




Performance-based Specifications for Concrete

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What is the P2P Initiative?

- Prescription-to-Performance
- An alternative to current prescriptive specifications
- Improve current specifications
- An initiative of the concrete industry
- Spearheaded by the NRMCA

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P2P Goals




- Performance as an alternative to current prescriptive
- Leverage expertise of all parties
- Establish roles and responsibilities based on expertise
- Define performance attributes of concrete for functional requirements in the structure
- Flexibility - concrete mixtures, construction means and methods
- Elevate the performance level and quality of ready mixed concrete
- Improve quality and reliability of concrete construction
- Foster innovation; accept new technology



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Prescriptive vs Performance Specifications


- Prescriptive Specifications
 - Limit the types and quantities of ingredients
 - Identify mixture proportions
 - Detail construction means and methods
- Performance Specifications
 - Focus on performance and function
 - Assignment of responsibility
 - Flexibility to adjust mixture ingredients and proportions to achieve consistent performance
 - Measurable and enforceable

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Prescriptive Specification

Intended Performance	Typical Criteria
□ Placing/Finishing	□ Slump
□ Strength	□ Max w/cm ratio
□ Max Shrinkage	□ Min cement content
□ Resistance To:	□ Min/max air
• Freeze-Thaw	□ Min/Max pozzolans/slag
• Deicer scaling	□ Blended cements
• Corrosion	□ Aggregate grading
• Sulfate attack	□ Source Limitations
• ASR	□ Chloride Limits
• Cracking	
• Abrasion	



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Problems with Prescriptive?

- Do not always cover intended performance
- Inherent conflicts with intended performance
- Responsibility without authority
- Limits competitive bidding
- No incentive for quality control
 - Not in the owner's best interest



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Performance Specifications

- Encourages partnering within construction team
- Leads to innovation and satisfied customers

11.3 k
22.0 k
21.1 k
19.9 k
20.5 k
15'-0"

Engineers and Architects
Contractors
Concrete Producers

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Water-cement Ratio

Air
Water
Cement
Paste
Air
Water
Cement

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Same w/cm – different performance

Compressive Strength, p
8000
7000
6000
5000
4000
3000
2000
1000
0
0.40 0.45 0.5 0.55
Water-Cement Ratio (w/c)

Mix 1
Mix 2
Mix 3

Change Passed Count
8000
7000
6000
5000
4000
3000
2000
1000
0
0.70 0.55 0.45
Water-Cement Ratio (w/c)

Portland cement
SCM1
SCM2
Ternary Blend

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Benefits to the Owner

- Improved quality
- Improved performance
- Supports sustainable construction
- Reduced construction time
- Reduced cost
- Confidence in concrete construction

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Benefits to the Engineer/Architect

- Focus on function and material properties
 - Strength, Durability, Shrinkage, etc.
- Simplified specification and submittal review
- Improved product consistency
- Reduced conflict with contractor/producer
- Reduced errors/troubleshooting

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Benefits to the Contractor

- Improved communication/coordination
- Constructability requirements addressed
- Predictable performance
- Innovate on construction means and methods

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Benefits to the Producer

- Eliminates conflicts and improves clarity in specifications
- Innovation
- Justify QC investment
- Mixture optimization for performance
- Permits real time mixture adjustments
 - Material variability
 - Ambient conditions



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Challenges?

- Acceptance of Change
- Trust / Credibility
- Knowledge Level (training)
- Reference Codes and Specifications
 - Prescriptive limitations
- Measurement and Testing
 - Reliability of existing tests
 - Reliability of jobsite tests



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Current Progress

- Communication
 - Articles and presentations – www.nrmca.org/p2p
 - Seminars (ASCE) and Symposiums
- Producer Quality Plan – ISO 9000
 - Audit Checklist
- Model Performance Specification
 - Phase 1 – Overview of global practice
 - Phase 2 – Specification alternatives
 - ACI Innovative Task Group 8
 - Report in 2 years



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Current Progress

- Code Revisions
 - Exposure Class for Durability – done
 - Proportioning and submittals – next code cycle
 - Include/permit performance alternatives – next cycle
- ASTM C 94 – ordering - associated responsibilities
 - Prescriptive
 - Performance
- Industry Education Programs
- Certification – plants and personnel
- Documenting Case Studies



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Current Progress

- Partnering
 - A/E
 - Specifying agencies – FHWA, state DOTs
 - Contractors - ASCC
- Research
 - Quantifying differences between prescriptive and performance mixes
 - State pooled fund research for durability tests
 - Data to support technical initiatives



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ACI 318 Exposure Classes - 2008

- Category F – Freezing and thawing cycles
- Category S – Water-soluble sulfates
- Category P – Low permeability to water
- Category C – Corrosion protection of reinforcement




