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Overview

- Types of Specifications
- Evolving to Performance Specifications
- Impact of Specifications on Sustainability
- ACI 329

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A/E Designs the Structure

Project Contract Documents

Establish Owner's Requirements
- **Resist Loads**
- **Serviceable**
- **Durable**
- **Aesthetics**
- **Service Life**
- **Sustainability**

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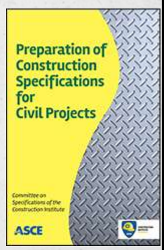
Types of Specifications

- Prescription Specification
  - Recipe for completing project
  - End result intended… not precisely defined
  - Contractor cannot be faulted if result is not achieved!
- Performance Specification
  - Describes end result desired … not how…
  - Must be clearly defined…
  - Contractor can develop methods to achieve result…
  - Needs straightforward testing and inspection…
- Hybrid
  - includes both – more common



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Performance for Concrete Mixtures

P2P INITIATIVE

- Performance of concrete materials are based on performance indicators measured by standard test methods with defined acceptance criteria stated in contract documents and with no restrictions on the parameters of concrete mixture proportions
- Performance/Service Life and Sustainability
  - Design
  - Specification
  - Concrete Mixtures
  - Construction

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Prescriptive Specifications

2.1.2 Water-Cement Ratio

Maximum water-cement ratio (w/c) for concrete shall be 0.40 by weight, for all work.

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. Fly Ash: Fly Ash shall have a high fineness and low carbon content and shall exceed the requirements of ASTM-C-618, "Specification for Fly Ash and Raw or Calcined Natural for Use in Portland Cement Concretes" for Class F, except that the loss of ignition shall be less than 3% and all fly ash shall be a classified processed material. 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.

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Goal: Performance Requirements

- Define Functional Requirements for Concrete
  - Strength, Stiffness
  - "Permeability"
  - Volume change
  - Durability required specific to exposure
- Avoid limitations on mixture
- Tests for:
  - Pre-qualification
  - Jobsite Acceptance
- Clear, achievable, measurable, enforceable
- Avoid means and methods
- Define end result of construction
  - Mockup
  - Surface finish…

~~*"I'll know it when I see it."*~~

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Most Common Prescriptive Requirements

Prescriptive Requirement	Frequency Seen
Maximum quantity of SCMs	85%
Max w/cm (when not applicable)	73%
Minimum cementitious content	46%
Restriction on SCM type, characteristics	27%
Restriction on aggregate grading	25%

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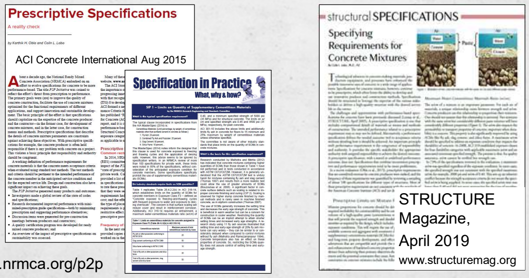
Resources



ACI Concrete International Aug 2015

www.nrmca.org/p2p

STRUCTURE Magazine, April 2019
www.structuremag.org

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Evolving to a Performance Specification

- Eliminate or Minimize prescription
  - Minimum Cementitious Materials content
  - Maximum limits on SCM quantity
  - Max w/cm limits not consistent with industry standards
  - Restrictions that impact constructability
- Assess Exposure Conditions (ACI 318)
  - Specify applicable requirements for durability
  - Do not specify w/cm when not required
- Consider performance-based requirements for some member types

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ACI 318-19 – Durability Requirements

Chapter 19

19.3.1.1

> **19.3.1 *Exposure categories and classes***
>
> **19.3.1.1** The licensed design professional shall assign exposure classes in accordance with the severity of the anticipated exposure of members for each exposure category in Table 19.3.1.1.

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

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Exposure Categories Durability (ACI 318)

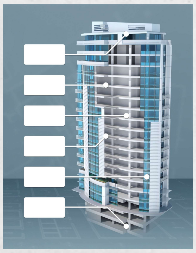

Table 19.3.2.1—Requirements for concrete by exposure class

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)
[redacted]				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
[redacted]							
W0		N/A	2500	None			
W1		N/A	2500	26.4.2.2(d)			
W2		0.50	4000	26.4.2.2(d)			
[redacted]				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]	

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Requirements for Concrete (partial)

Concrete Mixtures				
Members	Exposure	f'_c load/dur	w/cm	NMSA
Pool and deck	F2, S0, W1, 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	F3, S0, W0, C2	4,000 / 5,000	0.40	¾-in.
Exterior walls	F1, S0, W0, C1	3,500 / 3,500	0.55	1-in.
Foundation	F0, S1, W0, C1	3,000 / 4,000	0.50	1-in.
Parking Slabs	F0, S1, W0, C2	3,000 / 5,000	0.40	¾-in.

