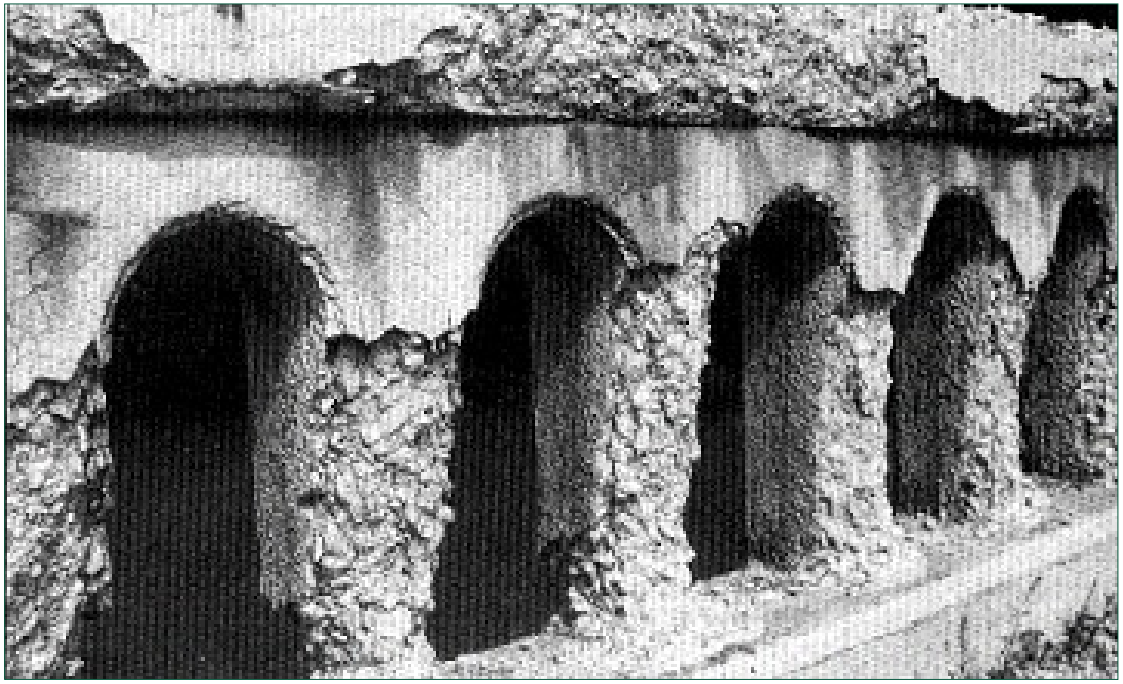
ACI 318-08 Chapter 4: Durability Requirements

Freezing and Thawing



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ACI 318-08 Chapter 4: Durability Requirements

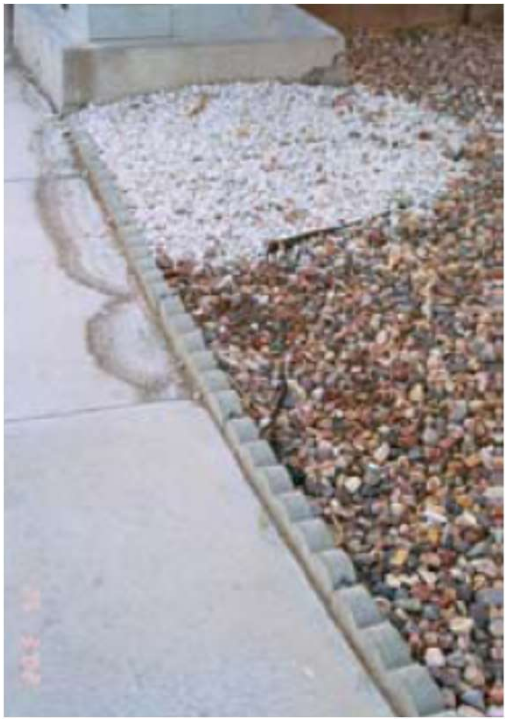
Class	Severity	Condition
F0	Not Applicable	Concrete not exposed to freezing and thawing cycles
F1	Moderate	Concrete exposed to freezing and thawing cycles, which may be occasionally exposed to moisture before freezing. Examples: exterior walls, beams, girders, and slabs not in direct contact with soil
F2	Severe	Concrete exposed to freezing and thawing cycles, which is in continuous contact with moisture before freezing. Examples: water tanks

