The Impact of Performance Specifications in Concrete

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NRMCA

BUILD WITH STRENGTH

PAVE AHEAD
DURABLE. SUSTAINABLE. CONCRETE.

Specifications

Performance vs. Prescription What's the difference??

Prescriptive vs. Performance Design

Performance:

I want a chocolate cake

VS.

Prescriptive:

I want a chocolate cake with:

- Gold Medal All Purpose Flour
- Organic cocoa powder
- 3:1 flour-to-cocoa ratio
- 150g sugar

Prescriptive vs. Performance Design

Performance:

I want a 4000-psi concrete mix

VS.

Prescriptive:

I want a 4000-psi concrete mix with:

- C150 Cement
- 0.40 w/cm ratio
- Maximum 20% fly ash

Prescriptive Specifications

Types:

1. Durability and Code-based
   - ACI 318 Exposure Classes

2. Specific properties desired
   - Crack control
   - Finish quality
   - Mechanical properties
   - Plastic properties

Table 19.3.2.1—Requirements for concrete by exposure class (ACI 318-19)

Exposure Class		Max w/cm [1,2]	Min f'_c, psi	Additional Requirements: Air content			Limits on SCM
F0		N/A	2500	N/A			N/A
F1		0.55	3500	Table 19.3.1.1 (Table 19.3.3.3 for shotcrete)			N/A
F2		0.45	4500	Table 19.3.1.1 (Table 19.3.3.3 for shotcrete)			N/A
F3		0.40 [3]	5000 [3]	Table 19.3.1.1 (Table 19.3.3.3 for shotcrete)			26.4.2.2(b)
				Cementitious materials [3] - 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	Opt. 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 [6]	Not permitted
	Opt. 2	0.45	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 weight 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		None
C2		0.40	5000	0.15	0.06		Concrete cover [11]

Examples of Prescriptive Requirements

A. Cementitious Materials
   1. Cement: Cements shall conform to ASTM C150, Type I or Type II.

Fly ash shall be obtained from one source for the concrete delivered to the project. Complete chemical and physical analysis of the fly ash shall be submitted to the Architect prior to use. Concrete mixes proportioned with fly ash shall contain not less than 10% nor more than 20% by weight of cement to fly ash.

segregation or bleeding. The cementitious materials content of concrete shall be at least 675 pounds per cubic yard. Except that concrete to be placed by tremie the cementitious materials content shall be at least 725 pounds per cubic yard.

C. Suspended Slabs, Interior Slabs-on-Grade : Proportion normal-weight concrete mixture

   1. Minimum Compressive Strength: 4000 psi, at 28 days.
   2. Maximum Water-Cementitious Materials Ratio: 0.35 with Air, .44 No Air.

e. MAXIMUM WATER-CEMENT RATIO UNLESS NOTED OTHERWISE:

