Sustainable Concrete: The Role of Performance-based Specifications

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What is Sustainable Concrete?
Versatility
Buildings
Bridges
Dams
Roads
Houses

Influence of Design Decisions
Loads
Wind
Seismic
Fire
Blast

Structural Efficiency
Durability

Marine

Heat

Freezing

Corrosive

Constructability

High Early Strength

Mass Concrete

Pumpability

Finishability
Concrete Frame vs. Steel Frame

12 stories
46,321 m²
(498,590 ft²)

Ochsendorf, J., et al., Methods, Impacts, and Opportunities in the Concrete Building Life Cycle, Massachusetts Institute of Technology Concrete Sustainability Hub, Cambridge, MA, 2011.
Urban Heat Island Effect

- Downtown areas are 3°C (5°F) warmer
- Due to dark-colored roofing and pavement
- Reduce UHI with light colored pavements and cladding

Source: Lawrence Berkeley National Laboratory

Aesthetics

Versatility

Color

Texture
Concrete Mixtures

<table>
<thead>
<tr>
<th>Material</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portland cement</td>
<td>208 kg/m³ (350 lb/yd³)</td>
</tr>
<tr>
<td>Slag cement</td>
<td>178 kg/m³ (300 lb/yd³)</td>
</tr>
<tr>
<td>Silica fume</td>
<td>25 kg/m³ (45 lb/yd³)</td>
</tr>
<tr>
<td>Coarse aggregate</td>
<td>1068 kg/m³ (1800 lb/yd³)</td>
</tr>
<tr>
<td>Fine aggregate</td>
<td>712 kg/m³ (1200 lb/yd³)</td>
</tr>
<tr>
<td>Water</td>
<td>178 kg/m³ (300 lb/yd³)</td>
</tr>
<tr>
<td>Air content</td>
<td>6%</td>
</tr>
</tbody>
</table>

*50% portland cement replacement!*  
*Is this Sustainable Concrete?*

High Early Strength Concrete
Mass Concrete

Sustainable Concrete

- Meet performance requirements of the owner, designers, contractor and producer
- Minimize Energy and CO₂ Footprint
- Minimize Potable Water Use
- Minimize Waste
- Increase Use of Recycled Content
Influence of Project Specifications

Strike a balance

- Sustainability initiatives should have minimum impact on attributes of concrete
- Specifications for concrete should not restrict concrete from being more sustainable
Definition

- Responsibility with Assigned Authority
  - Each party is responsible for own work
- Concrete producer cannot bear responsibility for service life...
  - Design and specification should address this
- 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

How it Can Work

- Qualify concrete producer and contractor
- Specifier defines performance requirements
- Producer and contractor ensure right mixture is designed, delivered and installed
- Submittals include pre-qualification tests
- Field acceptance tests determine if concrete meets performance criteria
- Instructions outlining what happens when concrete does not meet performance criteria
Problems with Prescription?

- Responsibility without authority
- May not cover intended performance
- Inherent conflicts within specification
- Limits competitive bidding
  - Low bid wins – may not be the best option
- No incentive for quality control
  - Not in the owner’s best interest

Typical Specification

<table>
<thead>
<tr>
<th>Structural Element</th>
<th>Minimum Cover (inches)</th>
<th>Concrete Strength (PSI)</th>
<th>W/C Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Footings</td>
<td>3” all surfaces</td>
<td>3000</td>
<td>SEE CHART</td>
</tr>
<tr>
<td>Footings in garage and under</td>
<td>3” all surfaces</td>
<td>4000</td>
<td>SEE CHART</td>
</tr>
<tr>
<td>Grade Beams</td>
<td>2” bottom, 2” sides, 1 1/2” top</td>
<td>3000</td>
<td>SEE CHART</td>
</tr>
<tr>
<td>Slab on Grade</td>
<td></td>
<td>3000</td>
<td>SEE CHART</td>
</tr>
<tr>
<td>Conventional (mesh)</td>
<td>2 5/8” bottom</td>
<td>3000</td>
<td>SEE CHART</td>
</tr>
<tr>
<td>Conventional (one layer rebar)</td>
<td>5 5/8” bottom</td>
<td>3000</td>
<td>SEE CHART</td>
</tr>
<tr>
<td>Conventional (two layer rebar)</td>
<td>1 1/2” top, 1 1/2” bottom</td>
<td>3000</td>
<td>SEE CHART</td>
</tr>
<tr>
<td>Retaining walls &amp; elevator pits</td>
<td>1” top &amp; 2” exterior, 3/4” interior</td>
<td>4000</td>
<td>SEE CHART</td>
</tr>
<tr>
<td>Pilaster column in garage</td>
<td>1 1/2 sides</td>
<td>5000</td>
<td>SEE CHART</td>
</tr>
</tbody>
</table>
| Portland cement shall conform to ASTM C150, Type 1. Minimum of 5 sacks of cement per cubic yard.

