feature

Experimental Case Study Demonstrates Advantages of Performance Specifications

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NRMCA is working on an initiative to evolve specifications from prescriptive requirements to performance-based concepts for concrete mixtures. The Prescription to Performance (P2P) Initiative has been identified by the concrete producers as one of the significant ways to raise the level of credibility and performance of the ready mixed concrete industry. It provides the concrete producer more control over his product to satisfy the needs of the owner.

When the concepts of P2P were discussed it was suggested that the advantages of performance specifications over prescriptive specifications should be clearly demonstrated through examples and technical data to support changes in codes and specifications. NRMCA Research Laboratory took up the challenge. The idea was to identify certain concrete applications, design the concrete mixture according to the current typical prescriptive specifications and demonstrate the benefits by developing concrete mixtures to intended performance criteria. Two applications, concrete floors and bridge decks, were chosen. The concrete floor mixture was designed according to the prescriptive specification used by one of the nation's largest retailers. The bridge deck was designed according to the prescriptive high performance concrete specification used by a state highway agency. A third part of the experimental study addressed some of the prescriptive requirements for concrete durability in the ACI 318 *Building Code for Structural Concrete*.

Concrete mixtures were prepared according to the prescriptive provisions of these

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specifications and compared to mixtures that satisfy the intended performance attributes. Fresh and hardened concrete properties were measured and compared. This comparison demonstrated the benefits and optimization of concrete mixtures for performance over prescriptive provisions. Funding for the study was provided by the RMC Research Foundation.

Experimental Study

Case 1: Concrete Floor Specification (FS)

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

a. Specified 28-day compressive strength = 4000 psi; a required over design of 1200 psi, the required average strength will be 5200 psi
b. Maximum water to cement ratio of 0.54. W/CM to be measured by microwave oven test — penalties for higher w/cm and concrete rejected beyond a limit
c. No fly ash or slag is allowed
d. Slump < 4 inches
e. Non-air entrained
f. Combined aggregate gradation shall be 8% - 18% retained on each sieve below the top size and above the No. 100 sieve. Maximum aggregate size will be 1 1/2"
g. No high range water reducer allowed

The performance criteria targeted the following requirements:

a. Specified 28-day compressive strength = 4000 psi; Average strength based on ACI 318 or ACI 301 from past test records
b. Supplementary cementitious materials may be used
c. Slump = 4 – 6 inches
d. Length change (drying shrinkage) (ASTM C 157) < 0.04% at 28 days of drying after 7 days of moist curing.
e. Setting time (ASTM C 403) under laboratory conditions = 5 1/2 hours