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Exposed to water-soluble sulfates


Exposure Category S – Exposure to water-soluble sulfates

Class	Description	Water-soluble sulfate (SO ₄) in Soil, percent by weight	Sulfate (SO ₄) in Water, ppm
S0	Negligible	SO ₄ < 0.10	SO ₄ < 150
S1	Moderate	0.10 ≤ SO ₄ < 0.20	150 ≤ SO ₄ < 1500 Seawater
S2	Severe	0.20 ≤ SO ₄ < 2.00	1500 ≤ SO ₄ < 10,000
S3	Very severe	SO ₄ > 2.00	SO ₄ > 10,000

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Requirements for Concrete - Exposure Class S


Exposure Class	Max w/cm	Min f' _c psi	Cementitious Materials - Types			Additional Requirement
			C 150	C 595	C 1157	
S0	-	-	-	-	-	
S1	0.50	4000	II	IP(MS), IS(<70)(MS)	MS	
S2	0.45	4500	V	IP (HS) IS(<70)(HS)	HS	No calcium chloride admixtures
S3	0.45	4500	V + pozz or slag	IP (HS) IS(<70)(HS) + pozz or slag	HS + pozz or slag	No calcium chloride admixtures


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CM Alternative - Exposure Class S


Alternatives to cementitious materials
Service records or ASTM C 1012 test

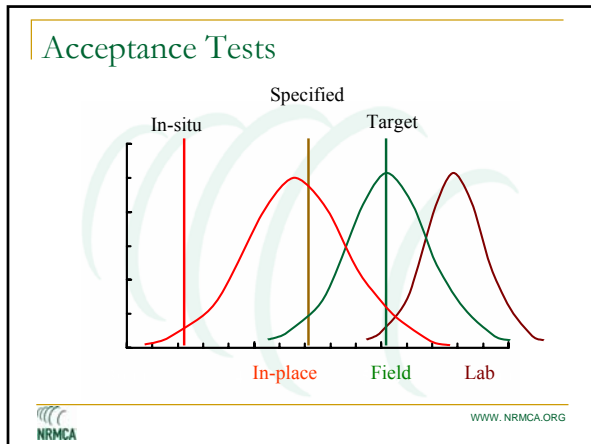
Exposure Class	Max Expansion ASTM C 1012
S0	-
S1	0.10 at 6 months
S2	0.05 at 6 months 0.10 at 12 months
S3	0.10 at 18 months

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- ### Future Specification for Concrete
- Concrete for parking garage
- Slabs and beams:
 - Max agg size = ¾ inch
 - f'_c = 5,000 psi
 - Exposure class F3, S0, P0, C2
 - Foundations
 - Max agg size = 1 inch
 - f'_c = 5,000 psi
 - Exposure class F3, S1, P0, C1
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- ### Specification Criteria
- Design
 - Relationship to service life
 - Confidence of extrapolating to service life
 - Pre-Qualification
 - Duration of test
 - Rational approach to satisfying criteria
 - Jobsite testing for project Quality Assurance
 - Test Method Precision
 - Duration of Test
 - Decisions on "failing" product
 - Referee testing
 - Establish criteria for "failing" QA results
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- ### Prequalification vs. Jobsite
- Precision of test
 - Qualified testing technicians and facilities
 - Affects of jobsite sampling and specimen care
 - Statistically based acceptance criteria
 - Allow for reasonable overdesign
 - Balance buyers and sellers risk
 - Property measurement vs. Mix verification
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Performance Properties of Concrete

Property	Test	Criteria	P	J	R
Strength	C 39	X MPa @ ? age	✓	✓	✓
Early Str.	C 39	Y MPa @ ? age	✓	✓	
Flex	C 78	F MPa @ ? age	✓	✓	?
E	C 469	25 - 40 GPa	✓		
Abrasion	C 944	? mm depth of wear	✓		
Shrinkage	C 157	<0.05% (cure/age)	✓		

P – Prequalification
J – Jobsite sample tests
R – Referee tests from structure

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Performance Properties of Concrete

Property	Test	Criteria	P	J	R
Permeability	C 1202	500 - 2000 coulombs	✓	?	?
Diffusion	C 1556	100 x 10 ⁻¹³ m ² /s	✓		
Chloride Penetration	T 259	Less than 0.07% Cl at 6 months	✓		
Chloride limits	C1218	1.0 to 0.3% wt of cement	✓		
Resistivity	G 59		✓		
Absorption	C 642	2% to 5%	✓		?

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Performance Properties of Concrete

Freeze Thaw

Property	Test	Criteria	P	J	R
Air content	C 231	4 to 7%	✓	✓	✓
Air voids	C 457	Spacing, size	✓		?
Durability Factor	C 666	80%	✓		
Scaling	C 672	Rating 0-2 or mass loss 0 to 0.5 kg/m ³ after 50 cycles	✓		
Permeability			?		

