

Experimental Case Study Demonstrating Advantages of Performance Specifications

Summary of Proposal¹ Submitted by

National Ready Mixed Concrete Association

Overview

NRMCA is working on an initiative to evolve specifications from prescriptive requirements to performance-based concepts. The Prescription to Performance (P2P) Initiative has been identified by the concrete producers as one of the significant ways to raise the level credibility and performance of the ready mixed concrete industry. It provides the technically competent concrete producer with a higher level of control on the concrete mixture to satisfy the needs of the owner. This project is a laboratory study designed to show the advantages of performance-based criteria over prescriptive requirements in concrete specifications. For the study typical specifications for two types of applications and the ACI 318 code provisions have been chosen. These specifications are generally prescriptive in nature. Concrete mixtures will be prepared according to the prescriptive provisions of these specifications and compared to mixtures that satisfy intended performance attributes. Fresh and hardened concrete properties will be quantified and compared. It is anticipated that this comparison will demonstrate the benefits and optimization of concrete mixtures from performance based specifications.

Three experimental case studies will be obtained to quantify the benefits and optimized cost of concrete mixtures furnished under performance based specifications. The study will also identify performance based alternatives and criteria to prescriptive requirements in the selected applications. The case studies will be used in the P2P presentation and will clearly identify the advantages of the performance design specification over prescriptive. These results will be very important to the success of the P2P Initiative to convince design professions with hard concrete test data to support performance-based specifications.

Statement of purpose

The Prescription to Performance (P2P) Initiative has been identified by the concrete producers as an important step to elevate the level of performance of the ready mixed concrete producer with more control over the concrete mix design to furnish the defined performance requirements of a specification. The current system of prescriptive specifications does not offer any incentive for a ready mixed concrete quality management system or product development. It follows an “one-size-fits-all” approach and limits the ability to optimize concrete mixtures for performance. Frequently the specifications include conflicts and are not clearly defined. This results in call backs, change orders and generally reduces the level of credibility of concrete construction relative to other construction products such as steel and wood.

A significant part of the P2P Initiative is proper communications. Several deliverables are necessary to develop this communication package. This study to quantify the experimental case study is one part of this package. Practical examples with actual concrete test results will go a long way in strengthening the P2P message. The benefits have to be demonstrated with practical examples to ensure buy-in from all

stakeholders. Individual companies have demonstrated this on specific projects. However, we are not aware of any published information in a planned case study that demonstrates the benefit.

Typical concrete specifications representing two market areas have been chosen. The first is for concrete floors used by one of the nation's largest retailers. The second is a High Performance Concrete specification for bridge decks used by a State Highway Agency. A third part of the experimental study addresses the prescriptive provisions in the ACI 318 building code.

In all cases concrete mixtures to satisfy the prescriptive specification are developed. Mixtures are also designed to demonstrate performance measures that satisfy performance criteria that are implied by the prescriptive measures. Various fresh and hardened concrete tests will be conducted. It will be shown that the properties of the concrete meeting the performance specification are significantly better than that meeting the prescriptive specification.

The completed study will be packaged in presentation format and published in a recognized journal to demonstrate the concept of performance based specifications.

Methodology

Case 1: Concrete Floor Specification

The main features of the concrete floor specification used by one of the nation's largest retailer's is as follows:

- a. Specified 28 day compressive strength=4000 psi; a required overdesign of 1200 psi, the required average strength will be 5200 psi
- b. Maximum water to cement ratio of 0.50
- c. No fly ash or slag is allowed
- d. Slump < 4"
- e. Combined aggregate gradation shall be 8% - 18% for large top size aggregates (1½") or 8% - 22% for smaller top size aggregates (1" or ¾") retained on each sieve below the top size and above the No. 100 sieve. Slabs on grade shall have a maximum aggregate size of 1½" footings and piers 1" and beams ¾".
- f. w/cm will be measured by micro-wave oven test and concrete accepted based on that

Several concrete mixtures will be developed to illustrate comparisons of options that might be used to optimize mixtures that follow performance-based requirements. The following will be simulated:

- Mix 1 = Control– to the prescriptive specification (producer targets w/cm=0.45 to avoid penalty of being over 0.50 thus ending up with high paste content and high shrinkage because of that)
- Mix 2 = Same as Mix 1, but with lower cement content and thus a higher w/cm-.53. this mix will have lower paste and so less shrinkage. Strength will be lesser but may still be over 5200 psi and certainly over 4600 psi. If strength is between 4600 and 5200 psi we can say that the producer uses statistical QA plan.