ACI 318-08 Chapter 4: Durability Requirements

Class	Severity	Condition
F3	Very Severe	Concrete exposed to freezing and thawing cycles, in continuous contact with moisture, where exposure to deicing chemicals is anticipated. Examples: parking structures in northern states

ACI 318-08 Chapter 4: Durability Requirements

Water Soluble Sulfate



ACI 318-08 Chapter 4: Durability Requirements

Class	Severity	Water-Soluble Sulfate in Soil, Percent by Weight	Sulfate in Water ppm	Commentary
S0	Not Applicable	$SO_4 < 0.01$	$SO_4 < 150$	Injurious sulfate attack is not common
S1	Moderate	$0.10 \leq SO_4 < 0.20$	$150 \leq SO_4 <1500$ sea water	More critical value of measured water-soluble sulfate concentration in soil or the concentration of dissolved sulfate in water governs

ACI 318-08 Chapter 4: Durability Requirements

Class	Severity	Water-Soluble Sulfate in Soil, Percent by Weight	Sulfate in Water ppm	Commentary
S2	Severe	$0.20 \leq SO_4 \leq 2.00$	$1500 \leq SO_4 \leq 10{,}000$	Same as above
S3	Very Severe	$SO_4 > 2.00$	$SO_4 > 10{,}000$	Same as above

ACI 318-08 Chapter 4: Durability Requirements

Permeability

Class	Severity	Condition	Commentary
P0	Not Applicable	Concrete not required to have low permeability to water	
P1	Applicable	Concrete required to have low permeability to water	When the permeation of water into concrete might reduce durability or affect the intended function of the structural element

ACI 318-08 Chapter 4: Durability Requirements

Corrosion of Reinforcement

ACI 318-08 Chapter 4: Durability Requirements

Class	Severity	Condition	Commentary
C0	Not Applicable	Concrete that will be dry or protected from moisture in service	No additional protection required against the corrosion of reinforcement
C1	Moderate	Concrete exposed to moisture but not to an external source of chlorides in service	
C2	High	Concrete exposed to moisture and to an external source of chlorides in service	Example sources: deicing chemicals, salt, brackish water, seawater, or spray from these sources

ACI 318-08 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.

ACI 318-08 Table 4.3.1.a – Exposure Category F

Exposure Class	Max. w/cm**	Min. f'_c psi	Additional Minimum Requirements	
			Air Content	Limits on CM
F0	N/A	2500	N/A	N/A
F1	0.45	4500	Table 4.4.1	N/A
F2	0.45	4500	Table 4.4.1	N/A
F3	0.45	4500	Table 4.4.1	Table 4.4.2

ACI 318-08 Table 4.3.1.b – Exposure Category S

Class	Max. w/cm	Min. f_c' psi	Required Cementitious Materials- Types			Calcium Chloride Admixtures
			C 150	C 595	C 1157	
S0	N/A	2500	--	--	--	--
S1	0.50	4000	II	IP(MS) IS(<70)(MS)	MS	--
S2	0.45	4500	V	IP(HS) IS(<70)(HS)	HS	Not Permitted
S3	0.45	4500	V + Pozzolan or Slag	[IP(HS) or IS(<70)(HS)] + Pozzolan or Slag	HS + Pozzolan or Slag	Not Permitted

ACI 318-08 Table 4.3.1.c – Exposure Category P

Exposure Class	Max. w/cm	Min. f'_c psi	Additional Minimum Requirements
P0	N/A	2500	None
P1	0.50	4000	None

ACI 318-08 Table 4.3.1.d – Exposure Category C

Class	Max. w/cm	Min. f_c' psi	Max. Water-Soluble Chloride Ion (CL^-) Content in Concrete, % by Weight of Cement*		Related Provisions
			Reinforced	Prestressed	
C0	N/A	2500	1.00	0.06	None
C1	N/A	2500	0.30	0.06	None
C2	0.40	5000	0.15	0.06	7.7.6, 18.16#

* 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.

Requirements of 7.7.6 shall be satisfied. See 18.16 for unbonded tendons.

ACI 318-14 Chapter 19 Durability of Concrete

Permeability is a material property and not a durability exposure condition. Therefore, Category P is renamed Category W to represent concrete members in contact with water that require low permeability. There are no changes to the requirements.

P ⇨ W

The whole “Severity” column in former Table 4.2.1 is deleted.