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Performance Properties of Concrete


Property	Test	Criteria	P	J	R
ASR	C 1567	0.1% exp @ 14d	✓		
Sulfate	C 1012	Expansion criteria	✓		
Creep	C 512	Creep coeff – project requirements	✓		

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- ### ASTM C 94 – Ordering
- #### Producer Responsibility
- Prescriptive
 - Comply with prescriptive requirements
 - Not responsibility for performance
 - Performance
 - Proportion mix to achieve performance
 - Comply with performance requirements
 - Communicate potential deficiencies
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Quality Plan

- Document what you will do
- Assign responsibility
- DO IT!
- Specifier – need for an audit?

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P2P Guideline Quality Plan

- Guideline Document
 - ISO 9001 format specific to RM Industry
 - 15 sections
- Appendices
 - Standard forms
 - Details of process and quality control activities
- Example Quality Plan
 - "Global Ready Mixed Company"

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P2P Quality Plan


- Documents Quality Systems/Processes
- Minimum Quality Process Requirements for Performance Specs
- Clarity for Producer and Purchaser
- Flexibility
 - Individual Company Needs
 - Evolve to a Quality Standard or Certification

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Lab Study: Advantages of Performance Specification


- Case 1:
 - Floor Specification from a Major Owner
- Case 2:
 - Typical HPC Bridge Deck Specification
- Case 3:
 - ACI 318 Chapter 4 Code – prescriptive durability provisions

□ Report – www.nrmca.org/p2p

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Case 2 - HPC Bridge Deck Specification

Prescriptive	Performance
Specified 28 d strength=4000 psi; Average past records	Specified 28 d strength=4000 psi; Average past records
Max w/cm = 0.39	-
Total CM = 705. 15% FA plus 7% to 8% SF	SCM required. Maximum amounts per ACI 318 for deicer scaling
Air = 4% to 8%	Air = 4% to 8%
RCPT < 1500 coulombs	RCPT < 1500 coulombs
-	Shrinkage < 0.04% at 28 days
Slump = 4" – 6"	Slump = 4" – 6"

 Specified by Contractor WWW.NRMCA.ORG

Experimental Program (4 mixtures)

- BR-1: Control
 - F fly ash (15%), SF (5%), CM 705, w/cm 0.39
- BR-2: Performance 1
 - F fly ash (25%), SF (4%), CM 600, w/cm 0.39
- BR-3: Performance 2
 - Slag (50%), CM 600, w/cm 0.39
- BR-4: Performance 3
 - F fly ash (25%), UFFA (5%), CM 612, w/cm 0.36

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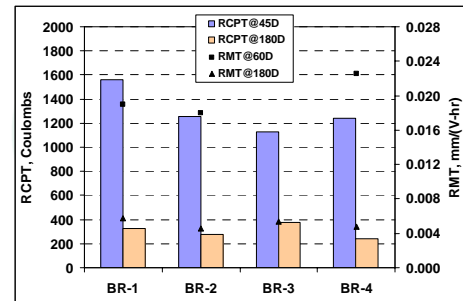
Strength

- Compressive Strength:
 - 28 day strengths were much higher than specified
 - 6800 to 8970 psi



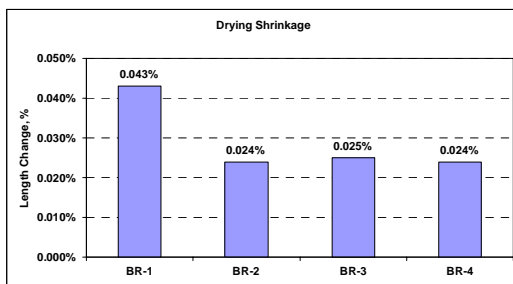
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RCPT (ASTM C 1202), RMT (AASHTO TP 64)



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Drying Shrinkage (ASTM C 157)



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Summary – HPC Bridge Deck Mixtures

- All performance mixtures met performance requirements
- Performance mixtures had similar or better performance than Prescriptive mixtures
 - Drying shrinkage, workability (stickiness), HRWR dosage, strength, RCPT, RMT
- Performance mixtures had substantial material cost savings



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Pooled Fund Research

- Develop performance tests and specification criteria for permeability
 - Evaluate durability performance
- Funding: \$1.6M – 4 years
 - RMC Research and Education Foundation
 - Portland Cement Association
 - FHWA
 - 10 state agencies – IN lead state
- PI – Purdue; NRMCA subcontractor



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Resources

- Visit www.nrmca.org/P2P
- Download Example Specifications
- Download P2P Articles
- Download Research Studies



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