   I) INTERIOR SLABS = 0.40

   II) EXTERIOR SLABS = 0.50

   III) OTHER = 0.45

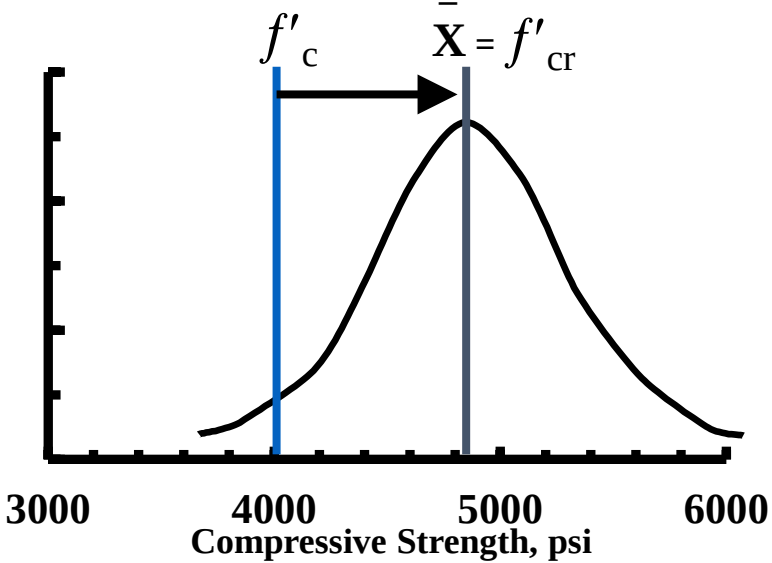
Common Prescriptive Requirements

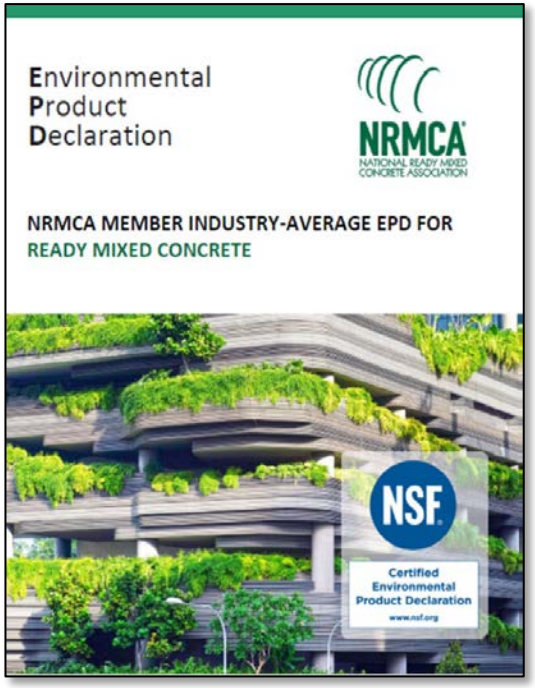
Prescriptive Requirement	Frequency Seen*	Sustainability	Performance	Cost
Restriction on SCM quantity	85%	↓	↔	↑
Max w/cm (when not applicable)	73%	↓	↔	↑
Minimum cementitious content	46%	↓	↕	↑
Restriction on SCM type, characteristics	27%	↓	↓	↑
Restriction on aggregate type or characteristics	25%	↓	↔	↑

* ACI survey

Concrete Strength and Embodied Carbon

Specified Strength ↑ Embodied Carbon ↑





Required Strength ↑ Embodied Carbon ↑

Strength ↑ 100 psi (0.7 MPa) GWP ↑ ~1.5 - 2.0%

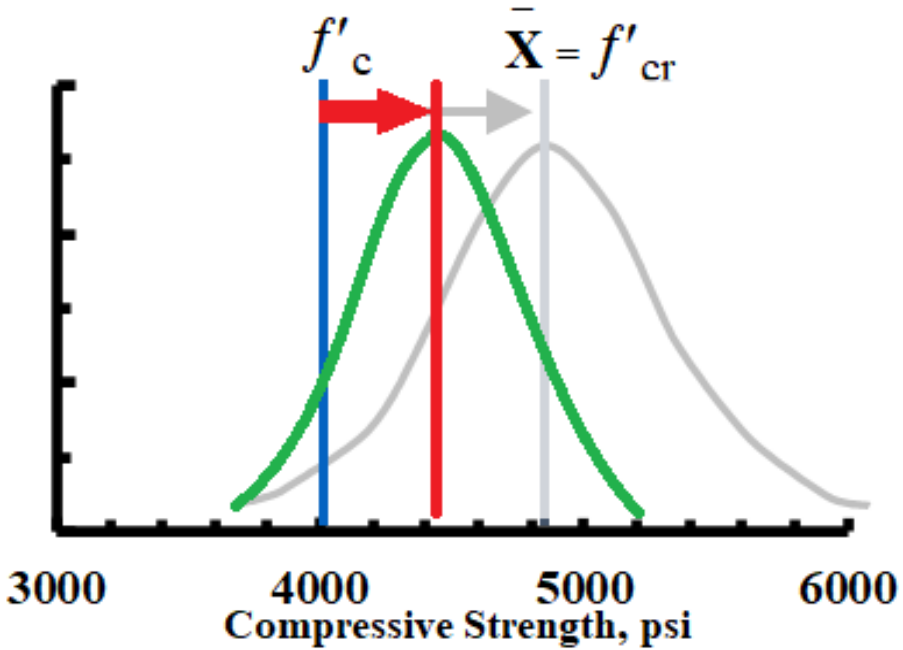
Impact of Prescriptive Specifications

Don't Limit Ingredients!