- Specify Exposure Class (ACI 318)
- Can test age >28 days?
- Performance criteria (permeability, shrinkage, etc.)

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Evolution to Performance

- Identify Exposure Classes

Member	Mix ID	Durability Exposure				Specified Strength, f'_c, psi	Max w/cm or Performance Alternative	Nom. max Aggregate, in.	Air Content	Slump/ Slump Flow	Chloride Limit	Temp. Limits
		F	S	W	C							
Footings												
Foundation Walls												
Slabs-on-grade												
Exterior slabs												
Suspended slabs (interior)												
Suspended slabs (exterior)												
Frame members												
Columns (interior)												
Columns (exterior)												
Walls (interior)												
Concrete toppings												

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Evolution to Performance

- Performance requirements as applicable

Member	RCP, C1202	Shrinkage, C157	Freeze Thaw		ASR	MOE, C469	Thermal Control Plan	Density	Other
			C666	C457					
Footings					X				
Foundations					X		X		
Slabs on Grade		X			X				
Exterior Slabs	X		X						
Interior Slabs		X						X (LW)	
Frame Members						X			
Interior Columns						X			
Exterior Columns									
Interior Walls									
Exterior Walls					X				
Slab Toppings					X				

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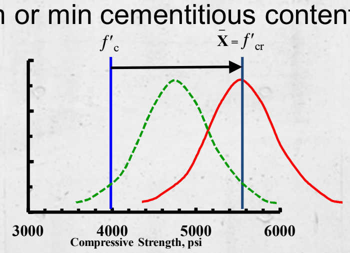
Impact of Prescriptive Specifications

Max w/cm or min cementitious content



1MPa = 145 psi

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Are we Significantly Over-designed?

- Typical “overdesign” ~15%> f'_c

w/cm	f'_c	Non Air	Air-Ent
0.40	5000	37%	23%
0.45	4500	34%	21%
0.50	4000	30%	18%
0.55	3500	29%	14%
		33%	**19%**

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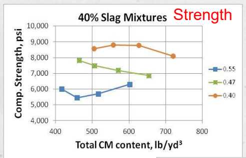
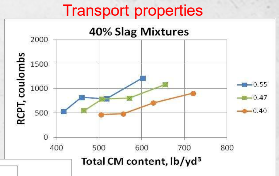
Optimizing Mixtures

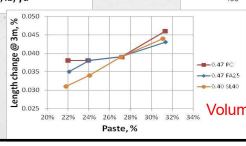
Strength



Transport properties



Strength/Workability
Higher Cementitious



Durability / Cracking
Lower Cementitious

Volume Change

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Specifications & Concrete Mixtures

- Quality of paste
  - Supplementary cementitious materials
  - Admixtures
- Quantity of paste - minimize
  - Cementitious materials
  - Control of water
  - Aggregate grading
- Improved Quality Control
- Specific durability issues
- Constructability

Strength
Permeability

Shrinkage
Thermal effects
Permeability

The specification should not restrict achieving these goals

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Specifications and Sustainability

- Sustainability criteria should have minimum impact on performance or service life of concrete
- Specifications should not restrict concrete from being sustainable

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Influence of Design Decisions

- Owner Objective
- Aesthetics
- Structural efficiency
- Energy efficiency
- Resilience
- Cost
- Others?

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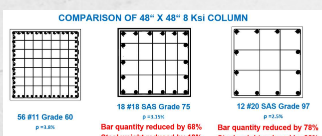
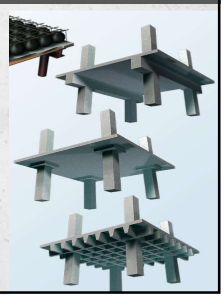
Influence of Design on Embodied Carbon

- Choice of structural system / grid
- Bay size variations
- Section dimensions
  - Concrete strength
  - Rebar Grade





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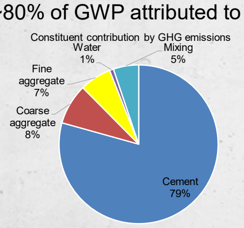
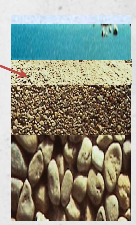
Sustainbility – Concrete Mixtures