ACI 318-19 19.3 Concrete Durability Requirements: Exposure to Water

Exposure Class W0 is split into W0 and W1, and the old W1 is renamed W2

ACI 318-14 Table 19.3.1.1

In contact with water (W)	W0	Concrete dry in service Concrete in contact with water and low permeability is not required
	W1	Concrete in contact with water and low permeability is required

Renamed W2

New W1

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ACI 318-19 19.3 Concrete Durability Requirements: Exposure to Water

Requirements for Exposure Category W are updated in Table 19.3.2.1

ACI 318-19 Table 19.3.2.1

Exposure Class	Maximum w/cm	Minimum f_c', psi	Additional requirements	Limits on cementitious materials
			Air content	
W0	N/A	2500	None	
W1	N/A	2500	26.4.2.2(d)	
~~W1~~ W2	0.50	4000	~~None~~ 26.4.2.2(d)	

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ACI 318-14 19.3 Concrete Durability Requirements: Exposure to Water

26.4.2.2(d) For concrete identified as being exposed to water in service, evidence shall be submitted that the concrete mixture complies with (1) and (2).

1) Aggregates are not alkali-silica reactive or measures to mitigate alkali-silica reactivity have been established.
2) Aggregates are not alkali-carbonate reactive.

19.3 Concrete Durability Requirements: Exposure to Sulfate

An Option 2 is added in the requirements for Exposure Class S3 in Table 19.3.2.1

- Maximum w/cm reduced to 0.40 from 0.45
- Minimum f_c' increased to 5000 psi from 4500 psi
- Allows use of Type V cements without pozzolans or slag cement
- Allows use of C595 HS and C1157 HS blended cements without additional pozzolans or slag cement

DURABILITY OF REINFORCEMENT
Concrete Cover

Concrete Protection for Reinforcement – ACI 318-71

7.14.1- The following minimum concrete cover shall be provided for reinforcing bars, prestressing tendons, or ducts. For bar bundles, … .

7.14.1.1 – Cast-in-place concrete (nonprestressed)

7.14.1.2 – Precast concrete (manufactured under plant control conditions)

7.14.1.3 – Prestressed concrete members – Prestressed and nonprestressed reinforcement, ducts, and end fittings

Concrete Protection for Reinforcement – ACI 318-71

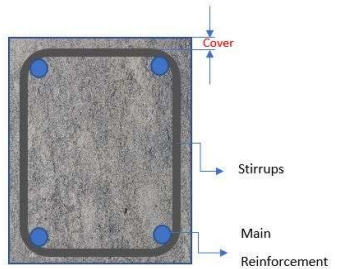
7.14.3 — In corrosive environments or other severe exposure conditions, the amount of concrete protection shall be suitably increased, and the denseness and nonporosity of the protecting concrete shall be considered, or other protection shall be provided.

7.14.4 — Exposed reinforcing bars, inserts, and plates intended for bonding with future extensions shall be protected from corrosion.

Concrete Protection for Reinforcement – ACI 318-95, -99

7.7.5.1 — For prestressed concrete members exposed to corrosive environments or other severe exposure conditions, and which are classified as Class T or C in 18.3.3, minimum cover to the prestressed reinforcement shall be increased 50 percent. This requirement shall be permitted to be waived if the precompressed tensile zone is not in tension under sustained loads.

Concrete Protection for Reinforcement – ACI 318-02



7.7 – Concrete protection for reinforcement

7.7.1 – Cast-in-place concrete (nonprestressed)

The following minimum concrete cover shall be provided for reinforcement, but shall not be less than required by 7.7.5 [Corrosive environments] and 7.7.7 [Fire protection]:

7.7.~~2~~3 – Precast concrete (manufactured under plant control conditions)

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Concrete Protection for Reinforcement – ACI 318-02

The following minimum concrete cover shall be provided for prestressed and nonprestressed reinforcement, ducts, and end fittings, but shall not be less than required by 7.7.5, 7.7.5.1, and 7.7.7:

7.7.~~3~~2 – Cast-in-place concrete (~~P~~prestressed) ~~concrete~~

The following minimum concrete cover shall be provided for prestressed and non prestressed reinforcement, ducts, and end fittings, but shall not be less than required by 7.7.5, 7.7.5.1, and 7.7.7:

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Concrete Protection for Reinforcement – ACI 318-08

Specified cover replaces ~~minimum~~ cover.