- ✗ Maximum w/cm ratio
- ✗ Minimum cement content
- ✗ Cementitious types
- ✗ Maximum SCM content

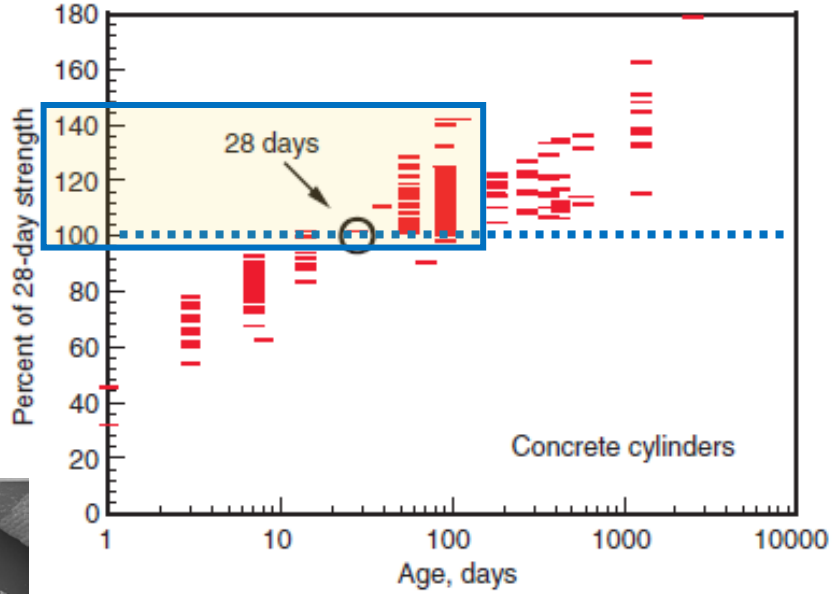
Instead...

- ✓ Exposure classification
- ✓ Broad raw material acceptance
- ✓ Alternative testing (shrinkage, etc.)
- ✓ Later age strengths



Important Performance Attributes

1. **Later Age Strength**
2. Strength and w/cm ratio
3. Permeability/Durability
4. Maximizing SCMs
5. Reducing Excessive Overdesign



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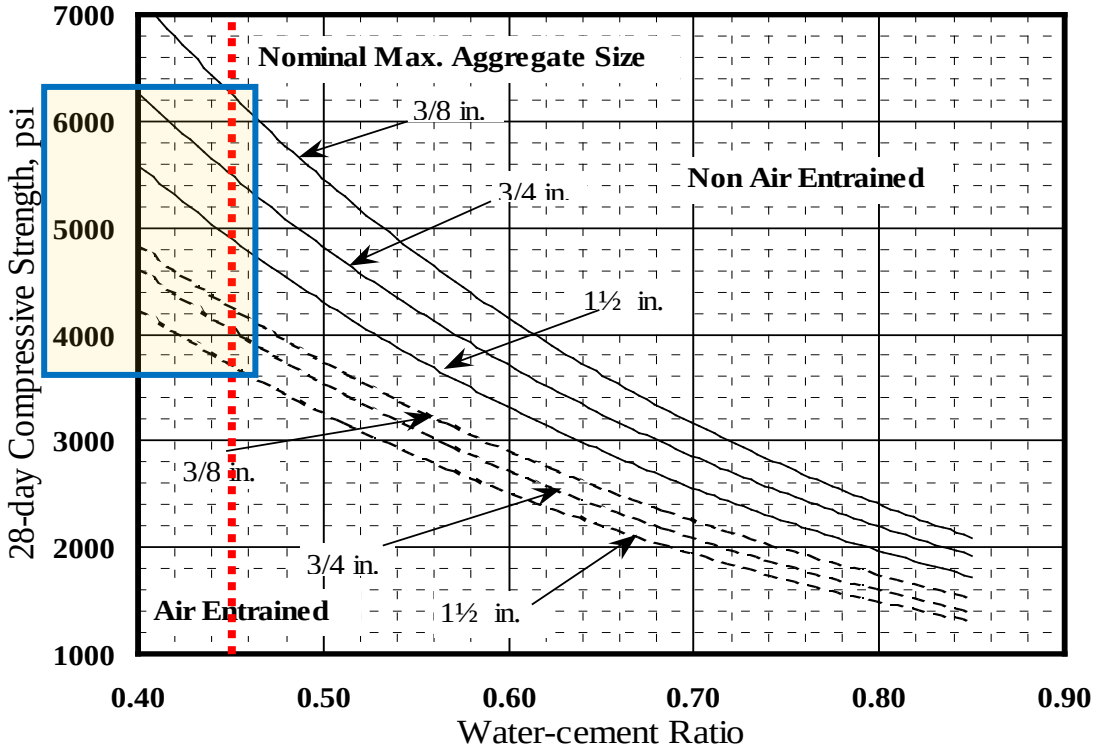