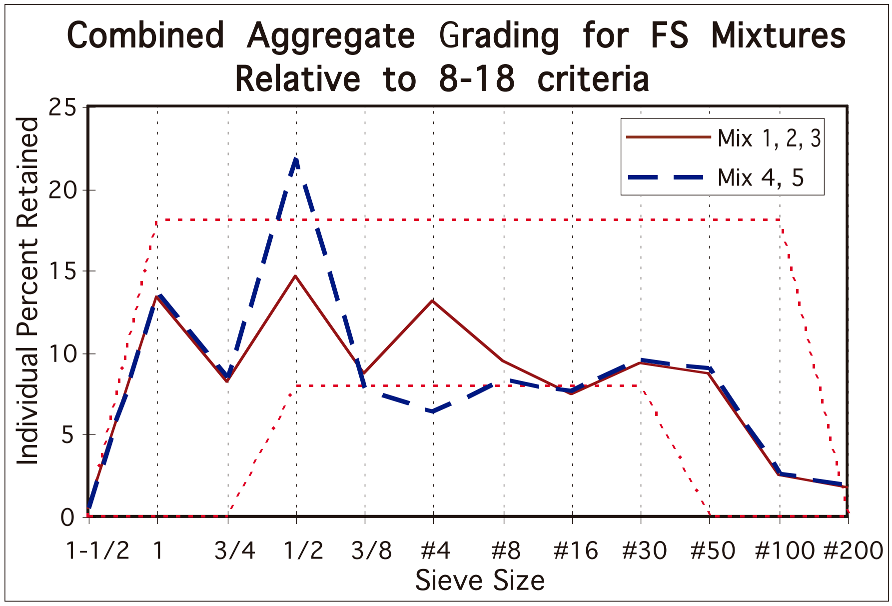

Table 1: Details of Floor Slab Mixes

	Mixture Number				
	FS-1	FS-2	FS-3	FS-4	FS-5
Mixture Proportions, lb/yd³					
Cement	611	517	424	424	345
Fly Ash	0	0	106	106	79
Slag	0	0	0	0	106
Coarse Agg #1 (#467)	1732	1732	1732	1813	1813
Coarse Agg #2 (#8)	306	306	306	0	0
Coarse Agg #3 (1/2"-3/4")	0	0	0	224	224
Sand	1152	1229	1230	1231	1230
Water	298	295	280	280	289
w/cm ratio	0.49	0.57	0.53	0.53	0.54
Fresh Concrete Properties					
Slump, in	4.00	4.75	6.00	4.75	5.50
Air Content, %	1.8	2	2.7	2.3	2.7
Density, lb/ft³	152.5	150.5	150.5	150.9	150.5
Temperature, °F	71	70	68	66	70
Initial Setting time, h	4:12	4:45	5:30	5:17	5:59
Finishability Index (1-5)	4.75	4.5	4.5	5	4.5
Hardened Concrete Properties					
28-day Strength, psi	5871	5047	4856	4977	4715
Length change 90-day, %	-.032	-0.045	-0.031	-0.022	-0.038
Segregation - Top to bottom diff in CA, %	22%	24%	21%	23%	15%
C 1202 Charge passed, Coulombs	2709	4520	3093	2726	839

Five concrete mixtures were cast. The mixture design and test results are provided in Table 1.

All mixtures were non-air entrained and adjusted to achieve the target slump requirement. No water reducing admixtures were used as initial trials with water reducing admixtures showed high air contents with the fly ash mixtures. It was felt that eliminating the use of water reducers would not affect the general conclusions of the project.

Discussion of Test Results

Mixture 1 is the control mixture designed according to the prescriptive specification. The 8-18 aggregate gradation specification was achieved by combining an ASTM C 33 No. 467 aggregate with a small amount of No. 8 aggregate. The specification also requires that the w/cm will be measured by the microwave oven test and concrete accepted based on the measured w/cm. To allow for the variability of the measured water content using the microwave oven test (AASHTO T 318), the producer will need to target a much lower w/cm to ensure compliance. The target w/cm ratio was set to 0.49 compared to the maximum limit of 0.54. To achieve this w/cm with the aggregates available, the producer is forced to use a higher cement content of 611 lbs/yd^3 and not include any supplementary cementitious materials. As shown in Table 1 this results in a 28-day compressive strength of 5870 psi, which is significantly higher than required. The average length change (ASTM C 157) after 7 days of moist curing and 28 days of drying was 0.018% and was 0.032% after 90 days of drying. The laboratory initial setting time (ASTM C 403) of the concrete mixture was 4 h 12 m.

Mixtures 2-5 were designed to satisfy the performance based criteria.

Mixture 2 was similar to Mixture 1 except that it had a lower cement content at 517 lbs/yd^3 and thus a higher w/cm (0.57). In this case it is assumed that the producer is not restricted by a prescriptive low w/cm requirement. This mixture was targeted to achieve an average strength of 4600 psi assuming that the producer has prior test records that will permit him to reduce his required average strength in accordance with ACI 318 and 301. The measured 28-day compressive strength was 5050 psi, which achieves the objective. The average length change (ASTM C 157) after 7 days of moist curing and 28 days of drying was 0.020% and was 0.045% after 90 days of drying. The length change was within the 28-day limit of 0.040%. It was surprising that the 90-day length change of Mixture 2 was much higher than Mixture 1, which had a higher cement (94 lbs+) and hence a higher paste content (1.95%+). The laboratory initial setting time of the concrete mixture was 4 h 45 m, which satisfies the performance requirement.