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<thead>
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<th>Structural Element</th>
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<th>Concrete Strength (PSI)</th>
<th>W/C Ratio</th>
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</thead>
<tbody>
<tr>
<td>Columns</td>
<td>1 1/2”</td>
<td>3000</td>
<td>SEE CHART</td>
</tr>
<tr>
<td>Elevated Slabs</td>
<td>1” at bottom, 1 1/2” at top in garage</td>
<td>6000</td>
<td>SEE CHART</td>
</tr>
<tr>
<td></td>
<td>1” at bottom, 3/4” at top of podium</td>
<td>6000</td>
<td>SEE CHART</td>
</tr>
</tbody>
</table>
## Typical Specification

PORTLAND CEMENT SHALL CONFORM TO ASTM C150, TYPE I. MINIMUM OF 5 1/2 SACKS OF CEMENT PER CUBIC YARD.

<table>
<thead>
<tr>
<th>WATER CEMENT RATIO (W/C)</th>
<th>CONCRETE %</th>
<th>NON-AIR ENTRAINED</th>
<th>AIR ENTRAINED</th>
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</thead>
<tbody>
<tr>
<td>3000</td>
<td>0.52 (MAX.)</td>
<td>0.45 (MAX.)</td>
<td></td>
</tr>
<tr>
<td>4000</td>
<td>0.44 (MAX.)</td>
<td>0.35 (MAX.)</td>
<td></td>
</tr>
<tr>
<td>4500</td>
<td>0.43 (MAX.)</td>
<td>0.34 (MAX.)</td>
<td></td>
</tr>
<tr>
<td>5000</td>
<td>0.42 (MAX.)</td>
<td>0.33 (MAX.)</td>
<td></td>
</tr>
<tr>
<td>6000</td>
<td>0.41 (MAX.)</td>
<td>0.33 (MAX.)</td>
<td></td>
</tr>
<tr>
<td>7000</td>
<td>0.36 (MAX.)</td>
<td>0.33 (MAX.)</td>
<td></td>
</tr>
<tr>
<td>8000</td>
<td>0.33 (MAX.)</td>
<td>0.33 (MAX.)</td>
<td></td>
</tr>
</tbody>
</table>

7. FLYASH MAY BE USED TO REPLACE A PORTION OF THE PORTLAND CEMENT. THE RATIO OF FLYASH TO THE TOTAL OF THE FLYASH AND CEMENT IN A MIX SHALL NOT EXCEED 26%. FLYASH SHALL CONFORM TO ASTM C618, TYPE C OR F.


9. CONCRETE SLUMP TESTS SHALL BE MADE BEFORE AND AFTER THE ADDITION OF ADJUVANTS AND MAY BE TAKEN AT THE BACK OF THE TRUCK. CONCRETE FOR THE PREPARATION OF TEST CYLINDERS SHALL BE TAKEN FROM THE NOSE END FOR CONCRETE PLACED BY PUMP.

## Example Specification (Hybrid)

Interior Building Column

- Maximum w/cm = 0.40
- Min. Cem matls = 640 lb/yd³ (380 kg/m³)
- Maximum fly ash = 15% by mass of CM
- Specified strength $f'_{c} = 4000$ psi (28 MPa)
- Max. Slump = 4 in. (100 mm)
Solution 1 - prescriptive

- Start with water – 295 lb/yd³
- w/cm 0.40
- CM - 740 lb/yd³
- Strength = 7000 psi (48 MPa)
  - Specified = 4000 psi (28 MPa)
- Paste volume = 31%
  - High heat of hydration
  - High shrinkage
  - High creep

Solution 2 - prescriptive

- Start with CM – 640 lb/yd³
- w/cm 0.40
- Water - 250 lb/yd³ + HRWRA
- Strength = 6500 psi (44 MPa)
  - Specified = 28 MPa
- Paste volume = 27%
  - Placing?
  - Finishing – sticky?
Solution 3 - performance

