The Synergy: Performance-based Specifications and Sustainability

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MCC, December 2019

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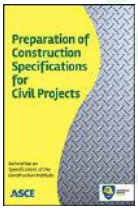
Prescription vs. Performance

- 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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Definition

P2P INITIATIVE

Performance for concrete mixtures?

- 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
- Responsibility with assigned authority
  - Each party is responsible for own work
- Performance and Sustainability
  - Impacted by design / specification / construction

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Design translated to Concrete Requirements – May be Prescriptive - Mixture

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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Design translated to Concrete Requirements – May be Prescriptive - Construction

5.3.4.2(b) *Float finish*—Place, consolidate, strike off, and level concrete; cut high spots; and fill low spots. Do not perform further finishing operations until concrete is ready for floating. Begin floating with hand float, bladed power float equipped with float shoes, or powered disk float when bleed water sheen has disappeared and surface has stiffened sufficiently to permit operation of the specific float apparatus. Unless otherwise specified, produce a finish that will meet tolerance requirements of ACI 117 for a conventional surface.

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Design translated to Concrete Requirements – May be Performance

- Concrete Mixture
  - Strength
  - Stiffness
  - "Permeability" or transport properties
  - Volume change – potential for cracking
  - Durability required specific to exposure
- Define end result of construction
  - Mockup
  - Surface finish…

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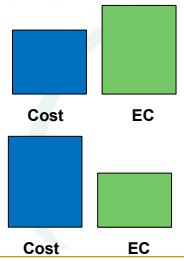
Challenge to Concrete Producer

- Comply with Specification
  - Prescriptive
  - Performance
- Cost
- Embodied Carbon
  - Disclose
  - Compete



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Focus on Embodied Carbon

	Cement limits for use with any compliance method 19.07.050.1 thru 19.07.050.4	GWP limits for use with any compliance method 19.07.050.1 thru 19.07.050.4
Minimum specified compressive strength f'_c, psi (5, 7)	Maximum ordinary Portland cement content , lbs/yd³ (1, 2, 4)	Maximum Global Warming Potential, GWP, kg CO_2e /m³
up to 2500 (3,4)	362	260
3000	410	289
4000	456	313
5000	503	338
6000	531	356
7000	594	394
7001 and higher	657	433
up to 3000 light weight	512	578
4000 light weight	571	626
5000 light weight	629	675

- Cement limits for project - offsets

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Strike a balance

- Sustainability initiatives should have minimum impact on performance/service life of concrete

- Specifications for concrete should not restrict concrete from being more sustainable

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Specifications and Sustainability

Recognize the synergy

- Concrete optimized for performance

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- Minimize Environmental Impact (CO_2)
- Conserve Available Resources
- Minimize Waste
- Increase Use of Recycled Content
- Minimize Energy in Use Phase

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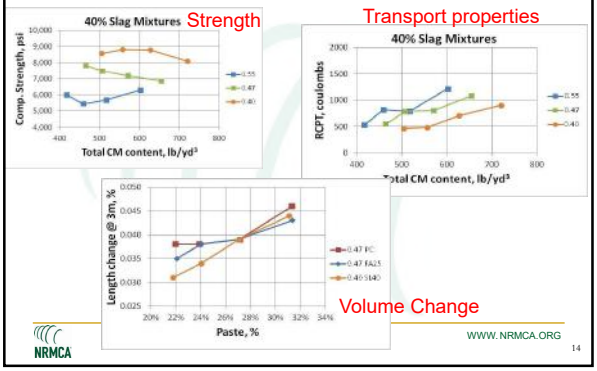
Optimizing Mixtures



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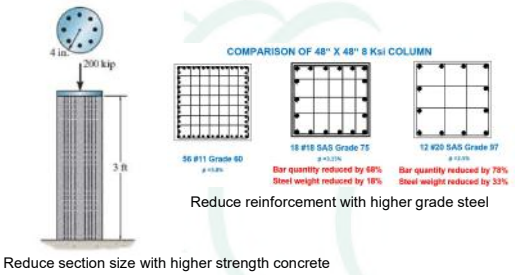
Impacted by Design



Reduce reinforcement with higher grade steel

Reduce section size with higher strength concrete (also reduces dead load)