Mixture 3 had 20% ASTM C 618 Class F fly ash and the total cementitious content was also slightly higher at 530 lbs/yd^3. The water requirement of the fly ash concrete mixture was slightly lower (280 lbs/yd^3) to achieve the target slump. The measured 28-day compressive strength was 4860 psi, which achieves the strength requirement. The average length change (ASTM C 157) after 7 days of moist curing and 28 days of drying was 0.014% and was 0.031% after 90 days of drying. The laboratory initial setting time of the concrete mixture was 5 h 30 min, which just satisfied the performance requirements.

Mixture 4 was similar to Mixture 3 except that the aggregate gradation did not meet the prescriptive 8-18 grading specification. The intermediate size No. 8 aggregate was not used. The combined grading of the No. 467 coarse aggregate and fine aggregate were found to be just out of range of the 8-18 grading. To further exaggerate the effect, additional coarse aggregate between 3/4 and 1/2 inch was added to the coarse aggregate. The water requirement of the fly ash concrete mixture was 280 lbs/yd^3 to achieve the target slump. The measured 28-day compressive strength was 4980 psi. The average length change (ASTM C 157) after 7 days of moist curing and 28 days of drying was 0.012% and was 0.022% after 90 days of drying. The laboratory initial setting time of the concrete mixture was 5 h 17m. The lack of uniform aggregate grading did not adversely impact the drying shrinkage. In fact this mixture had the lowest length change values recorded of all five mixtures.

Mixture 5 was identical to Mixture 4 except that it was a ternary mix with Class F fly ash (15%) and slag (20%) as part of the total cementitious content. The water requirement of the ternary concrete mixture was 289 lbs/yd^3 to achieve the target slump. The measured 28-day compressive strength was 4720 psi. The average length change (ASTM C 157) after 7 days of moist curing and 28 days of drying was 0.035% and was 0.038% after 56 days of drying. Even though the shrinkage value met the performance requirements this concrete mixture had the highest length change value. The laboratory initial setting time of the concrete mixture was 5 h 59 m, which exceeded the targed limit of 5 h:30 m. The slower setting was likely due to the higher quantity of supplementary cementitious materials (35% of total cementitious) used.

In addition, the following tests were also carried out:

Slab Finishability: Small concrete slabs 2x1 foot at 4 inches thickness were made in the lab and finished by hand. A "finishability rating" value between 1 and 5 was given as a measure of the concrete finishability with the following criteria (5=Excellent to 1=Poor). All 5 slabs had a rating above 4.5 thus indicating excellent finishability.

Rapid Indication of Chloride Ion Penetration (ASTM C 1202): Two cylinders from each mixture were cast and moist cured till the test age. The rapid chloride permeability test was carried out at an age of 75 to 80 days except for Mixture 5, which was tested at an age of 95 days. Mixtures 1, 3 and 4 had an average chloride ion penetrability of about 3000 coulombs and hence these mixtures would be classified as having a moderate chloride ion penetrability. Mix-

Finishability Test in Progress

ture 2 had about 4500 coulombs and would be classified as having a high chloride ion penetrability. Mixture 5 had an average chloride ion penetrability of 839 coulombs and would be classified as having a very low chloride ion penetrability. Rapid chloride penetrability is typically not a desired performance requirement for concrete floor applications. Comparing the performance of Mixtures 3 and 4 indicates that the aggregate grading did not have much impact on the chloride ion penetrability.