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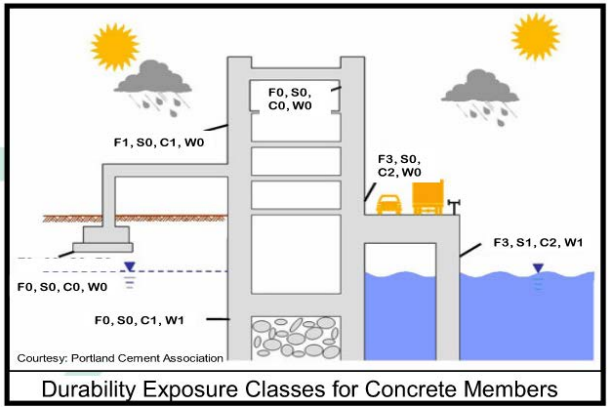
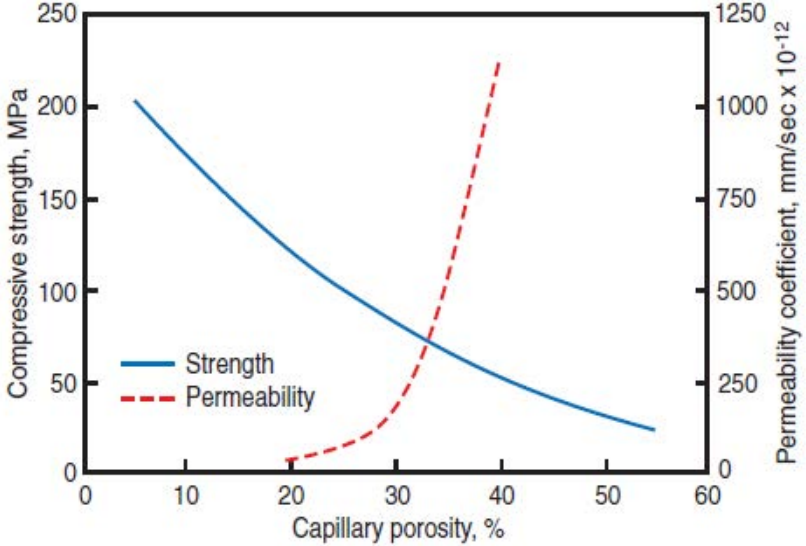


Durability Exposure Classes for Concrete Members



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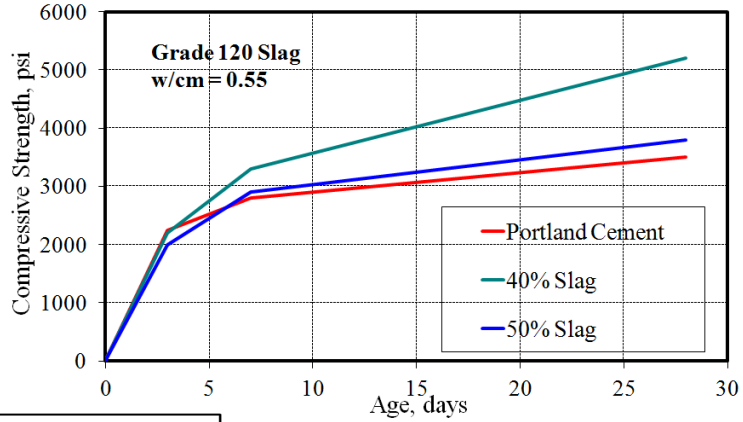