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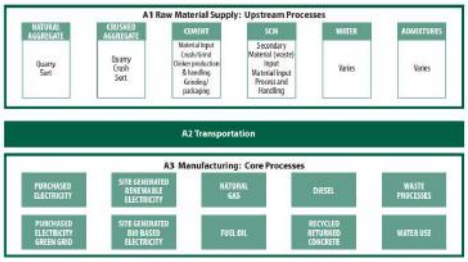
Impacted by Concrete Mixture

Cradle-to-Gate Life Cycle of Concrete

Figure 1: Cradle-to-gate product system for concrete



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Building LCA – EPD

Building Life Cycle Information Modules (x: Included in LCA; mnd: Module Not Declared)															
Product stage			Construction Process stage		Use stage							End-of-life stage			
Raw Material supply	Transport	Manufacturing	Transport	Construction/Installation	Use	Maintenance	Repair	Replacement	Refurbishment	Operational Energy Use	Operational Water Use	De-Construction/ Demolition	Transport	Waste processing	Disposal
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4
x	x	x	mnd	mnd	mnd	mnd	mnd	mnd	mnd	mnd	mnd	mnd	mnd	mnd	mnd

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Impacted by Concrete Mixture

NRMCA MEMBER INDUSTRY-AVERAGE EPD FOR READY MIXED CONCRETE

Table 8a. Summary Results (A1-A3): 3001-4000 psi (20.7-27.6 MPa) RMC product mix design, per cubic meter

		Minimum	Maximum	3001-4000-00-FA/SL	3001-4000-20-FA	3001-4000-30-FA	3001-4000-40-FA	3001-4000-30-SL	3001-4000-40-SL	3001-4000-50-SL	6001-8000-50-FA/SL
Core Mandatory Impact Indicators											
GWP	kg CO_2e	261.19	426.75	426.75	365.48	332.17	297.41	327.67	294.65	262.62	261.19
ODP	kg CFC11e	7.84E-06	1.11E-05	1.11E-05	9.56E-06	8.73E-06	7.84E-06	1.01E-05	9.75E-06	9.41E-06	8.49E-06
AP	kg SO_2e	0.99	1.33	1.33	1.17	1.08	0.99	1.28	1.26	1.25	1.12
EP	kg Ne	0.37	0.55	0.55	0.48	0.44	0.40	0.45	0.41	0.38	0.37
POCP	kg O_3e	21.38	28.22	28.22	24.98	23.23	21.38	25.58	24.70	23.82	22.20
ADPF	MJ, NCV	1,522.19	2,229.70	2,229.70	1,921.20	1,754.51	1,578.49	1,850.63	1,724.28	1,597.92	1,522.19
ADPe	kg Sbe	2.44E-04	3.69E-04	3.69E-04	3.25E-04	3.02E-04	2.77E-04	2.94E-04	2.69E-04	2.44E-04	2.46E-04
FFD	MJ Surplus	143.16	180.58	180.58	162.85	153.28	143.16	172.58	169.91	167.24	154.43

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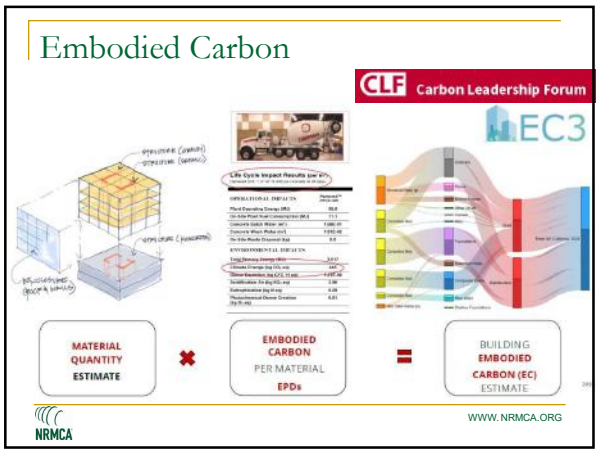
Embodied Carbon