Rapid Indication of Chloride Ion Penetration (ASTM C 1202) Test Set Up

Segregation Test: In this test a concrete 6 x12 inch cylinder was cast after the concrete slump was raised to between 5 and 6 inches. The cylinder was vibrated using an internal vibrator. The cylinder was cut after 7 days of moist curing and the density of the top and bottom halves were determined by weighing them in air and submerging in water. Variation in density was presumed to be a result of segregation, i.e. migration of the coarse aggregate particles toward the bottom. Since the calculated density of coarse aggregate particles (specific gravity x unit wt. of water) in this case is much denser (177 lbs/ft^3) as compared to the mortar (calculated to be about 131 lb/ft^3), this was used to estimate the variation in coarse aggregate content between the top and bottom specimens from the difference in density. The difference in the coarse aggregate content was consistently about 20% except for Mixture 5, which was about 15%. This leads to a conclusion the aggregate grading differences of the mixtures within the scope of this study did not impact the segregation characteristics of the mixtures at higher slumps.

The above experimental study brings out the following conclusions:

1. Prescriptive specifications do not essentially result in good performance. Conforming to a uniform aggregate grading in this study did not have significant impact on the segregation, finishability or drying shrinkage of the concrete. A more extensive study focused on the effectiveness of uniform aggregate gradation is ongoing at the NRMCA Research Laboratory. Specifying the 1200 psi over design and conforming to the required w/cm ratio is unnecessary and could in fact adversely impact intended performance.
2. Another analysis that can be conducted here is the economy of the concrete mixture. Using certain assumptions of material costs from the NRMCA Industry Data Survey, it is estimated that the material costs of Mixture 1 will be about \$43.4/yd^3. In comparison the performance concrete mixtures save between 8.8% and 15.2% of the material costs. Cost savings will be higher if one considers the elimination of the use of the intermediate size No. 8 aggregate needed to achieve the 8-18 aggregate grading.

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

The main features of the high performance concrete bridge deck specification used by one Department of Transportation are 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 0.39
c. Total Cementitious Content = 705 lbs/yd^3. 15% Fly ash plus 7% to 8% silica fume is required as a replacement to cement
d. Slump = 4 – 6 inches
e. Air entrainment of 4% to 8% required

The performance criteria were established to 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 salt scaling
c. Slump = 4 – 6 inches
d. Air entrainment of 4% to 8% required
e. RCPT (ASTM C 1202) = 1500 coulombs after 45 days of moist curing
f. Length change (drying shrinkage) < 0.04% at 28 days of drying after 7 days of moist curing

Four concrete mixtures were cast. The mixture design and test results are provided in Table 2.

All mixtures were designed for the slump and air requirement. All four mixtures contained a standard ASTM C 494 Type A water reducer dosage at 4 oz/cwt and an ASTM C 494 Type F HRWR dosage sufficient to attain the desired slump.

Discussion of Test Results

Mixture 1 is the control mixture designed according to the prescriptive specification. The w/cm was 0.39 and the total cementitious content was 705 lbs/cyd out of which 15% was Class F fly ash and 7% was silica fume. The measured 28-day compressive strength was 7480 psi, which is significantly higher than required. The 45-day charge passed by ASTM C 1202 was 1563 coulombs (average of two specimens). The average length change (ASTM C 157) after 7 days of moist curing and 28 days of drying was 0.043%.

Mixture 2 had the same w/cm (0.39) as Mixture 1 but had a much lower total cementitious content (600 lbs/yd^3 as opposed to 705 lbs/yd^3). The silica fume content was set at 4% and the quantity of Class F fly ash was increased to 25% by mass of cementitious materials. The measured 28-day compressive strength was 6800 psi, which exceeded the strength requirement. The 45-day rapid chloride permeability value was 1257 coulombs (average of 2 specimens). The average length change (ASTM C 157) after 7 days of moist curing and 28 days of drying was 0.024%. The reduced shrinkage value is likely because of the lower paste content (4.36%). Another interesting observation is that the required HRWR dosage was about 27% lower for Mixture 2 compared to Mixture 1 even at a lower water content of the concrete by over 15%. This is because of the much lower silica fume content and higher fly ash content used in Mixture 2. The performance of Mixture 2 exceeded that of Mixture 1.