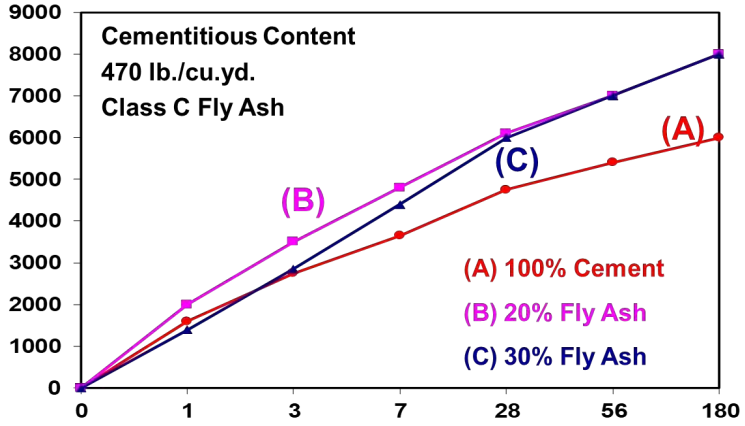

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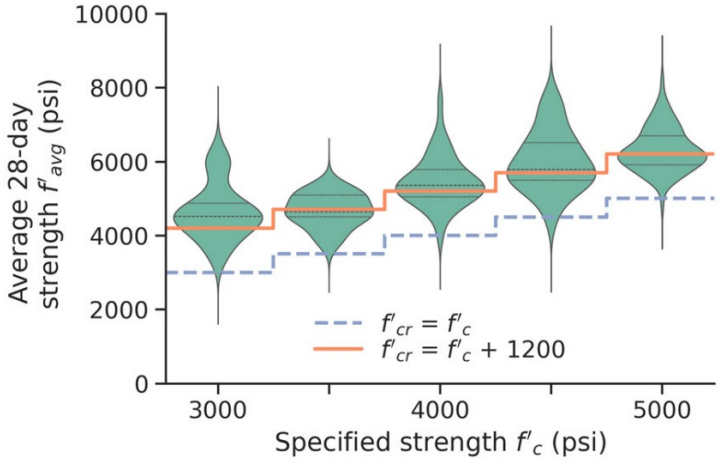

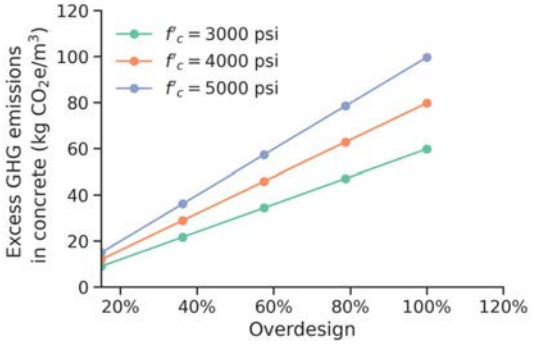

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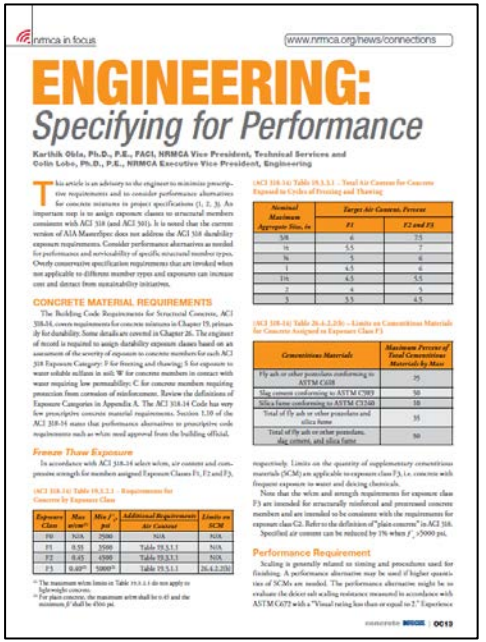
Performance Alternatives

Summary of Performance Alternatives

Durability Exposure Class/Property/MeNNumber	*Prescriptive Requirement*	*Performance Alternative*
F3	SCM limits (ACI 318)	ASTM C672 Visual rating less than or equal to 2. Note that this test is not very repeatable or necessarily representative of field performance.
S1, S2, S3	Cementitious types	ASTM C1012 expansion criteria (ACI 318-14 Table 26.4.2.2(c)
W1, C2	w/cm (ACI 318)	ASTM C1202 less than: 2500 coulombs (for W1) 1000 coulombs (for C2)
Alkali Silica Reaction	Low alkali cement, SCM types and dosages, alkali content of concrete	ASTM C1567 using combination of cementitious materials used in the project – length change less than 0.10% at 16 days
Shrinkage (W1, C2, Concrete Floors)	w/cm	ASTM C157 (7 days lime water curing and dried for 28 days – length change less than 0.05%
Concrete Floors	w/cm, SCM limits, cement content, paste volume, aggregate grading/shape	Shrinkage – see above ASTM C403 initial setting time (contractor requirement) Test slab placement to ensure desired workability, finishability