- Embodied Carbon (GWP) related to design (specified) strength
- ~80% of GWP attributed to cement





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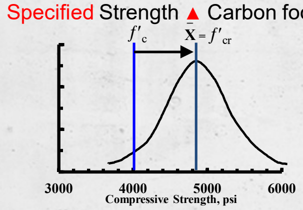
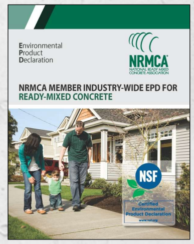
Concrete Strength and Embodied Carbon

Specified Strength ▲ Carbon footprint ▲





Average Strength ▲ Carbon footprint ▲

Strength ▲ 100 psi (0.7 MPa) GWP ▲ 1.5%

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Factors Impacting Strength / GWP

Increases Strength

- Prescriptive requirements
- Early age strength
- Quality control
  - standard deviation
- Quality Assurance
  - acceptance testing

Decrease GWP for strength

- Paste volume
- Use of SCMs
- Delaying strength age
- Optimizing design
- Use anticipated strength to advantage

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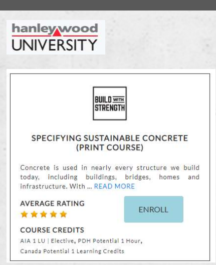
Impact of Prescription



Ref: Lemay, Lobo, Obla, Hanley Wood University, 2019

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Impact of Prescription

Specification Provision	Impact of provision		
	Sustainability	Performance	Cost
Restrictions on characteristics of aggregates	↓	↔	↑
Invoking a minimum content for cementitious materials	↓	↕	↑
Prescriptive requirements toward green building credit	↑	↕	↕
Restriction on SCM characteristics	↓	↓	↑
Restriction on quantity of SCM	↓	↓	↑

Ref: Lemay, Lobo, Obla, Hanley Wood University, 2019

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Impact of Prescription

Table 1. Impact of Prescriptive Specification on Sustainability, Performance and Cost

Specification Provision	Impact		
	Sustainability	Performance	Cost
1. Restrictions on type and source of cement	↓	↕	↑
2. Not permitting cements conforming to ASTM C1157 and ASTM C595	↓	↔	↔
3. Restriction on cement alkali content	↓	↔	↑
4. Restriction on type and source of aggregates	↓	↔	↑
5. Restrictions on characteristics of aggregates	↓	↔	↑
6. Minimum content for cementitious materials	↓	↕	↑
7. Restriction on quantity of SCM	↓	↓	↑
8. Restriction on type and characteristics of SCM	↓	↓	↑
9. Restriction on type or brands of admixtures	↔	↓	↑
10. Same class of concrete for all members in a structure	↓	↔	↑
11. Requiring higher strength than required for design	↓	↔	↑
12. Invoking maximum w/cm when not applicable or one that is not compatible with the design/specified strength.	↓	↔	↑
13. Requiring a high air content or requiring air content for concrete not exposed to freezing and thawing	↓	↓	↑
14. Restricting the use of a test records for submittals	↓	↓	↑
15. Restriction on changing proportions when needed to accommodate material variations and ambient conditions	↓	↓	↑
16. Requirement to use potable water	↓	↕	↑
17. Not permitting recycled aggregates and materials	↓	↕	↕
18. Not requiring accredited testing labs	↓	↔	↑
19. Specific limitations on slump	↓	↓	↕

7. Quantity of SCM: Some specifications place limits on the quantity of SCMs. Often, the use of more than one type of SCM is prohibited. This prevents optimizing concrete mixtures for performance and durability. The only building code restriction is for exterior concrete subject to application of deicing chemicals. Maximum limits on the quantity of SCM increases cost and does not support sustainable development. Increasingly, projects seeking green certification impose prescriptive requirements on concrete mixtures such as minimum replacement for cement or minimum recycled content. These requirements can often impact the performance of fresh and hardened concrete properties, such as setting characteristics, ability to place and finish and rate of development of in-place properties. In the long run, this may impact the quality of construction or the service life of the structure. The implication to initial cost may be reduced, but it could cost more in the long term. Alternatives to limiting quantities of SCM to lower environmental impact are discussed later.