Mixture 3 had the same w/cm (0.39) as Mixture 1 but had a much lower total cementitious content (600 lbs/yd^3 as opposed to 705 lbs/yd^3). This mixture contained 50% slag by mass of cementitious materials without silica fume or fly ash. The measured 28-day compressive strength was 8970 psi, which is much higher than required. The 45-day charge passed by ASTM C 1202 was 1126 coulombs (average of two cylinders). The average length change (ASTM C 157) after 7 days of moist curing and 28 days of drying was 0.026%. The HRWR dosage required was about 40% higher than that of Mixture 1. The performance of this mixture was significantly better than the DOT-specified Mixture 1.

Mixture 4 was similar to Mixture 2 with the replacement of ultra fine fly ash (UFFA) instead of silica fume. Based on supplier's recommendations the quantity of the UFFA

Table 2: Details of the HPC Bridge Mixtures

	Mixture Number			
	Br-1	Br-2	Br-3	Br-4
Mixture Proportions, lb/yd^3				
Cement	550	426	300	426
Fly Ash	105	0	0	0
Silica Fume	50	24	0	0
Slag	0	150	300	150
Ultra Fine Fly Ash	0	0	0	34
Coarse Agg (#67)	1800	1922	1940	1945
Sand	1121	1199	1209	1214
Water	275	234	234	218
AEA (oz/cwt)	0.40	0.45	0.40	0.40
Water Reducer (oz/cwt)	4.0	4.0	4.0	4.0
HRWR (oz/cwt)	13.0	9.4	18.4	11.1
w/cm ratio	0.39	0.39	0.39	0.36
Fresh Concrete Properties				
Slump, in	4.00	5.00	5.00	5.75
Air Content, %	4.6	7.2	4.7	7.6
Density, lb/ft^3	145.7	144.1	150.5	142.5
Temperature, ºF	69	69	65	69
Hardened Concrete Properties				
28-day Strength, psi	7477	6797	8974	7176
Length change 90-day, %	-0.043	-0.024	-0.026	-0.023
C 1202 Charge passed, Coulombs	1563	1257	1126	1244
Rapid Migration, mm/V-hr	0.019	0.018	N/A	0.023

Rapid Migration Test (AASHTO TP 64) Showing Chloride Penetration Depths

Sorptivity Test (ASTM C 1585) Set Up

was about 40% higher than that of silica fume used in Mixture 2. The water content of this mixture was about 7% lower than Mixture 2. The measured 28-day compressive strength was 7180 psi. The 45-day charge passed by ASTM C 1202 was 1244 coulombs (average of two specimens). The average length change (ASTM C 157) after 7 days of moist curing and 28 days of drying was 0.023%. The required HRWR dosage was about 15% lower for Mixture 4 as compared to Mixture 1 even with a water content that was reduced by over 20%. The performance of this mixture achieved the performance criteria by a significant margin over the DOT-specified Mixture 1.

In addition the following tests were also carried out:

Rapid Migration Test (AASHTO TP 64): This test is similar to ASTM C 1202 in that chloride ions are driven into the concrete with an electric current. In this method, the depth of penetration of chloride ions is measured by spraying the fractured specimen with silver nitrate. The Rapid Migration Test is considered to be a more reliable indicator of the permeability of concrete. The results are reported as rate of penetration, which is calculated by dividing the depth of penetration (mm) by the product of applied voltage (V) and the test duration (hr). The measured rate of penetration for the mixtures after 65 days of moist curing varied between 0.018 mm/V-hr and 0.023 mm/V-hr (average of two cylinders). These numbers indicate no significant differences

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Chloride Diffusion Test (ASTM C 1556) Specimens Immersed in Chloride Solutions. (5 gallon bucket is covered and sealed until test age)

between the concrete mixtures and comply with the performance requirements of FHWA's HPC Grade 2 according to AASHTO TP 64. No measurable chloride penetration was observed for the slag concrete mixture (Mixture 3).