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ENGINEERING:

Specifying for Performance

Kurthik Obla, Ph.D., P.E., FACI, NRMCA Vice President, Technical Services and Colin Lobo, Ph.D., P.E., NRMCA Executive Vice President, Engineering

This article is an advisory to the engineer to minimize prescriptive requirements and to consider performance alternatives for concrete mixtures in project specifications (1, 2, 3). An important step is to assign exposure classes to structural members consistent with ACI 318 (and ACI 301). It is noted that the current version of AIA MasterSpec does not address the ACI 318 durability exposure requirements. Consider performance alternatives as needed for performance and serviceability of specific structural member types. Overly conservative specification requirements that are invoked when not applicable to different member types and exposures can increase cost and detract from sustainability initiatives.

CONCRETE MATERIAL REQUIREMENTS

The Building Code Requirements for Structural Concrete, ACI 318-14, covers requirements for concrete mixtures in Chapter 19, primarily for durability. Some details are covered in Chapter 26. The engineer of record is required to assign durability exposure classes based on an assessment of the severity of exposure to concrete members for each ACI 318 Exposure Category: F for freezing and thawing; S for exposure to water soluble sulfates in soil; W for concrete members in contact with water requiring low permeability; C for concrete members requiring protection from corrosion of reinforcement. Review the definitions of Exposure Categories in Appendix A. The ACI 318-14 Code has very few prescriptive concrete material requirements. Section 1.10 of the ACI 318-14 states that performance alternatives to prescriptive code requirements such as when need approval from the building official.

Freeze Thaw Exposure

In accordance with ACI 318-14 select w/cm, air content and compressive strength for members assigned Exposure Classes F1, F2 and F3.

(ACI 318-14) Table 19.3.2.1 – Requirements for Concrete by Exposure Class

Exposure Class	Max w/cm[a]	Min f'_c, psi	Additional Requirements for Air Content	Limits on SCM
F0	N/A	2500	N/A	N/A
F1	0.55	3500	Table 19.3.3.1	N/A
F2	0.45	4500	Table 19.3.3.1	N/A
F3	0.40[b]	5000[b]	Table 19.3.3.1	26.4.2.2(b)

[a] The maximum w/cm limits in Table 19.3.1.1 do not apply to lightweight concrete.

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

(ACI 318-14) 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	7.5
½	5.5	7
¾	5	6
1	4.5	6
1½	4.5	5.5
2	4	5
3	3.5	4.5

(ACI 318-14) Table 26.4.2.2(b) – Limits on Cementitious Materials for Concrete Assigned to Exposure Class F3

Cementitious Materials	Maximum Percent of Total Cementitious Materials by Mass
Fly ash or other 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 other pozzolans and silica fume	35
Total of fly ash or other pozzolans, slag cement, and silica fume	50

respectively. Limits on the quantity of supplementary cementitious materials (SCM) are applicable to exposure class F3, i.e. concrete with frequent exposure to water and deicing chemicals.

Note that the w/cm and strength requirements for exposure class F3 are intended for structurally reinforced and prestressed concrete members and are intended to be consistent with the requirements for exposure class C2. Refer to the definition of "plain concrete" in ACI 318.

Specified air content can be reduced by 1% when $f'_c \geq 5000$ psi.

Performance Requirement

Scaling is generally related to timing and procedures used for finishing. A performance alternative may be used if higher quantities of SCMs are needed. The performance alternative might be to evaluate the deicer salt scaling resistance measured in accordance with ASTM C672 with a "Visual rating less than or equal to 2." Experience

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Spec Review: Performance Based Improvements

Consider explicitly communicating 56 day strength option when applicable or even leaving the age figure off. Note 'I' is somewhat vague and you'll most likely still get 28 day concrete based on the fact that 28 days is listed in the heading. Can possibly extend age for footings, walls, columns, SOG, topping, etc. Will dramatically improve sustainability.