- Mix 3 = same as Mix 2 but with fly ash
- Mix 4 = same as Mix 3 but producer uses 1 stone and 1 sand (too expensive to get intermediate aggregate source) and does not meet 8-18, uniform grading specification
- Mix 5 = ternary mix with fly ash and slag. Producer has many silos and is taking advantage, producer uses 1 stone and 1 sand
- Mix 6 = SRA mix, producer uses 1 stone and 1 sand, same paste content as Mixes 2-5. Mix has lower w/cm so that it can give same strength as Mixes 2-6
- Mix 7 = to show effect of reducing water content with MRWR and cement content (for same w/cm) and have a low paste content

This part of the study represents a total of 8 concrete mixtures (control mix repeated) and the details of mixture design and tests are provided in Table 1 in Appendix I.

The performance criteria will target the following requirements:

- a. Specified 28 day compressive strength=4000 psi; Average strength will be based on ACI 318 or ACI 301 from past test records
- b. Supplementary cementitious materials will be used
- c. Slump = 4" – 6"
- d. Shrinkage < 0.05% at 28 days of drying after 7 days of moist curing.
- e. A procedure to evaluate the degree of curling relative to the measured drying shrinkage will be attempted

By following performance specification over prescription following favorable outcomes will be demonstrated:

1. Demonstrate where prescriptive specs results in poor performance (higher shrinkage) inspite of good strength, and low w/cm
2. Improved potential durability by permeability measurements with use of fly ash and slag
3. Various options of optimizing concrete for performance with cementitious combinations
4. Benefits of improved quality control and test record documentation
5. Demonstrate whether the option of a 2-aggregate mixture (coarse and fine) is comparable to the performance of a mixture meeting the 8-18 aggregate grading requirement.
6. Use of admixture technology to reduce shrinkage

In summary all mixes will perform better than the prescriptive concrete mixture.

Case 2: High Performance Concrete (HPC) Bridge Deck Concrete Specification

The main features of the concrete bridge deck specification used by one of the Department of Transportation is as follows:

- a. Specified 28 day compressive strength=4000 psi; Required average strength will be based on a historical test record in accordance with ACI 318.

- b. Maximum water to cementitious ratio of 0.38
- c. Total Cementitious Content = 705 lbs/yd³. 15% Fly ash plus 7% to 8% silica fume is required as a replacement to cement
- d. Air entrainment of 5% to 7% required
- e. Slump = 5" – 7"
- f. RCPT = 1000 coulombs by 28 day heat method

Several concrete mixtures will be developed to illustrate comparisons of options that might be used to optimize mixtures that follow performance-based requirements. They are:

- Mix 1 = control according to prescriptive specs
- Mix 2 = much lower paste content, same w/cm as #1, lower CM, lower silica fume, more fly ash, this mix will have less shrinkage, and adequate strength/durability
- Mix 3 = same w/cm as #1, similar paste content as #2, 50% slag mix, no silica fume
- Mix 4 = similar to Mix 2 except that ultra fine fly ash replaces silica fume, water content lower as per manufacturer recommendations

This part of the study represents a total of 4 concrete mixtures and details are provided in Table 2 in Appendix I.

The performance criteria will target the following requirements:

- a. Specified 28 day compressive strength=4000 psi; Required average strength based on ACI 318 or ACI 301 using past test records.
- b. Supplementary cementitious materials are allowed and their dosages will not exceed limits of ACI 318 to protect against deicer scaling.
- c. Slump = 5" – 7"
- d. Air entrainment of 5% to 7% required.
- e. RCPT = 1000 coulombs by 28 day heat method
- f. Shrinkage < 0.05% at 28 days of drying after 7 days of moist curing.

By following performance specification over prescription following favorable outcomes will be shown:

1. Demonstrate the potential for similar or improved performance at an improved workability, lower shrinkage, and lower cost, similar durability, adequate strength.

Case 3: ACI 318 Code Provisions

Chapter 4 of the ACI 318 Building code is the primary part that has prescriptive requirements for concrete for reasons related to durability. These include freeze-thaw, deicer scaling, sulfate resistance, protection from corrosion and reduce permeability.

Several concrete mixtures will be developed to illustrate comparisons of options that might be used to optimize mixtures that follow performance-based requirements. ACI 318's idea to controlling durability is to control w/cm. The aim is to show that with the same w/cm concrete can perform quite differently:

- Mix 1 = control according to prescriptive specs
- Mix 2 = 25% fly ash mix with a lower paste content
- Mix 3 = 25% fly ash mix with an even lower paste content due to use of HRWR (lower water)

This part of the study represents a total of 3 concrete mixtures and the aim is to show that with the use of mineral and chemical admixtures concrete performance can be drastically different even at the same w/cm. Durability, and shrinkage will be shown to drastically vary even at the same w/cm.