- Target strength
  - 5500 psi (32 MPa) 28 days
  - 2500 psi (17 MPa) 3 days
  - Self consolidating concrete
- Concrete mixture
  - CM 460 lb/yd³ (270 kg/m³), 25% fly ash
  - w/cm = 0.45
  - Optimized aggregates
  - Admixtures for SCC
- Paste volume = 22%
  - Improved performance

Lab Study

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

- **HPC Bridge Deck**
  
  Strength = 4000 psi (28 MPa)
  Slump = 4-5 in. (100 – 125 mm)
  Air = 4% to 8%

### Prescriptive – BR-1

- Max w/cm = 0.39
- Total CM = 700 lb/yd³ (420 kg/m³)
- 15% FA + 7% to 8% SF

### Performance – BR 2, 3, 4

- SCM allowed
- RCPT < 1500 coulomb
- Shrinkage < 0.04%

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Experimental Program

- **28-day strength**
  - 6800 – 9000 psi
  - 47 to 62 MPa
Indicators of Permeability

<table>
<thead>
<tr>
<th>Mixture</th>
<th>RCPT - 45</th>
<th>RCPT - 180</th>
<th>RMT - 60</th>
<th>RMT - 180</th>
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</thead>
<tbody>
<tr>
<td>BR-1</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
</tr>
<tr>
<td>BR-2</td>
<td>0.020</td>
<td>0.020</td>
<td>0.020</td>
<td>0.020</td>
</tr>
<tr>
<td>BR-3</td>
<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
</tr>
<tr>
<td>BR-4</td>
<td>0.028</td>
<td>0.028</td>
<td>0.028</td>
<td>0.028</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Chloride Diff. Coeff.</th>
<th>Mixture ID</th>
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</thead>
<tbody>
<tr>
<td>BR-1</td>
<td>10^-13 m^2/s</td>
<td>BR-1</td>
</tr>
<tr>
<td>BR-2</td>
<td>10^-13 m^2/s</td>
<td>BR-2</td>
</tr>
<tr>
<td>BR-3</td>
<td>10^-13 m^2/s</td>
<td>BR-3</td>
</tr>
<tr>
<td>BR-4</td>
<td>10^-13 m^2/s</td>
<td>BR-4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Drying Shrinkage</th>
<th>Workability (stickiness)</th>
<th>Strength</th>
<th>RCPT</th>
<th>RMT</th>
</tr>
</thead>
<tbody>
<tr>
<td>BR-1</td>
<td>30.0</td>
<td>35.0</td>
<td>40.0</td>
<td>10^{-13} m^2/s</td>
<td></td>
</tr>
<tr>
<td>BR-2</td>
<td>140</td>
<td>290</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BR-3</td>
<td>15.0</td>
<td>20.0</td>
<td>25.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BR-4</td>
<td>20.0</td>
<td>25.0</td>
<td>30.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Summary – HPC Bridge Deck

- All meet requirements for Work
- Performance mixtures similar or better performance than Prescriptive mixture
  - Drying shrinkage, workability (stickiness), strength, RCPT, RMT
- Performance mixtures
  - Reduced “footprint” - sustainable
Specifications and Sustainability

- Ingredient materials
  - Limitations on source or brands
  - Limitations on composition or characteristics
  - Prohibit use

- Concrete Mixtures
  - Limits on mixture composition
  - w/cm
  - Strength
  - Air content

- Testing

Ingredient Materials

- Cement from specific source or Type
- Low alkali cement
- Fly Ash
  - Available alkalis
  - More restrictive loss on ignition (LOI)
  - Prohibit use of Class C fly ash
  - Maximum limits
- Slag cement (GGBFS)
  - Prohibit use
  - Maximum limits
Ingredient Materials

- Types and brands of admixtures
- Characteristics of aggregates
  - grading, crushed vs. natural
  - Restriction on use of local sources
- Require use of potable water
- Restrict use of recycled aggregates

Alkali Aggregate Reactions (Example)

- Use non-reactive aggregates
- Use low alkali cement
- Do not use Class C fly ash
- Max 25% Class F fly ash

Performance
- Expansion less than 0.1% at 14 days – ASTM C1567
- ASTM C1157, Option R or ASTM C595
- Overboard?
  - Expansion less than 0.08% at 28 days
Low alkali cement