Remove w/cm requirement to dramatically improve sustainability

Add shrinkage to remove w/cm requirement? (i.e., 0.045% or 0.050%, etc.)

c. NO CALCIUM CHLORIDE IS PERMITTED IN ANY FORM IN THE CONCRE

d. SUPER PLASTICIZERS AND WATER REDUCERS ARE ALLOWED BUT M

e. MAXIMUM WATER-CEMENT RATIO UNLESS NOTED OTHERWISE:

I) INTERIOR SLABS = 0.40

II) EXTERIOR SLABS = 0.50

III) OTHER = 0.45

f. SLUMPS LISTED ARE BEFORE THE ADDITION OF SUPER PLASTICIZEF THE TRUCK, OR IF PUMPED, SLUMP SHALL BE MEASURED AT THE EN

g. CONCRETE CONTRACTOR SHALL BE RESPONSIBLE FOR THE SLUMP SECTION AND THE SPECIFICATIONS.

h. MINIMUM CONCRETE PURPOSES INCLUDED BELOW ARE THOSE REC BY THE CONTRACTOR TO DEFINE CONSTRUCTION REQUIREMENTS. OR OTHER), WORKABILITY, PUMPABILITY, AND FINISHABILITY.

ELEMENT	MIN 28-DAY STRENGTH (PSI)	MAX AGGREGA SIZE
MISC EXTERIOR CONRETE	3000	1"
FOOTINGS	4000	1"
WALLS (INTERIOR)	5000	3/4"
COLUMNS (INTERIOR)	5000	3/4"
SUSPENDED SLABS/BEAMS	5000	3/4"
SLAB ON GRADE	4000	1"
EXTERIOR SLABS	4500	1"
EXTERIOR CONCRETE (OTHER)	4500	3/4"
TOPPING SLAB (INTERIOR)	4500	3/8"

I) DATES OF ACCEPTANCE WILL BE DETERMINED BASED ON CONTRA FINAL PROJECT ACCEPTANCE CRITERIA, TRIAL BATCHES SHALL REF CONCRETE STRENGTHS.

5. MIX DESIGN DOCUMENTATION SHALL BE SUBMITTED, PER ACI 318, TO TH PROPOSED MATERIALS AND CONCRETE MIX DESIGN SHALL BE FULLY DO

B. Cementitious Materials:

1. Portland Cement: ASTM C 150/C 150M, Type II/V, gray.
2. Fly Ash: ASTM C 618, Class F.

Expand cementitious materials to include:
Blended Cements ASTM C595
Slag Cement ASTM 989

B. Cementitious Materials:

1. Portland Cement: ASTM C150 ~~Type II~~
2. Blended hydraulic cement: ASTM C595
3. Hydraulic cement: ASTM C1157
4. Fly ash or natural pozzolan: ASTM C618/C618M
5. Slag cement: ASTM C989/C989M
6. Silica Fume: ASTM C1240/C1240M
7. Ground Glass Pozzolan: ASTM C1866/C1866M

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Added to broaden the acceptance of industry standardized materials.

2. Aggregate: Coarse aggregate size number in accordance with ASTM C33 for normal-weight aggregate. Coarse aggregate size in inches for lightweight aggregates.
3. Slump: Slump tolerance should follow the requirements of ASTM C94, Table A1.1.
4. Other Requirements (apply only as noted in Schedule of Concrete Mixes):
   a. Cementitious material shall contain ~~a minimum 20-35 percent fly ash.~~
   b. Shrinkage Controlled Concrete: Use special coarse aggregates specified. Select materials and proportion mix to minimize drying shrinkage.
   c. Water Cement Ratio: Mix shall have a water to cementitious material ratio by weight not exceeding 0.40 for slab-on-grade and 0.45 for walls when specified in schedule.

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Consider removing item as previously set sustainability goals will encourage SCM usage. SCM strategies and capabilities will vary by producer, region and project/site conditions.

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When shrinkage limits are needed, list design limit and allow producer to proportion mix accordingly to achieve. Typical low shrink ranges: 0.050%, 0.045%, 0.040%, and 0.035%

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Limit should only be prescribed when required by exposure class of concrete as dictated in ACI 318 Table 19.3.1.1 (conditions) and Table 19.3.2.1 (requirements). 0.40 w/cm ratio is only required for extreme chloride exposure and freeze thaw exposure. Unnecessarily requiring a low w/cm will negatively impact sustainability.

CONCRETE

1. All concrete shall have a minimum ultimate compressive strength (f'_c) as outlined below at 28 days. All concrete shall be regular weight (unless specifically noted otherwise).
   A. Concrete for caissons, footings, and slab on grade: 3,000 psi w/c = 0.50 max.