The performance criteria will target the following requirements:

- a. Supplementary cementitious materials are allowed and their dosages are restricted according to ACI 318.
- b. Slump = 5" – 7"
- c. Air entrainment of 5% to 7% required.
- d. RCP <2000 coulombs
- e. Sulfate resistance, C 1012 expansion < 0.05 at 6 months

The main aim of this case study is to show that since the development of the prescriptive ACI 318 durability provisions considerable advances have been made in understanding the influence of concrete mixture optimization for concrete durability. ACI 318 has not kept pace with those developments. It continues to attach importance to w/cm and strength as the main measure of ensuring concrete durability. This test program will show that significant difference in durability and shrinkage may be attained even at the same w/cm which satisfies the ACI 318 prescriptive requirements.

In summary the above 3 examples of concrete floors, HPC bridge decks, ACI 318 code recommendations show that performance specifications would allow a great opportunity to optimize the concrete mixture designs. It also rewards producers who maintain good quality control and maintain a database of past testing. This ensures that different producers can compete based on their strengths. This ensures that improved performance can be attained at optimized cost.

Timeline or schedule of activities

Material Procurement: 1 month

Test Program: 9 months

Report, paper for publication and Power Point Presentation: 2 months

Total Project Duration: 12 months from date of approval

Proposed allocation of staff, consultants, collaborating organizations, and other human resources

The complete project will be conducted at the NRMCA Research laboratory located at College Park, MD. The work will be conducted by the NRMCA staff. The time break down for each project task for each of The NRMCA personnell is provided under the budget information

Deliverable Product and Dissemination Plan

This project demonstrates through an experimental case study the benefits of performance based specification. The deliverables will be

1. A project report with all the detailed data
2. A presentation that can be used in information dissemination
3. A paper submitted to a refereed journal that can be used as a reference document

The target audience of the research findings will be primarily engineers and contractors, and other concrete producers.

Replicability or Application in Association Community

The major findings of this project will be that performance specifications will help achieve better concrete performance in a competitive environment where the concrete producers can optimize the concrete mixtures. As such the individual concrete producers can duplicate these tests with local materials to demonstrate the concept to engineers and contractors in their local areas.

Evaluation

An interim project report will be made available two months after the casting of all of the concrete mixtures. This report will just have the mixture design information and the test results to that point. At that time evaluation will be made on the potential outcome of the test results and the need to change the project direction if any. Selected members of the NRMCA RES Committee and/or the P2P Steering Committee will be included in planning the research program and developing the final deliverable products.

Qualifications

All of the personnel involved in the project have expertise in concrete technology and the relevant codes and standards.

Karthik Obla, Ph.D. is the Director of Research and Materials Engineering at the NRMCA. Prior to joining NRMCA, Mr. Obla was Technical Manager at Boral Material Technologies in San Antonio. Mr. Obla manages the research projects at the NRMCA and plays an important role in various other NRMCA activities such as P2P. Mr. Obla is Secretary of ACI committee 236 and a member of ACI committees 222, 232, and 365. He served as President of ACI San Antonio chapter. He is a member of the TRB committee on Durability of Concrete as well as several ASTM sub committees on concrete. He hold a Ph.D. from the University of Michigan, Ann Arbor.

Gary Mullings is the Senior Director of Operations and Compliance at NRMCA. He has been involved with the laboratory operations for 30 years. He has planned and administered several NRMCA industry and contract research programs, both at the laboratory and in field studies. Gary is the primary trainer for ACI technician certification programs and is involved in training basic concrete technology topics at the NRMCA Short Course, Environmental course, Dispatcher course, Concrete Delivery Professional certification program and sales training course. Mr. Mullings holds ACI Field and Laboratory certifications.

Soliman Ben Barka is the Senior Laboratory Technician at the NRMCA Research Laboratory and has been at the laboratory for 16 years. He has been an integral part of NRMCA industry and contract research and is competent in planning, scheduling and conducting concrete tests and documenting procedures and reporting test results. He holds ACI Field Testing and Laboratory Testing Certification. He is responsible for conducting the laboratory's reference sample testing program that is required to maintain its accreditation status. Mr. Mullings has been a primary or co-author on numerous technical publications.

Colin Lobo, Ph.D., P.E. is the Vice President of Engineering at the NRMCA. He holds a Ph.D. from Purdue University and is a licensed engineer in the state of Maryland. Mr. Lobo has been at the NRMCA for 12 years during which time he has been involved in planning, administering and reporting on research projects for the industry and individual companies on contract projects. Mr. Lobo is a member of ACI Committees 318 and 301 and on several key committees on ASTM. He has authored several technical publications and laboratory reports.