- 1.6Mt raw feed for 1 Mt clinker
  - CKD = 1 to 5%
- To produce low alkali
  - Possibly increase waste
  - Import raw feed
  - Import cement

Water

- Use potable water

Potable
Non potable or recycled
Wash Water
Water – Alternative

- Water complies with ASTM C1602
  - Permitted in ACI 318, ACI 301, ASTM C94
- ASTM C1602 qualification
  - Strength and time of setting
  - Optional
    - Chlorides
    - Sulfates
    - Alkalis
    - Solids

Recycled Aggregate
Specifications

- **ASTM C33**
  - 9.1 Coarse aggregate shall consist of gravel, crushed gravel, crushed stone, air-cooled blast furnace slag, or crushed hydraulic cement concrete
  - Note 6 – cautions.

- **ASTM C125**
  - Manufactured sand – fine aggregate produced by crushing rock, gravel, iron blast-furnace slag, or hydraulic cement concrete

- Specification can permit use of recycled aggregate
  - For certain applications

### Minimum Cement Content

<table>
<thead>
<tr>
<th>Use</th>
<th>Cementitious Material Content (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Concrete designated by compressive strength:</strong></td>
<td></td>
</tr>
<tr>
<td>Deck slabs and slab spans of bridges</td>
<td>400 min., 475 max.</td>
</tr>
<tr>
<td>Roof sections of exposed top box culverts</td>
<td>400 min., 475 max.</td>
</tr>
<tr>
<td>Other portions of structures</td>
<td>350 min., 475 max.</td>
</tr>
<tr>
<td><strong>Concrete not designated by strength:</strong></td>
<td></td>
</tr>
<tr>
<td>Deck slabs and slab spans of bridges</td>
<td>400 min.</td>
</tr>
<tr>
<td>Roof sections of exposed top box culverts</td>
<td>400 min.</td>
</tr>
<tr>
<td>Prestressed members</td>
<td>400 min.</td>
</tr>
<tr>
<td>Seal courses</td>
<td>400 min.</td>
</tr>
<tr>
<td>Other portions of structures</td>
<td>350 min.</td>
</tr>
<tr>
<td><strong>Concrete for precast members</strong></td>
<td>350 min., 550 max.</td>
</tr>
</tbody>
</table>
Impact of specifying cement

![Graph showing compressive strength distribution with average strength and standard deviation.]

**Cement content – for sustainability**

- Reduce carbon footprint of concrete by 40%
- Max. portland cement – 400 lb/yd³ (240 kg/m³)
- Cement from wet-process plants prohibited

- Concrete should meet performance requirements
  - Post tensioning
  - Fast track construction
  - Durability
  - Comply with code requirements
Strength

- Concrete mixtures shall be designed for an average strength 1200 psi (8.3 MPa) greater than the specified strength
  - No incentive for good quality control

- Improved quality control  ➔ optimized mix

Developing Concrete Mixtures

\[ f'_c \quad \bar{X} = f'_c \quad \text{Specified} \]

3000  4000  5000  6000
Compressive Strength, psi
Air Content

- Air content shall be 7.5%
  - Tolerance shall be ±1%

- Air content is a function of aggregate size
- Is it needed for application?
- Higher air content
  - More cement to achieve strength

Water – cement ratio – w/cm

- w/cm specified for durability
  - Permeability
- Lower w/cm
  - Impacts placement
  - Increases cementitious materials factors
  - Increase mix cost
  - Not supportive of sustainability
- Do not specify when not applicable
Effect of W/C on Permeability

![Effect of W/C on Permeability](image)

Specifying Water-Cement Ratio

![Specifying Water-Cement Ratio](image)
Proficiency in Testing

Data for Medium Strength 4 x 8 Specimens

- Lab ID
- Strength, psi
- Med 4x8
- Average
- Outlier

nrmca.org

- ASCC and NRMCA Checklist for Concrete Producer-Concrete Contractor Fresh Concrete Performance Expectations (PDF)
- Guide Performance Based Specification for Concrete Materials - Section 0300 for Cast in Place Concrete (PDF)
- Guide to Improving Specifications for Ready Mixed Concrete (XML to PDF here)
- Guide to Specifying Concrete Performance (PDF)
- Quality Management System for Ready Mixed Concrete Companies (PDF)
- Research Report: Preparation of a Performance Based Specification for Cast in Place Concrete (PDF)
- Research Report: Experimental Case Study Demonstrating Advantages of Performance Specifications (PDF)
- P2P Article (PDF)
- Specifying Concrete for Durability: Performance Based Criteria Offer the Best Solutions (PDF)
- Performance Specifications for Durable Concrete (PDF)
- Acceptance Criteria for Durability Tests (PDF)
Guide to Performance