Only for ACI 318 S1 exposure

2. Maximum Fly Ash content shall be 15%, by weight, of total cementitious materials and shall conform to ASTM C618.

Do not limit SCM content. Only code-based SCM limit is for ACI 318 F3 exposure

3. All concrete work shall comply with CBC Chapter 19A and ACI 318-14 and latest edition of ACI Manual of Concrete Practice.
4. Special Inspection (as required or specified) shall conform to CBC Chapter 17A.
5. Cement shall be Portland Cement Type II/V and shall conform to ASTM C150.

Add acceptance of ASTM C595 blended cements

Performance-Focused Mix Table

Application	Strength (psi)	Exposure Classes	Maximum w/cm	Max. Aggregate Size (in)	Suggested GWP Target ($kg/CO^2e/yd$)	Notes
Footings, Grade Beams	4000 @ 56 days	S2	0.45	1-1/2		1
Foundation Walls	5000 @ 56 days	S2	0.45	1		1
Shear Walls, Columns	6000 @ 56 days			1		
Slabs-on-grade	4000 @ 28 days			1-1/2		3
Elevated Post-Tensioned Slabs	3000 @ 4 days 5000 @ 28 days					3
All other uses	4000			3/4		
REQUIRED Weighted Average GWP ($kg/CO^2e/yd$)					XXX	4

A. Notes:

1. S2 exposure classification requires the use of sulfate resistant cement, C150 Type II/V or C595/C1157 with HS designation.
2. C2 exposure classification requirement of 0.40 w/cm can be overridden with rapid chloride permeability values less than 1000 coulombs as tested per ASTM C1202.
3. ASTM C157 shrinkage requirement of 0.050% after 7 days of moist curing followed by 21 days of air drying.
4. Required weighted average GWP is taken across all concrete mix classes and their individual volumes, allowing suggested GWP to be exceeded for certain applications as long as overall GWP is achieved.

Performance Based Improvements

Goal:

Prescription → Performance

Methods:

- Emphasize ACI 318 Exposure Classes
- Alt testing for durability/design
  - ✓ Shrinkage, MOE, RCP, ASR
- Expand acceptable materials
- Extended strength development

Results:

- Efficient and Optimized Mix Designs
- Optimal cost and performance

The Impact of Prescriptive Specs

[redacted]

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CONCRETE

Concrete strength: 3000 psi @ 28 days (Designed for 2500 psi)

Minimum cement content: 5.7 sacks per yard

Maximum water-cement ratio: 0.43 - max water to cement ratio

Concrete materials:

a) Cement: Portland Type II, ASTM C150.

Designed:

- 2500 psi
- Estimated GWP: 135 kg/CO2e/yd

Prescriptive additions:

- +500 psi
- 5.7 sacks cement per yard
- 0.43 w/cm
- C150 Type II/V only

Installed:

- 5000 psi
- Estimated GWP: 358 kg/CO2e/yd

+200% Overdesign **+265% Carbon** **+++ Cost**

Post-Mortem Quote: “Concrete is expensive and high carbon!”

The Value of Performance Specs

Example:

Prescriptive Mixes:

Mix	Application	Strength	Prescription	$GWP_{Benchmark}$	$GWP_{Supplied}$	Delta
1	Foundations	5000 psi @ 28 days	0.40 w/cm, 30% max SCM	289	293	+ 1.4%
2	Slabs	4000 psi @ 28 days	0.45 w/cm, 611 lbs cementitious, 20% max SCM	247	307	+ 24.3%
3	Columns/Walls	6000 psi @ 28 days	0.45 w/cm, C150 Cement, 30% max SCM	306	293	- 4.2%

Performance Focused Mixes:

Mix	Application	Strength	Prescription	$GWP_{Benchmark}$	$GWP_{Supplied}$	Delta
1	Foundations	5000 psi @ 56 days	Exposure S2 (0.45 w/cm)	289	166	- 42.6%
2	Slabs	4000 psi @ 28 days	Max Shrinkage 0.045%	247	206	- 16.6%
3	Columns/Walls	6000 psi @ 56 days	None	306	220	- 28.1%

Discussion

How does your firm manage project specifications? How are they reviewed and updated?

What checks and balances can be implemented to ensure efficient and constructible specifications?

How can you achieve low carbon concrete without prescriptively impacting mix designs? (i.e., must use xx% SCM)

In what ways can risk be mitigated and alignment with code be ensured?

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