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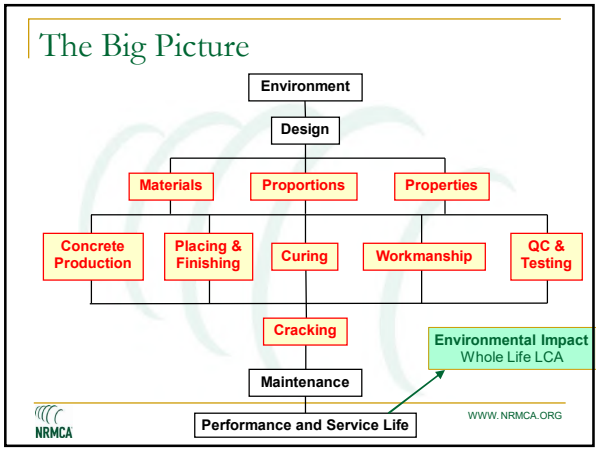
The Big Picture



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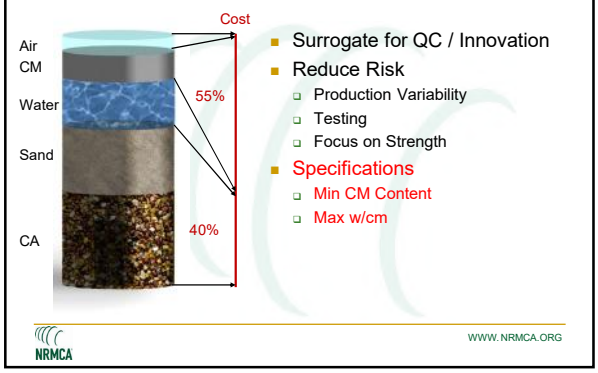
Reasons for Higher Cement Content



- Surrogate for QC / Innovation
- Reduce Risk
  - Production Variability
  - Testing
  - Focus on Strength
- Specifications
  - Min CM Content
  - Max w/cm

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Example Specification (Hybrid)

Interior Building Column

- Maximum w/cm = 0.40
- Min. CM = 640 lb/yd^3 (380 kg/m^3)
- Maximum fly ash = 15% by mass of CM
- Specified strength f'_c = 4000 psi (28 MPa)
- Max. Slump = 4 in. (100 mm)

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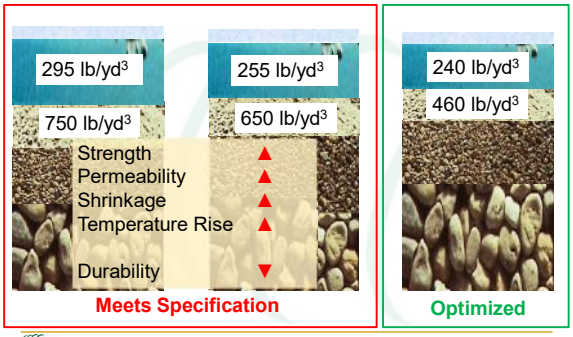
Alternate Bids



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State of Prescription – Top 5

Prescription	% of specs	Industry Standards
Restriction on SCM quantity	85%	Exposure F3
Max w/cm (when not applicable)	73%	ACI 318 – Durability
Minimum cementitious content	46%	ACI 301 – floors
Restriction on SCM type, characteristics	27%	None
Restriction on aggregate grading	25%	Suggested for floors
Overall average	**51%**	

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Prescription to Performance

Why should we change?

- Drawbacks of Prescription?
- Advantages of Performance?

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Drawbacks of Prescription

- Does not assure required performance
- Prevents mixtures from being optimized
- No incentive
  - Quality
  - Innovation
- Contradicts sustainability initiatives
- Responsibility is unclear

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1. Prescription *does not assure* Performance

- Minimum cementitious content
  - Improve durability, other reasons?
- Maximum limits on SCMs
  - Control setting time, rate of strength gain
- Specifying combined aggregate grading
  - Control shrinkage, curling, workability
- Maximum w/cm
  - Permeability and durability

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2. Prescription – *unoptimized mixtures* negatively impacts performance

- High CM; Less SCM; High paste volume
  - Workability / segregation
  - Permeability / durability
  - Later age strength
  - Potential for cracking – thermal and shrinkage