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Factors Impacting Embodied Carbon

- Typically higher
  - Early strength – PT, formwork removal
  - Self-consolidating concrete
  - Workability for Placement
  - Slabs – finishing
- Can be lower
  - Later age strength
  - Mass concrete
  - Performance-based – shrinkage, permeability, modulus…

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Specifications for Sustainability

- Avoid GWP limits for each mixture
- Establish carbon budget for all concrete
  - Percent reduction from benchmark OR Max GWP for all concrete

Member	Mix ID	Durability Exposure				Specified Strength, f'_c, psi	Max w/cm or Performance Alternative	Nom. max Aggregate, in.	Air Content	Slump/ Slump Flow	Chloride Limit	Temp. Limits	Max. GWP (kg/yd3 CO_2e)
		F	S	W	C								
Footings													250
Foundation Walls													250
Slabs-on-grade													250
Exterior slabs													[illegible]
Suspended slabs (interior)													[illegible]
Suspended slabs (exterior)													[illegible]
Frame members													300
Columns (interior)													300
Columns (exterior)													300
Walls (interior)													250
Concrete toppings													250

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Establishing a Carbon Budget

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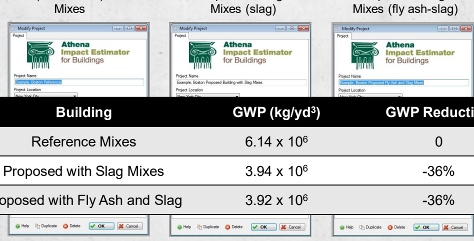
Defining Reference and Proposed Buildings in Athena IE

Reference (benchmark) Mixes

Option 1: Proposed Design Mixes (slag)

Option 2: Proposed Design Mixes (fly ash-slag)



Building	GWP (kg/yd³)	GWP Reduction
Reference Mixes	6.14×10^6	0
Proposed with Slag Mixes	3.94×10^6	-36%
Proposed with Fly Ash and Slag	3.92×10^6	-36%

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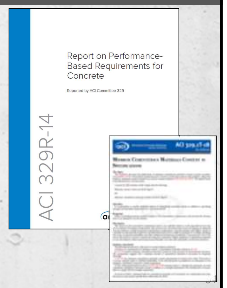
ACI Committee 329

- Guide to writing a performance specification
  - Basis – Section 033000
  - Specification language
  - Performance alternatives
  - Advisory info (commentary)
  - Brief info on test methods



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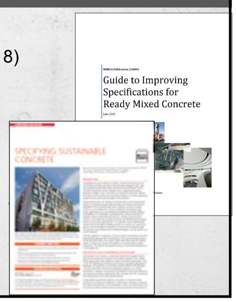
Summary

- Evaluate specification for prescriptive limits
- Assign exposure classes for durability (ACI 318)
- Consider performance-based alternatives
- Use anticipated performance to advantage in design
- Projects with sustainability goal
  - Establish carbon budget for entire project

www.nrmca.org/p2p
www.nrmca.org/sustainability



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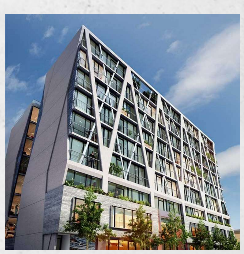
Case Study: Rowan, San Francisco

- Zigzagging concrete exoskeleton
- Stands out from other buildings
- Negates the need for interior columns
- Maximizing the interior space for residents
- Concrete on the project used high volumes of slag cement and fly ash to reduce environmental footprint



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Case Study: 1 World Trade Center, NYC

Pumping and construction

Slump flow	25 in.
Design Strength	16,000 psi
MOE	7.5 M psi

Cement	300
Fly ash	65
Slag	483
Silica fume	25
w/cm	0.25

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Case Study: I35W Bridge, MN

ACI Concrete International, Feb 2009

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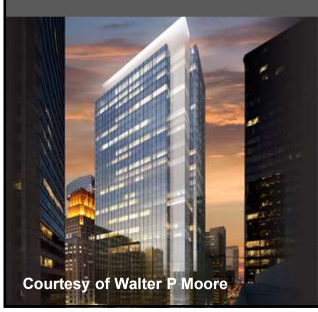
Case Study: Bank of America Tower, Houston



- 35-stories
- 750,000 ft^2
- Concrete Frame
- LEED EPD and LCA Credit
- High Volume SCM Mixes
- 19% Reduction in CO_2

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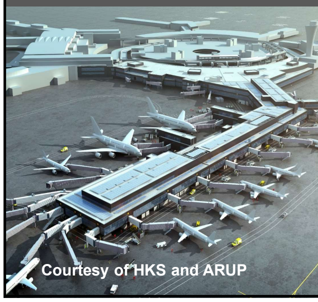
Case Study: San Francisco Airport Expansion



- $2.4 million expansion
- Concrete and Steel Frame
- LEED EPD and LCA Credit
- High Volume SCM Mixes
- 20% Reduction in CO_2

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