Guide to Specifying Concrete Performance

Negotiating Specifications

Guide to Improving Specifications for Ready Mixed Concrete

Guide Performance-Based Specification for Concrete Materials
Specification Evolution - Durability

- The Engineer specifies
  - Basic requirements (Code)

<table>
<thead>
<tr>
<th>Primary Requirement</th>
<th>Mix (B)</th>
<th>Durability Exposure</th>
<th>Specified Strength, Fc, psi</th>
<th>Max w/cm</th>
<th>Non-air entrained</th>
<th>Air entrainment</th>
<th>Slump at 7 days</th>
<th>Chloride limit</th>
<th>Temperature limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Footings</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Foundation Walls</td>
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<tr>
<td>Slabs, etc.</td>
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<tr>
<td>Exterior slabs</td>
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<tr>
<td>Insulated slabs (interior)</td>
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<td>Columns (interior)</td>
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<tr>
<td>Columns (exterior)</td>
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<td>Walls (interior)</td>
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</tr>
<tr>
<td>Concrete toppings</td>
<td></td>
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</tr>
</tbody>
</table>
Specification Evolution

- The Engineer specifies
  - Additional Performance requirements

### Specification Criteria

- Pre-Qualification
  - Can be more complex – duration of test
  - Rational approach to satisfying criteria
  - Procedures that cannot be used for jobsite acceptance
- Jobsite testing for project Quality Assurance
  - Simpler tests – may be “indicator” tests
  - Point of discharge (default for many performance criteria)
    - Point of placement (in addition to point of discharge?)
  - Consider test method precision and standard of care
  - Consider duration of test
- Referee testing
  - Establish criteria for “failing” QA results
Coordinate with Contractors

ACI and NRMCA
Checklist for Concrete Producer-Contractor Fresh Concrete Performance Expectations
Prescriptive for Performance (P3P) Initiative

Developed and approved by
ACI Technical Committee and
NRMCA Research, Engineering and Standards (RES) Committee

Guide to Performance

ACI/ITI#-329
Report on Performance-Based Requirements for Concrete
Reported by ACI Innovation Task Group 8

ACI Committee 329
### Specifications and Sustainability

<table>
<thead>
<tr>
<th>Specification Provision</th>
<th>Impact of provision</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Sustainability</td>
</tr>
<tr>
<td>Restrictions on Type and source of cement</td>
<td>↓</td>
</tr>
<tr>
<td>Restrictions on the use of cements conforming to ASTM C1157 and ASTM C595</td>
<td>↓</td>
</tr>
<tr>
<td>Restriction on cement alkali content</td>
<td>↓</td>
</tr>
<tr>
<td>Restriction on type and source of aggregates</td>
<td>↓</td>
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<tr>
<td>Invoking a minimum content for cementitious materials</td>
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</tr>
<tr>
<td>Prescriptive requirements toward green building credit</td>
<td>↑</td>
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<tr>
<td>Restriction on quantity of SCM</td>
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</tr>
<tr>
<td>Restriction on type or brands of admixtures</td>
<td>↔</td>
<td>↓</td>
</tr>
<tr>
<td>Establishing same class of concrete for all members</td>
<td>↓</td>
<td>↔</td>
</tr>
<tr>
<td>Requiring higher strength than required for design</td>
<td>↓</td>
<td>↔</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Specification Provision</th>
<th>Impact of provision on</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Invoking maximum w/cm when not applicable</td>
<td>↓</td>
<td>↔</td>
</tr>
<tr>
<td>Requiring a high air content</td>
<td>↓</td>
<td>↓</td>
</tr>
<tr>
<td>Restricting the use of a test record for submittals</td>
<td>↓</td>
<td>↓</td>
</tr>
<tr>
<td>Restriction on changing proportions when needed to accommodate material variations and ambient conditions</td>
<td>↓</td>
<td>↓</td>
</tr>
</tbody>
</table>
## Specifications and Sustainability