The National Ready Mixed Concrete Association is the premier industry association representing the majority of the ready mixed concrete produced in the US through its membership. The NRMCA's research facility has a strong history in establishing research programs that have benefited the industry and has established the standards for the production and testing of ready mixed concrete and constructed concrete structures. The NRMCA Research Laboratory is very well equipped to conduct standard and special testing of concrete and concrete making material. The laboratory participates in the Cement and Concrete Reference Laboratory (CCRL) Reference Sample Testing Program and the Laboratory Inspection Program and holds a current accreditation under the AASHTO Accreditation Program. This accreditation ensures that the laboratory maintains requisite procedures and practices in accordance with ASTM C 1077 and has demonstrated proficiency through the above mentioned CCRL sample testing and inspection programs.

Notes

1. This document is a summary of a proposal submitted to the Ready Mixed Concrete Research Foundation for research funding. The summary should be used for information purposes only. Many of the details including cost, schedule, and detailed qualifications of the researchers have been removed.

Appendix I – Experimental Details

Table 1 – Case 1: Proposed Test Conditions

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---------------------------|--------|--------|--------|--------|--------|--------|--------|
| Strength | 5200 | 4600 | 4600 | 4600 | 4600 | 4600 | 4600 |
| Air | na | na | na | na | na | na | na |
| Slump | 4"-6" | 4"-6" | 4"-6" | 4"-6" | 4"-6" | 4"-6" | 4"-6" |
| Aggregate | 8-18 | 8-18 | 8-18 | binary | binary | binary | binary |
| cement | 611 | 517 | 424 | 424 | 345 | 549 | 395 |
| fly ash | 0 | 0 | 106 | 106 | 79 | 0 | 99 |
| slag | 0 | 0 | 0 | 0 | 106 | 0 | 0 |
| Total CM | 611 | 517 | 530 | 530 | 530 | 549 | 494 |
| FA, % | 0.0% | 0.0% | 20.0% | 20.0% | 14.9% | 0.0% | 20.0% |
| SCM, % | 0.0% | 0.0% | 20.0% | 20.0% | 34.9% | 0.0% | 20.0% |
| water (pls adjust) | 275 | 275 | 260 | 260 | 260 | 265 | 240 |
| w/cm | 0.45 | 0.53 | 0.49 | 0.49 | 0.49 | 0.48 | 0.49 |
| paste, % | 27.84% | 26.06% | 26.04% | 26.04% | 26.06% | 26.07% | 24.14% |
| Type A WR | 3 oz | 3 oz | 3 oz | 3 oz | 3 oz | 3 oz | 3 oz |
| SRA | NO | NO | NO | NO | NO | YES | NO |
| MRWR | NO | NO | NO | NO | NO | YES | YES |

Repeat Control for quantifying repeatability

Mix 1 = Control– to the prescriptive specification (producer targets w/cm=0.45 to avoid penalty of being over 0.50 thus ending up with high paste content and high shrinkage because of that)

Mix 2 = Same as Mix 1, but with lower cement content and thus a higher w/cm-.53. this mix will have lower paste and so less shrinkage. Strength will be lesser but may still be over 5200 psi and certainly over 4600 psi. If strength is between 4600 and 5200 psi we can say that the producer uses statistical QA plan.

Mix 3 = same as Mix 2 but with fly ash

Mix 4 = same as Mix 3 but producer uses 1 stone and 1 sand (too expensive to get intermediate aggregate source) and does not meet 8-18, uniform grading specification

Mix 5 = ternary mix with fly ash and slag. Producer has many silos and is taking advantage, producer uses 1 stone and 1 sand

Mix 6 = SRA mix, producer uses 1 stone and 1 sand, same paste content as Mixes 2-5. Mix has lower w/cm so that it can give same strength as Mixes 2-6

Mix 7 = to show effect of reducing water content with MRWR and cement content (for same w/cm) and have a low paste content

Tests

slump, density, temp, combined aggregate sieve analysis and packing density (from void ratio C 29), set time (ASTM 403), strength (3, 7, 28), 6 x 12 inch cyl - 2 at each age, 6 total

bleeding, mortar, C 403, shrinkage 2 beams - 7 day moist - drying through 28 --- keep for 180 days, Simulate curling? 3x1.5x10 beam, finishability (hand finish pad of 2'x1'x4"), RCPT (90 days) - 2 4x8s, top 2" - cure them for 7 day moist room, segregation tests