Sorptivity Test (ASTM C 1585): In this test 2-inch-thick concrete slices from a cylinder are exposed to a thin layer of water in contact with one face of the specimen. The other surfaces are sealed. The increase in specimen weight due to moisture absorption is measured with time. The rate of water absorption is calculated and reported. The tests are in progress at the time of writing this article.

Chloride Diffusion Test (ASTM C 1556): In this test the concrete cylinders are sealed and immersed in chloride solution with one unsealed face exposed to the solution. After a specific exposure period the cylinder is removed and ground in 2 mm thick layers from the exposed surface. The chloride content is measured at different depths from which an apparent chloride diffusion coefficient is calculated. At the time of this report the exposure to solution is continuing and data are not available.

The above experimental study brings out the following conclusions:

1. The prescriptive DOT specification for bridge deck concrete can be significantly optimized for improved performance on drying shrinkage, strength and permeability. The optimized mixtures resulted in improved workability (were less sticky) and had reduced dosage of HRWR.
2. Concrete mixtures optimized for performance help achieve remarkable cost savings. It is estimated that the material costs of Mixture 1 will be about \$57.8/yd^3. In comparison, the performance concrete mixtures save between 15.5% and 22.8% of the material costs.

Case 3: ACI 318 Code Provisions

Durability provisions are addressed in Chapter 4 of ACI 318 Building Code for Structural Concrete. The code addresses durability requirements for concrete exposed to freeze-thaw cycles, deicer scaling, sulfate resistance, protection from corrosion of reinforcing steel and conditions needing low permeability. In all cases, the primary requirement of controlling the permeability of concrete is a maximum limit on the water to cementitious materials ratio (w/cm).

The scope of this part of the study was limited to compare the performance of concrete mixtures with different cementitious materials and content with regards to permeability. Drying shrinkage measurements are also compared even though this is not a

P2P provides the concrete producer more control over his product...

limitation in the code. Four concrete mixtures were prepared with the same w/cm=0.42. Mixtures were designed in accordance with ACI 211.1, with certain variations. The slump ranged between 3.75 and 6.5 inches and the air content ranged between 4.1% and 7.4%. The mixture proportions and test results are provided in Table 3.

Discussion of Test Results

Mixture 1 contained 750 lbs/yd^3 of ASTM C 150 Type I portland cement. The measured 28-day compressive strength was 5440 psi. The 28-day charge passed by ASTM C 1202 was 8356 coulombs (average of two specimens). The average length change (ASTM C 157) after 7 days of moist curing and 28 days of drying was 0.060%. The measured rate of penetration using the Rapid Migration test for the mixture after 53 days of moist curing was 0.069 mm/V-hr.

Mixture 2 contained 700 lbs/yd^3 of total cementitious content out of which 25% was ASTM C 618 Class F fly ash. The paste content was lower by 1.16% as compared to Mixture 1. The measured 28-day compressive strength was 5950 psi and the 28-day charge passed by ASTM C 1202 was 5610 coulombs (average of two specimens). The average length change (ASTM C 157) after 7 days of moist curing and 28 days of drying was 0.044%. The measured rate of penetration for the mixture after 52 days of moist curing was 0.042 mm/V-hr.