<table>
<thead>
<tr>
<th>Specification Provision</th>
<th>Impact of provision on</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sustainability</td>
</tr>
<tr>
<td>Requirement to use potable water</td>
<td>↓</td>
</tr>
<tr>
<td>Use of recycled aggregates and materials for specific applications</td>
<td>↑</td>
</tr>
<tr>
<td>Ensuring reliable testing</td>
<td>↑</td>
</tr>
<tr>
<td>Accurate estimation and optimizing scheduling of concrete delivery</td>
<td>↑</td>
</tr>
<tr>
<td>Specific Limitations on Slump</td>
<td>↓</td>
</tr>
</tbody>
</table>

- **Qualified Production Facilities**
  - Qualified Personnel
  - Qualified Products
NRMCA Concrete Plant Certification

- Ensures quality concrete production
- Quality control leads to lower environmental footprint
  - Optimize mix designs
  - Reduce waste
- Reduce cement use by significantly with good quality control program

NRMCA Quality Certification (new)

<table>
<thead>
<tr>
<th>Plant &amp; Truck Certification</th>
<th>Quality Certification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual Plant</td>
<td>Company or Division</td>
</tr>
<tr>
<td>Trucks</td>
<td>Quality Plan</td>
</tr>
<tr>
<td>Facility complies with</td>
<td>Qualified People</td>
</tr>
<tr>
<td>minimum industry standards</td>
<td>Testing Capabilities</td>
</tr>
<tr>
<td></td>
<td>Ingredient materials quality monitoring</td>
</tr>
<tr>
<td></td>
<td>Production facilities</td>
</tr>
<tr>
<td></td>
<td>Product Quality</td>
</tr>
<tr>
<td></td>
<td>Measurement systems</td>
</tr>
</tbody>
</table>
NRMCA Green-Star Certification

- Utilizes an EMS
- Plan-Do-Check-Act model
- Easy to use templates to develop an EMS

NRMCA Sustainable Plant Certification

- Guidance for continuous improvement
- Assessment tool for producers
- Rating system for concrete plants
- 3rd Party Audited
- Embodied Energy
- Carbon Footprint
- Water Use
- Waste
- Recycled Content
- Social Concerns and Human Health
NRMCA Certified Concrete Professionals

- Concrete Technology
- Operations & Production
- Sales & Marketing
- Sustainability
- Business Management

NRMCA Certified EPDs

- Certify EPDs
- Review LCAs
- Develop PCRs
- Consistent with other EPD Programs
## Qualifications of Plants

- NRMCA Concrete Plant Certification
- NRMCA Green-Star Plant Certification (optional)
- NRMCA Sustainable Concrete Plant Certification, Bronze Level or Higher (optional)

## Qualifications of Personnel

- NRMCA Certified Concrete Technologist Level 2
- NRMCA Certified Plant Manager (optional)
- NRMCA Certified Delivery Professionals (optional)
Qualification of Product

- Concrete supplier shall submit an Environmental Product Declaration (optional)*
  - Plant specific EPD is preferred
  - Industry wide EPD (where company is listed) is acceptable

* This requirement should be for all products, not just concrete

Concrete Mixture Requirement

<table>
<thead>
<tr>
<th>Application</th>
<th>Nominal Max. Aggregate Size*</th>
<th>Exposure Class*</th>
<th>$f'c^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interior slabs and beams</td>
<td>19 mm (3/4 in.)</td>
<td>F0, S0, P0, C0</td>
<td>28 MPa (4,000 psi)</td>
</tr>
<tr>
<td>Interior Columns</td>
<td>19 mm (3/4 in.)</td>
<td>F0, S0, P0, C0</td>
<td>35 MPa (5,000 psi)</td>
</tr>
<tr>
<td>Footings</td>
<td>38 mm (1-1/2 in.)</td>
<td>F0, S1, P0, C1</td>
<td>28 MPa (4,000 psi)</td>
</tr>
<tr>
<td>Exterior slabs and beams</td>
<td>19 mm (3/4 in.)</td>
<td>F3, S0, P0, C1</td>
<td>35 MPa (5,000 psi)</td>
</tr>
</tbody>
</table>

- Specify strength at age (more than 28 days)
- Specify Exposure Class (ACI 318)
- Additional criteria (permeability, shrinkage, etc.)
Conclusion

- Performance Specifications
  - Encourages partnering within construction team
  - Leads to innovation and satisfied customers
  - Reduces environmental impact

Thank you

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