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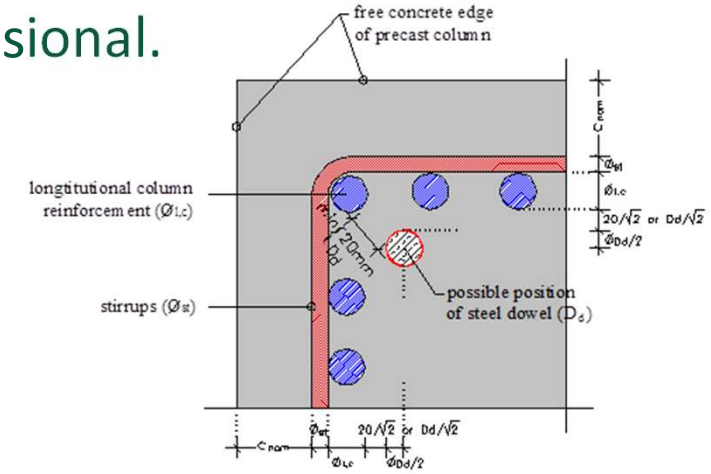
318-11 Chapter 7 – Details of Reinforcement

7.7.5 – Headed shear stud reinforcement

For headed shear stud reinforcement, specified concrete cover for the heads and base rails shall be at least that required for the reinforcement in the member.

318-11 Chapter 7 – Details of Reinforcement

7.7.6 — In this section on corrosive environments and other severe exposure, “amount of concrete protection shall be suitably increased” was changed to: “the concrete cover shall be increased as deemed necessary and specified by the licensed design professional.



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318-14 Chapter 20 – Steel Reinforcement Properties, Durability, and Embedments

20.6—Provisions for durability of steel reinforcement

20.6.1 *Specified concrete cover*

20.6.1.1 Unless the general building code requires a greater concrete cover for fire protection, the minimum specified concrete cover shall be in accordance with 20.6.1.2 through 20.6.1.4.

318-14 Durability of Steel Reinforcement

20.6.1.3 *Specified concrete cover requirements*

20.6.1.3.1 Nonprestressed cast-in-place concrete members shall have specified concrete cover for reinforcement at least that given in Table 20.6.1.3.1.

20.6.1.3.2 Cast-in-place prestressed concrete members shall have specified concrete cover for reinforcement, ducts, and end fittings at least that given in Table 20.6.1.3.2.

318-14 Durability of Steel Reinforcement

20.6.1.3 *Specified concrete cover requirements*

20.6.1.3.3 Precast nonprestressed or prestressed concrete members manufactured under plant conditions shall have specified concrete cover for reinforcement, ducts, and end fittings at least that given in Table 20.6.1.3.3.

20.6.1.3.5 For headed shear stud reinforcement, specified concrete cover for the heads and base rails shall be at least that required for the reinforcement in the member.

318-14 Durability of Steel Reinforcement

20.6.1.4 *Specified concrete cover requirements for corrosive environments*

20.6.1.4.1 In corrosive environments or other severe exposure conditions, the specified concrete cover shall be increased as deemed necessary. The applicable requirements for concrete based on exposure categories in 19.3 shall be satisfied, or other protection shall be provided.

318-14 Durability of Steel Reinforcement

20.6.1.4.2 For prestressed concrete members classified as Class T or C in 24.5.2 and exposed to corrosive environments or other severe exposure categories such as those given in 19.3, the specified concrete cover for prestressed reinforcement shall be at least one and one-half times the cover in 20.6.1.3.2 for cast-in-place members and in 20.6.1.3.3 for precast members.

20.6.1.4.3 If the precompressed tension zone is not in tension under sustained loads, 20.6.1.4.2 need not be satisfied.

318-14 Durability of Steel Reinforcement

20.6.2 *Nonprestressed coated reinforcement*

20.6.3 *Corrosion protection for unbonded prestressing Reinforcement*

20.6.4 *Corrosion protection for grouted tendons*

20.6.5 *Corrosion protection for post-tensioning anchorages, couplers, and end fittings*

20.6.6 *Corrosion protection for external post-tensioning*

318-19 Chapter 20 – Steel Reinforcement Properties, Durability, and Embedments

20.5—Provisions for durability of steel reinforcement

New! **20.5.1.3.4** Deep foundation members shall have specified concrete cover for reinforcement at least that given in Table 20.5.1.3.4.

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