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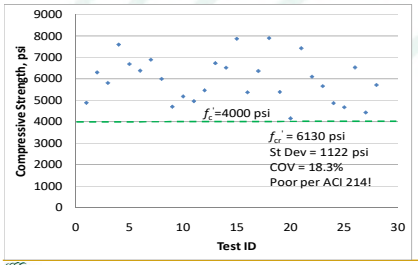
3. Prescription – *no incentive* for quality

- Minimum CM and max w/cm result in strength much higher than required by design



No low strength
Complies with spec

High variability

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4. *Limits* on SCMs *impacts* sustainability

- Overall industry average (lb./yd^3)
  - Cement = 457
  - Fly ash = 83
  - Slag cement = 18
  - Silica fume = 0.2
  - Blended cement = 2.7
- Based on annual consumption of materials
- Increased SCM use prevented by specifications

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5. Prescription - *responsibility* unclear

- Can the concrete producer be responsible for performance of concrete mixtures?
- Can the contractor be responsible for end result with prescribed means and methods
- Hybrid specifications (prescription and performance) make responsibility less clear

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Advantages – Minimize Prescription / Specify Performance

- Better assures performance (and service life)
- Concrete mixtures better optimized
  - Supports sustainability
- Incentivizes quality (reduced variability)
- Supports Innovation
- Clearer assignment of responsibility
- Elevates competency of stakeholders
  - Improved schedules and reduced cost

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Performance-based Specification

- Design, exposure, serviceability, service life
  - Defines performance requirements
- Construction requirements (Contractor's order)
- Producer develops proposed mixtures
- Submittal of proposed mixture and pre-qualification tests
- Field acceptance tests determine if concrete meets selected performance criteria
  - Must be simple for the typical technician to perform
- Consequences/resolution when concrete does not meet performance criteria

Need qualified producer and contractor who partner well

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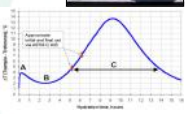
Contractor's Requirements – Fresh Concrete

Not in specification – typically decided when ordered

- Consistency between batches
- Workability
  - Slump
  - Pumpability
  - Resistance to Segregation
  - Finishability
- Predictable setting time
- Rate of Strength Gain
- Air content – hard-trowelled slabs
- Density – yield and check on mixture
- Tests at chute and placement (if needed)



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Evolving to a Performance Specification

- Eliminate or Minimize prescription
  - Min. CM, SCM limits, restriction on aggregate
- Assess Exposure Conditions (ACI 318)
  - Specify applicable requirements for durability
  - Do not specify w/cm when not required
- Performance requirements applicable to different member types

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Durable Concrete - What do we need?

- Use Quality Materials
  - Avoid those that cause a durability problem
  - Use those that mitigate a durability problem
- Reduce permeability of concrete
- Minimize shrinkage or factors that increase cracking
- Quality of paste
  - SCMs, Admixtures …
- Quantity of paste - minimize
  - SCMs, Control of water, Aggregate grading …
- Improved Quality Control
- Other requirements for specific durability issues

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Exposure Conditions for Durability

- ACI 318 – Durability Requirements
  - Applies to buildings
  - Alternatives to Code can be proposed
  - Concepts can be applied to other structures
- Relies on w/cm for low permeability
  - Benefit provided by SCMs not recognized
- Project specifications have to consider other factors
  - ASR
  - Potential for cracking

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ACI 318 Exposure Categories and Classes

- Category F - Freezing and thawing
  - Class F0, F1, F2, F3
- Category S – Sulfate
  - Class S0, S1, S2, S3
- Category W - In contact with water
  - Class W0, W1, W2
- Category C - Corrosion protection of reinforcement
  - Class C0, C1, C2

Design professional assigns Exposure Class

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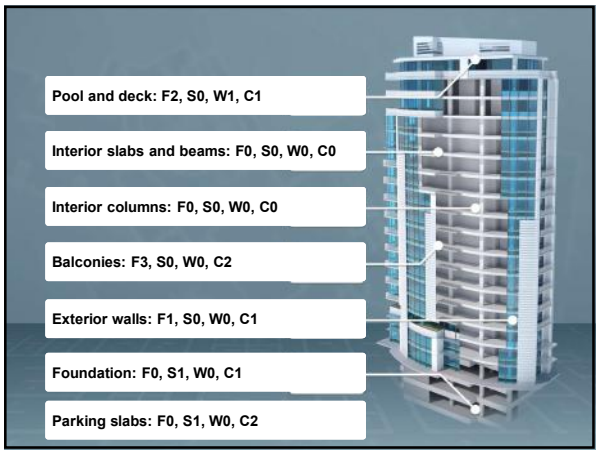

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Requirements for Concrete (partial)

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.