Table 3: Details of the ACI 318 Mixtures

	Mixture Number			
	318-1	318-2	318-3	318-4
Mixture Proportions, lb/yd^3				
Cement	750	525	423	423
Fly Ash	0	175	141	141
Coarse Agg (#67)	1800	1800	1800	2020
Sand	1005	1055	1328	1128
Water	312	291	235	235
AEA (oz/cwt)	0.35	0.39	0.49	0.39
Water Reducer (oz/cwt)	4.0	4.0	4.0	4.0
HRWR (oz/cwt)	n/a	n/a	7.4	9.0
w/cm ratio	0.42	0.42	0.42	0.42
Fresh Concrete Tests				
Slump, in	4.75	6.50	3.75	5.25
Air Content, %	7	4.1	7.2	7.4
Density, lb/ft^3	138.8	146.5	143.7	143.7
Temperature, ºF	70	69	67	65
Hardened Concrete Properties				
28-day Strength, psi	5442	5948	5673	5602
Length change 56-day, %	-0.06	-0.044	-0.038	-0.032
C 1202 Charge passed, Coulombs	8356	5610	4462	4036
Rapid Migration, mm/V-hr	0.069	0.042	0.049	0.037

Mixture 3 contained 564 lbs/cyd of total cementitious content out of which 25% was ASTM C 618 Class F fly ash. The w/cm was maintained at 0.42 by using a HRWR. This helped to reduce the cement paste content by 7.24% as compared to Mixture 1. The reduction in paste content was compensated for by increasing the fine aggregate content. The measured 28-day compressive strength was 5670 psi and the 28-day charge passed by ASTM C 1202 was 4462 coulombs (average of 2 specimens). The average length change (ASTM C 157) after 7 days of moist curing and 28 days of drying was 0.038%. The measured rate of penetration for the mixture after 52 days of moist curing was 0.049 mm/V-hr.

Mixture 4 was identical to Mixture 3 except that the reduction in paste content was accomplished largely by an increase in the total coarse aggregate content. The measured 28-day compressive strength was 5600 psi and the 28-day charge passed by ASTM C 1202 was 4036 coulombs (average of two specimens). The average length change (ASTM C 157) after 7 days of moist curing and 28 days of drying was 0.032%. The measured rate of penetration for the mixture after 52 days of moist curing was 0.037 mm/V-hr.

Chloride diffusion studies are still ongoing at this stage. The above experimental study brings out the following conclusions:

1. At the same w/cm concrete performance can be drastically different by changing the type and quantity of cementitious materials and by using chemical admixtures. Code limitations on w/cm ratio do not assure the owner that a concrete mixture with a low permeability will be achieved. Even though the compressive strength was fairly similar the drying shrinkage varied over a very wide range, between 0.032% and 0.060%. The durability represented by the 28-day rapid chloride permeability values varied

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> "Prescriptive specifications that imply performance do not assure anything."

between 4036 coulombs and 8356 coulombs and the measured rate of penetration varied between 0.037 mm/V-hr and 0.069 mm/V-hr. Even though these values are high, suggesting that all mixtures have a high chloride ion penetrability, these are expected to decrease with age, especially for mixtures containing the supplementary cementitious materials and it is expected that the difference in the concrete performance will be more pronounced.

2. Over the years considerable advances have been made in understanding the influence of concrete mixture optimization for concrete durability. Requirements in the ACI 318 Building Code have not kept pace with those developments. It continues to attach importance to w/cm as the primary means of controlling concrete durability. This test program shows that significant difference in durability and shrinkage can be attained at the same w/cm and similar strength. Alternative options for durability should be considered to the current limitations of the ACI 318 Building Code.

Summary

The above three examples of concrete floors, HPC bridge decks and ACI 318 code limitations demonstrate that:

1. Performance criteria in specifications for concrete will assure the owner that the performance objectives are achieved. Prescriptive specifications that imply performance do not assure anything. In both applications studied in this project — concrete floor and HPC bridge deck — targeting specific performance criteria resulted in equal or better performance (shrinkage, workability/lower admixture dosage, lower chloride permeability, etc.) as compared to prescriptive limitations in the specification.
2. Performance specifications allow a great opportunity to optimize the concrete mixture designs. This ensures that different producers can compete based on their knowledge and resources and better serve the needs of the project.
3. ACI 318 w/cm limits that control intended durability need a fresh look as this test program demonstrates significant differences in performance related to permeability and shrinkage can be attained even at the same w/cm and similar strength.