Table 2 – Case 2: Proposed Test Conditions

| | 1 | 2 | 3 | 4 |
|--------------------|-----------|-----------|-----------|-----------|
| Strength | 4600 | 4600 | 4600 | 4600 |
| Air | 5-7% | 5-7% | 5-7% | 5-7% |
| Slump | 5" - 7" | 5" - 7" | 5" - 7" | 5" - 7" |
| Aggregate | no. 57 | no. 57 | no. 57 | no. 57 |
| Cement | 550 | 426 | 300 | 426 |
| Fly ash | 105 | 150 | 0 | 150 |
| Slag | 0 | 0 | 300 | 0 |
| Silica fume | 50 | 24 | 0 | 36 |
| Total CM | 705 | 600 | 600 | 612 |
| FA, % | 14.9% | 25.0% | 0.0% | 24.5% |
| SF, % | 7.1% | 4.0% | 0.0% | 5.9% |
| SCM, % | 22.0% | 29.0% | 50.0% | 30.4% |
| Water w/cm | 0.380 | 0.380 | 0.380 | 0.343 |
| paste, % | 30.22% | 25.92% | 25.33% | 25.17% |
| Type A WR | 3 oz/cwt. | 3 oz/cwt. | 3 oz/cwt. | 3 oz/cwt. |
| HRWR | YES | YES | YES | YES |

Mix 1 = control according to prescriptive specs

Mix 2 = much lower paste content, same w/cm as #1, lower CM, lower silica fume, more fly ash, this mix will have less shrinkage, and adequate strength/durability

Mix 3 = same w/cm as #1, similar paste content as #2, 50% slag mix, no silica fume

Mix 4 = similar to Mix 2 except that ultra fine fly ash replaces silica fume, water content lower as per manufacturer recommendations

Tests

slump, density, temp, Air, set time (ASTM 403), bleeding mortar, C 403, strength (3, 7, 28, 90), 4 x 8 inch cyl - 2 at each age, shrinkage 2 beams - 7 day moist - drying through 28 --- keep for 180 days, RCPT (28, 90, 180, 365 days) - 2 4x8s at each age - top 2" - cure them for 7 day moist room, sorptivity - cure them for 7 day moist room, 7 day lab air dry, then curing by C1585, rapid migration test NTBUILD 492 at 90 days - on same specimens as RCPT some of the RMT specimens, immerse them in 3% sodium chloride solution at after 28 days of curing at 90 days, 180 days, 365 days measure RMT for immersed and non immersed cases, Do same thing (immersed vs nonimmersed) for chloride diffusion test, 90, 180, 365 days age, Make many extra 4x8s and immerse in salt solutions

Table 3. Case 3: Proposed Test Conditions

| | 1 | 2 | 3 |
|--------------------|-----------|-----------|-----------|
| Strength | 4600 | 4600 | 4600 |
| Air | 5-7% | 5-7% | 5-7% |
| Slump | 5" - 7" | 5" - 7" | 5" - 7" |
| Aggregate | no. 57 | no. 57 | no. 57 |
| Cement | 750 | 525 | 405 |
| Fly ash | 0 | 175 | 135 |
| Slag | 0 | 0 | 0 |
| Silica fume | 0 | 0 | 0 |
| Total CM | 750 | 700 | 540 |
| FA, % | 0.0% | 25.0% | 25.0% |
| SF, % | 0.0% | 0.0% | 0.0% |
| SCM, % | 0.0% | 25.0% | 25.0% |
| Water | 285 | 265 | 205 |
| w/cm | 0.380 | 0.379 | 0.380 |
| paste, % | 31.05% | 29.95% | 23.14% |
| Type A WR | 3 oz/cwt. | 3 oz/cwt. | 3 oz/cwt. |
| HRWR | NO | NO | YES |

Mix 1 = control according to prescriptive specs

Mix 2 = 25% fly ash mix with a lower paste content

Mix 3 = 25% fly ash mix with an even lower paste content due to use of HRWR (lower water)

Tests

slump, density, temp, Air, set time (ASTM 403)

strength (3, 7, 28, 90)

shrinkage 2 beams - 7 day moist - drying through 28 --- keep for 180 days

RCPT (28, 90, 180, 365 days) - 2 4x8s - top 2" - cure them for 7 day moist room

sorptivity - cure them for 7 day moist room, 7 day lab air dry, then curing by C1585

rapid migration test NTBUILD 492 at 90 days - on same specimens as RCPT

some of the RMT specimens, immerse them in 3% sodium chloride solution at after 28 days of curing at

90 days, 180 days, 365 days measure RMT for immersed and non immersed cases

Do same thing (immersed vs nonimmersed) for chloride diffusion test, 90, 180, 365 days age

Make many extra 4x8s and immerse in salt solutions