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Evolution to Performance

- Identify Exposure Classes
  - Basic requirements (Code)

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									
Foundations									
Slabs on Grade									
Exterior Slabs									
Interior Slabs									
Frame Members									
Interior Columns									
Exterior Columns									
Interior Walls									
Exterior Walls									
Slab Toppings									

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Evolution to Performance

- Some suggested 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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Bridge deck in NY

- ACI 318 Exposure Class – F3, S0, W1, C2
- Typical prescription
  - 0.40 w/cm/5000 psi, air-entrained
- Performance Criteria
  - ASTM C1202 < 1500 Coulombs - 28 days (accelerated curing)
  - ASTM C157 < 0.05% - 7 days curing; 28 days of drying
  - 5-8% air entrainment
  - Strength = 4000 psi or higher
  - Largest coarse aggregate size
  - ASR considerations

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Interior floor slab

- ACI 318 Exposure Class – F0, S0, W0, C0
- Typical prescription
  - water, cement content, aggregate grading, SCM limits
- Performance Criteria
  - ASTM C157< 0.05% - 7 days curing; 28 days of drying
  - Setting time evaluation – contractor needs
  - Test slab placement for workability, finishability, bleed
  - Strength = 3500 psi or higher
  - Choose largest coarse aggregate size feasible

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Building foundation in CO

- ACI 318 Exposure Class – F0, S3, W1, C0
- Typical prescription
  - 0.45 w/cm; 4500 psi; sulfate resistant CM
- Performance Criteria
  - Strength = 4000 psi or higher
  - ASTM C1012 < 0.10% at 18 months for sulfate resistance
  - Choose largest coarse aggregate size feasible
  - Thermal Control Plan for mass concrete
    - max internal temp;
    - temp differential

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Qualification of Stakeholders

- Contractor
  - Concrete Contractor
- Concrete Supplier
- Inspectors and Testing Agencies

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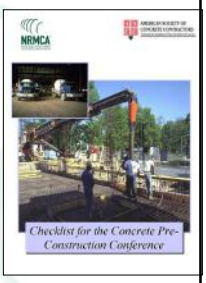
Pre-construction Conference

All parties should attend and decisions should be on record

- Sampling location
- Placement type
- Jobsite mix adjustments - signatures
- Responsibility to accept/reject concrete
- Initial curing
- Early age strength testing
- Changes reqd. for resubmittal
- Test results reporting
- Responsibility for low strength evaluations and resolution



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GWP - Minimizing Cement

- Review specification
  - Minimum cement content
  - Max w/cm - when not needed
  - Limits on SCMs (exception exposure F3)
  - Specifying strength at later age if design permits
- Expertise of contractor/producer/lab
- Review and discussion on submittal (post bid)
- Lower than industry average GWP (EC3 or other tool)
  - More complicated
  - Should balance with project goals
- Avoid prescriptive limits to control high CM content

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Specifications and Sustainability

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Specificatio

Specification Prov
Restrictions on charac aggregates
Invoking a minimum cementitious materia
Prescriptive requirem green building credit
Restriction on SCM ch
Restriction on quantit

Ref: Lemay, Lobo, Obla

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But how to guarantee lower GWP

- Longer term - Evolve towards specifying maximum GWP (lb/yd^3) for whole building (like gas mileage for cars)
- Short term - Maximum cement content requirements with following caveats
  - SCM contents are not counted as cement
  - Need to be mindful about performance req.

Strength, psi	Maximum Cement requirements, lb/yd^3
3000	400
5000	500
8000	600

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Innovation Possible

Bridge to Prince Edward Island – 100 year service life – Opened in 1996

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Innovation Possible

I-35W bridge, MN – Concrete International, Feb 2009

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Optimized Performance – Severe Conditions

I-35W bridge, MN – Concrete International, Feb 2009

Member	Performance Achieved
Super structure	Air entrained; PT; Strength > 8000 psi; RCP <250 Coulombs (90 d); shrinkage <0.04% (56d drying)
Piers	Conventional slump; thermal control for 3 d; strength > specified; RCP 500 coulombs (90 d)
Footings	Similar to drilled shaft mix; conventional slump; shrinkage = 0.04% (28d drying)
Drilled Shafts	Strength>10,000 psi (cores); RCP 750 coulombs (28d) Low heat considerations (mass concrete); SCC mix

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Innovation Possible

Cement	300
Fly ash	65
Slag	483 } 66%
Silica fume	25
w/cm	0.25
Slump flow	25 in.
Strength	16,160 psi
MOE	7.5 M psi

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Innovation Possible

Specifying for Performance

Case studies show that cooperative efforts lead to success

by Karthik H. Obla, Daniel J. Goncarz, William R. (Rusty) Owings III, Fouad H. Yazbeck, and David G. Tepke

MAY 2018 | Ci | www.concreteinternational.com

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Innovation Possible

MO DOT Spec

- Drilled Shafts
  - 105 lb./yd³ lower CM
- Foundation – Mass
  - 95 lb./yd³ lower CM
  - 58°C peak temp
- Pylons
  - 50 lb./yd³ lower CM
  - Ternary/optimized aggregate
  - 8-in slump; 7000 psi; AE
- Bridge Deck
  - 105 lb./yd³ lower CM
- Pavement
  - 40 lb./yd³ lower CM

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Performance Engineered Mixtures Program

National Concrete Pavement Technology Center

IOWA STATE UNIVERSITY
Institute for Transportation

Standard Practice for

Developing Performance Engineered Concrete Pavement Mixtures

AASHTO Designation: PP 84-17[1]
Tech Section: 3c, Hardened Concrete
Release: Group 1 (April 2017)

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Performance Engineered Mixtures Program

National Concrete Pavement Technology Center

Iowa State University
Institute for Transportation

Standard Practice for

Developing Performance Engineered Concrete Pavement Mixtures

AASHTO Designation: PP 84-17
Tech Section: 3c, Hardened Concrete
Release: Group 1 (April 2017)

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PEM Methods and Criteria

Property	Method	Criteria	Pre	Acc
Strength	T97 Flexural	600 psi	Y	Y
	T22 Compressive	4000 psi	Y	Y
Cracking Warping	Paste Volume	<25%	Y	N
	C157 Vol Change (28d)	420 με	Y	N
	C157 cracking probability (91d)	360,420,480με	Y	N
	T334 restrained shrinkage (180d)	No crack	Y	N
	T363 dual ring shrinkage (7d)	Stress < 0.6 f_{sp}	Y	N
	Cracking probability (model)	As specified	Y	N
	QC check		N	Y

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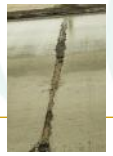
PEM Methods and Criteria

Property	Method	Criteria	Pre	Acc
F/T	Max w/cm	0.45	Y	Y
	T152, T196 TP118 Air content	5 to 8%	Y	Y
	T152, T196 TP118 Air content / SAM	4 to 8; <0.2	Y	Y
	C1585 Time to critical saturation	30 yr	Y	N
Deicing salts	Min SCM	35%	Y	Y
	Topical treatment	-	Y	Y
	T365 LTDSC Cal OXY	<0.15g/g paste	Y	N



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PEM Methods and Criteria

Property	Method	Criteria	Pre	Acc
Transport	Max w/cm	0.45 or 0.50	Y	Y
	T277 (RCPT), T 358 (SR), TP 119 (BR) Formation Factor (91d or 28d acc cure)	No F/T > 500 F/T > 1000	Y	Y
	Ionic Penetration (F-Factor)	25 mm @ 30 y	Y (F)	Y (ρ)
Aggregates	T161, C666 D-cracking		Y	N
	R80, C1778 AAR		Y	N
Workability	Box Test	Edge slump<6 in; <30% voids	Y	N
	Mod VKelly	15-30 mm / root s	Y	N



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Resources for Specifications

www.nrmca.org/P2P

ACI 329 – Guide to Performance Spec (work in progress)

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www.nrmca.org/P2P
www.nrmca.org/sustainability

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